

SMART GRID INDEX 2026

Tenaga Nasional Berhad



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DIMENSION 1: PERVASIVE SENSING

1.1 Building Sensing Coverage and Network Visibility

Pervasive Sensing is an important capability supporting TNB's Grid Modernization journey. TNB is progressively exploring, piloting and deploying intelligent sensors, online monitoring devices, communication infrastructure and centralized data platforms to improve visibility across generation plants, the transmission system and distribution network. These initiatives are intended to strengthen the monitoring of operating conditions and asset health, while supporting more timely operational response, improved asset management and data-driven decision-making.

TNB is adopting a range of sensing and online monitoring initiatives across selected assets, locations and voltage levels, with deployment progressing in phases according to operational needs and asset priorities. Collectively, these initiatives demonstrate TNB's ongoing efforts to expand sensing applications, improve data granularity and reliability, explore suitable connectivity technologies, and enhance integration with centralized platforms so that relevant information can be accessed more effectively by authorized users.

1.1.1 Advanced Metering Infrastructure (AMI)

TNB's Advanced Metering Infrastructure (AMI) is a smart grid network that replaces traditional meters with digital smart meters. AMI is an integrated system comprising smart meters, communication networks, and data management systems, which facilitates two-way communication between the utility provider (TNB) and customer-end smart meters. The AMI initiative aims to support the adoption of a smart energy lifestyle for customers, while simultaneously improving TNB's grid operational efficiency.

Data gathered from the smart meter could be used for various purposes, such as accurate billing, monitoring asset condition, detecting anomalies and tampering, improving grid efficiency, and restoring supply interruption in a faster manner. Data gathered is also "translated" and visualized into the energy consumption information on the myTNB web portal and mobile application for view by customers. This empowers the customers to consume electricity more efficiently with greater visibility.

The Smart Meter project is a fundamental catalyst for our 'Reimagining TNB' vision – empowering and enhancing customer satisfaction, developing the grid of the future and building a greener Malaysia for future generations. The main objective of implementing the AMI project is to provide Smarter Energy Choices for a Sustainable Future. Figure 1.1 provides an end-to-end view of smart metering architecture.

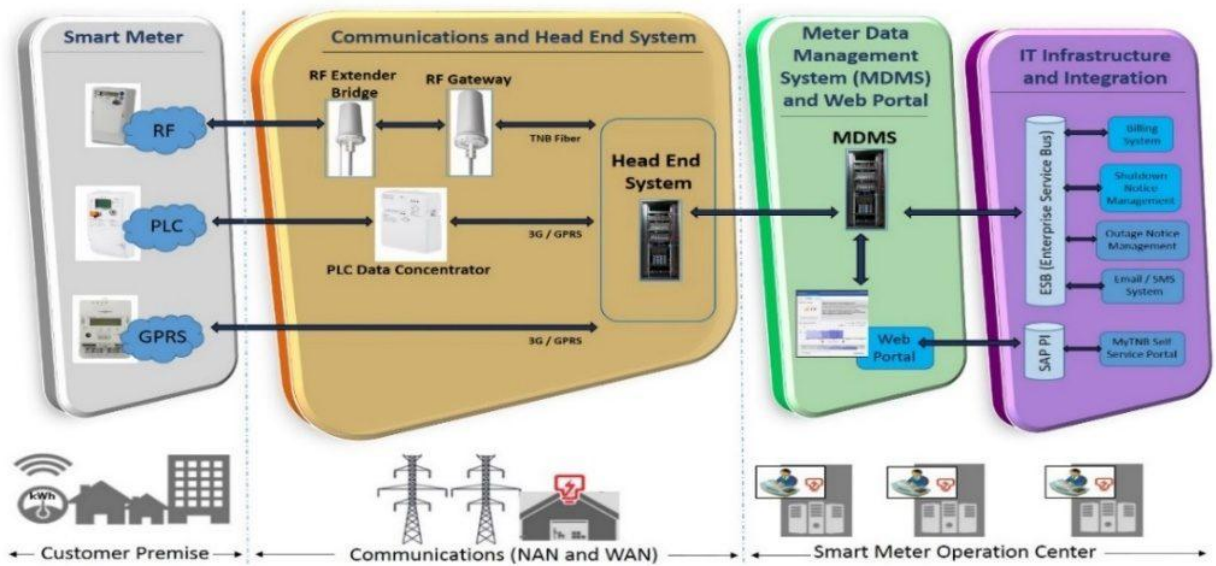


Figure 1.1: End-to-end smart metering architecture showing smart meter, communication, and data management.

AMI architecture shows how electricity usage data is collected from smart meters, transmitted through the communication network, processed by the backend systems, and displayed in customer applications. The architecture ensures reliable data flow to support utility operations and provide consumers with better visibility of their energy consumption. The architecture is illustrated in Figure 1.2.

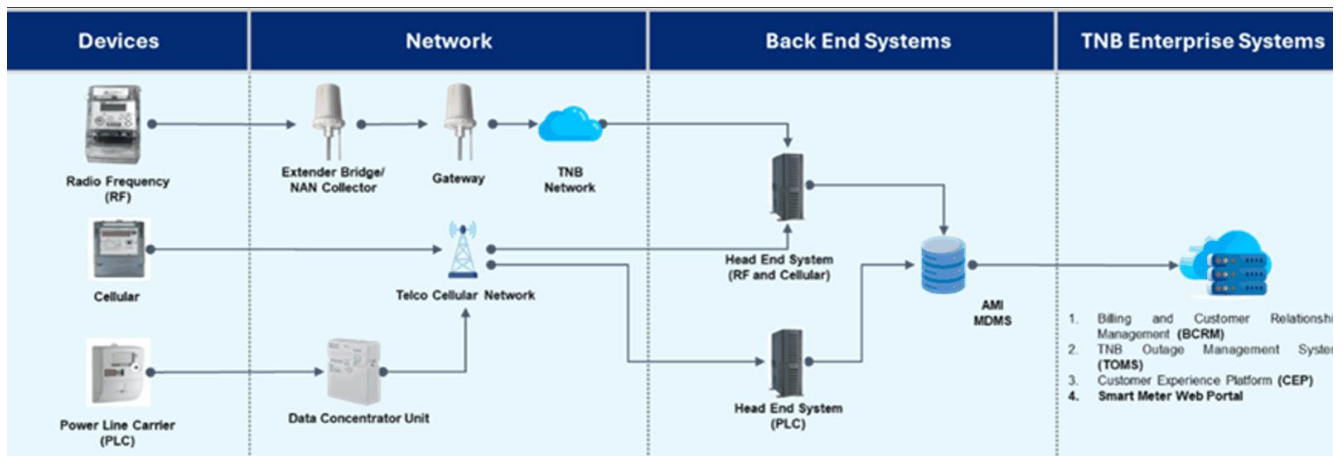


Figure 1.2: Architecture of the Advanced Metering Infrastructure (AMI)

AMI technologies are the foundation of smart meter data communication, which unlocks customer offerings and ultimately delivers value to all stakeholders in the process of grid modernization and energy transition. Three types of technologies are deployed: Radio Frequency (RF), Cellular and Power Line Carrier (PLC). The smart meter types are shown in Figure 1.3.



Figure 1.3: Smart Meter Types

AMI communication infrastructure connects installed smart meters to TNB's central systems. Different types of smart meters communicate through appropriate networks to transmit meter readings and events securely and reliably. A high-level view of the communication infrastructure is shown in Figure 1.4.

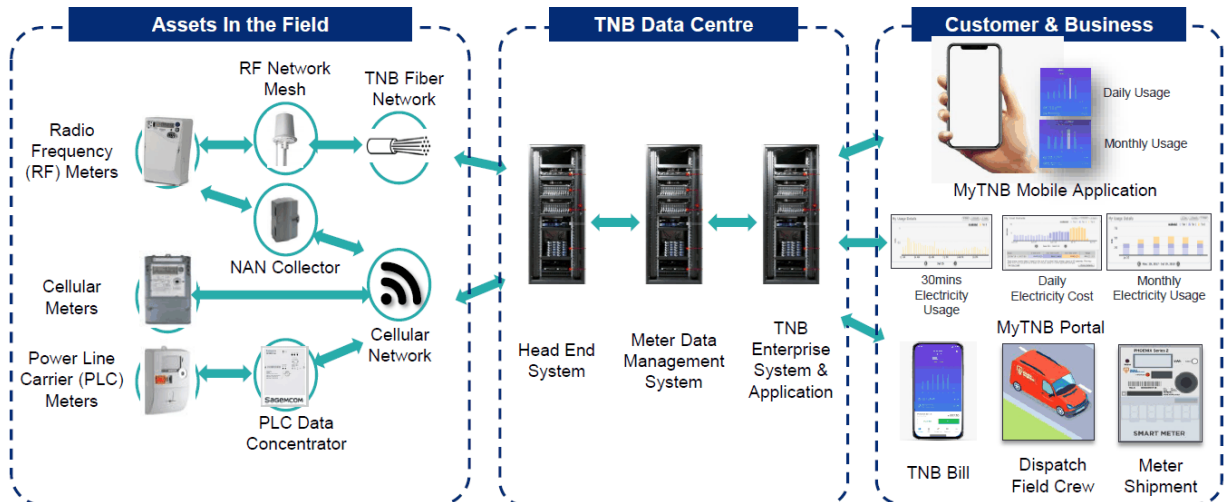


Figure 1.4: Communication Infrastructure for Smart Meter Data Transmission

The collected smart meter data is processed through TNB's central metering systems and presented in a simpler format through the myTNB Mobile Application, making it easier for customers to understand their electricity usage. Customers can monitor their daily and monthly consumption, while the same data also supports relevant TNB operational processes.

AMI offers seven (7) customer offerings to smart meter users. The offerings include:

- Actual and Timely Electricity Bill
- Energy Budget
- Manage Electricity Consumption
- Time of Use (TOU)
- Service Disruption (Outage Notification)
- Remote Energization and De-Energization
- Flexible payment scheme (Prepayment)

The Smart Meter deployment is currently being carried out in phases across Peninsular Malaysia. The rollout began in 2018 and aims to replace conventional meters with smart meters to improve meter-reading accuracy, increase the efficiency of metering operations and provide customers with access to their electricity-usage information.

To date, AMI has unlocked 6,050,006 smart meters mainly in Klang Valley, Malacca, Penang, Johor, Perak, Kedah and Pulau Tenaga Hijau. As a result, smart meter penetration has reached 58% nationwide. Continuing this momentum, AMI aims to expand deployment in Peninsular Malaysia to approximately 6.9 million meters during RP4 in 2027. The next phase will focus on installing smart meters in the remaining areas while maintaining existing operations and improving system performance and customer services. The nationwide rollout plan is shown in Figure 1.5.

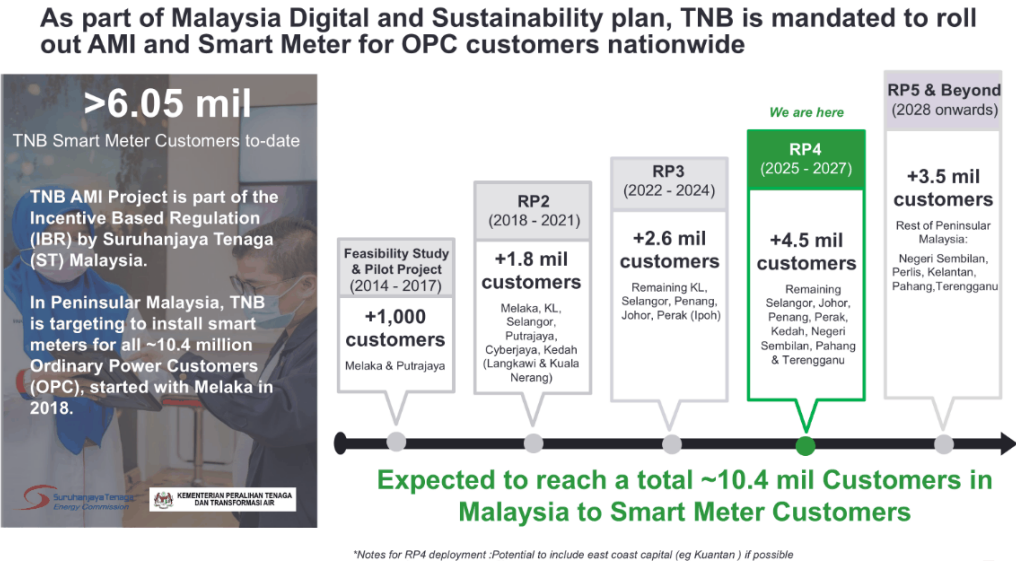


Figure 1.5: TNB AMI Project Rollout Plan for Nationwide

As one of the key enablers for Energy Transition, AMI provides valuable network visibility for TNB and enables customers to participate in solar energy generation as prosumers through the Net Energy Metering (NEM) scheme. As of July 2026, 90,822 customers participated in the NEM scheme, supplying excess solar energy to the network. Figure 1.6 shows the Net Energy Metering yearly installation.

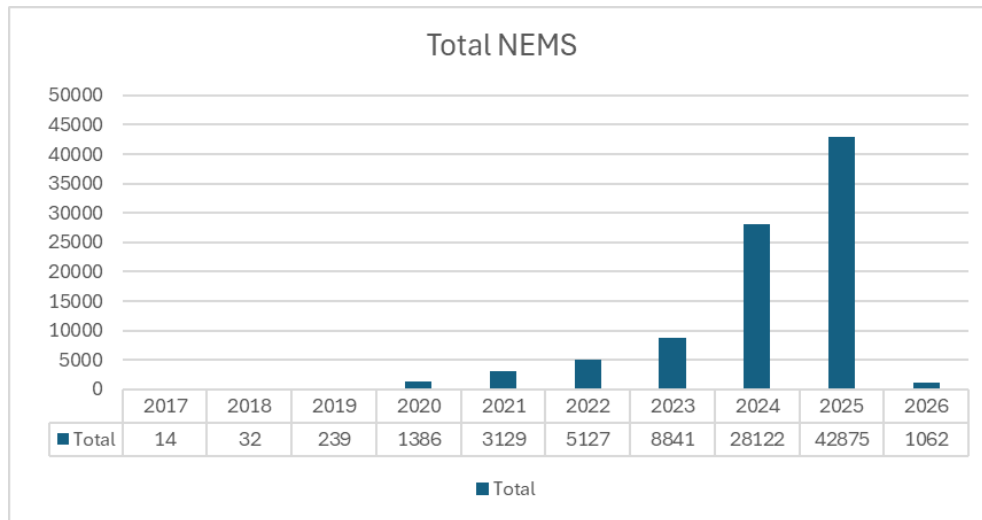


Figure 1.6: TNB AMI Net Energy Metering Scheme (2017–Jul 2026)

Customer Mobile Application

AMI is equipped with advanced digital features, providing near real-time consumption data accessible via the myTNB Web Portal and Mobile Application as well as providing the utility with near real-time events and ability to control the meters remotely. This empowers customers to actively monitor and manage their electricity usage, potentially resulting in greater energy efficiency and cost savings and enables the utility to improve the overall customer experience. Figure 1.7 illustrates the AMI components and customer applications.

What is Advanced Metering Infrastructure (AMI)?

AMI is an integrated system of **smart meters**, **communication networks** and **data management systems** that enables 2-way communication between the utilities and the customers.

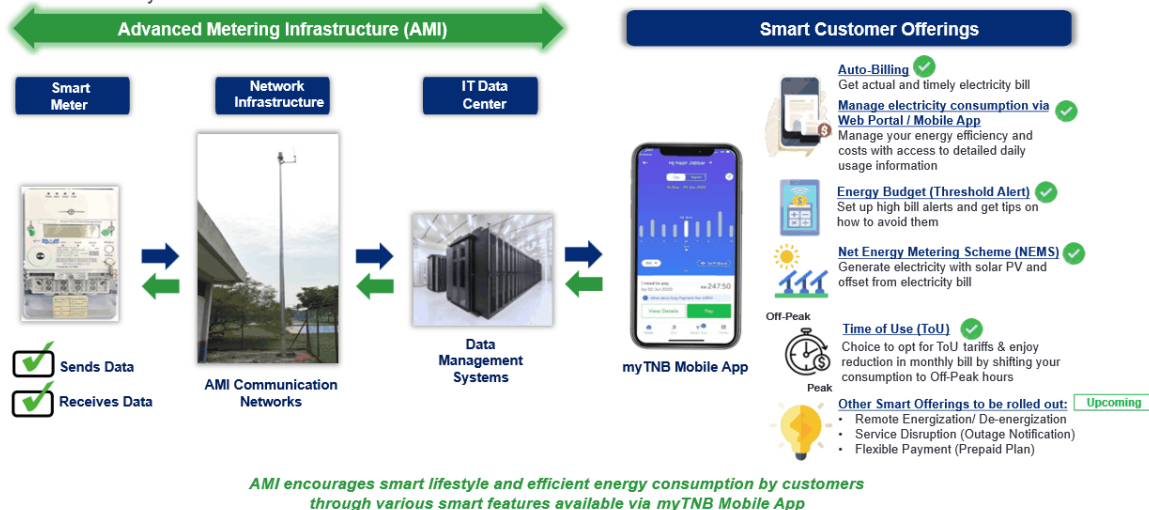


Figure 1.7: AMI Components and Customer Applications

TNB AMI works closely with various stakeholders, including the Energy Commission (ST), to deliver the customer offerings. Figure 1.8 summarizes the customer offerings through the myTNB application. Below is a brief description of the smart-meter benefits intended by the project:

- Actual and Timely Electricity Bill – Smart meter gives actual readings remotely daily; hence no site meter reading by meter reader is required. Timely electricity bill will be available in myTNB Web Portal and Mobile Application.
- Energy Budget – Customers will receive alert notification via myTNB Mobile Application once they have reached the energy usage threshold limit set earlier. This feature allows customers to be more aware of and purposeful in their energy usage from time to time, which will contribute to savings on their electricity bills.
- Manage Electricity Consumption - using daily profile via myTNB Web Portal and Mobile Application – Smart Meter customers can view detailed information on their energy consumption and electricity bills through myTNB Web Portal (down to 30 minutes' interval) and Mobile Application (daily), which empowers customers to better manage their electricity usage and be more energy efficient.
- Time of Use (TOU) – This feature provides customers the choice to opt for ToU scheme tariffs, which offer different pricing throughout various periods in a day e.g. peak, mid-peak and off-peak periods via Interval Billing Mechanism (IBM). As a result, customers could manage their energy usage according to the different tariffs offered in a day and enjoy reduction in monthly bills by shifting consumption to off-peak hours. Besides, with TOU implementation, the overall energy demand during peak-periods is reduced – resulting in lowered strain on grid infrastructure, increased energy efficiency and reduced customer impact.
- Service Disruption (Outage Notification) – Customers will receive timely information on power outages and updates on when power will be restored via the myTNB Mobile Application instead of calling TNB CareLine to obtain an update on the electricity-supply situation. Hence, notifications on supply disruptions will reduce customer complaints and enquiries.
- Remote Energization and De-Energization (Faster Power Reconnection (Move in / Move Out)) – with this feature, customers could request to connect and disconnect power supply remotely when moving in or out of their houses and hence reducing the time for supply reconnection from up to 3 days by conventional method to within a day using smart meters – greatly enhancing existing customer experience. Customers can also choose the time and date at their convenience for connection and disconnection.
- Flexible payment scheme (Prepayment) – this feature helps customers to control their energy consumption by empowering them to manage their energy budget and spending. The flexible Payment Scheme also enables the premises owner to control energy usage at rented premises and reduce the risk of unpaid bills by the tenant. It allows customers to opt for flexible payment options such as post-paid or prepaid plans. Besides, customers could top-up credit online without visiting a pay-point.

Customer offerings on the Actual and Timely Electricity Bill (Auto-Billing), Manage Electricity Consumption using Daily Profile, Energy Budget, Time of Use (TOU) as well as the Net Energy Metering (NEM) scheme are available for all smart meter customers. Meanwhile, three other customer offerings on Service Disruption (Outage Notification) of Electricity Supply Interruption & Restoration, Remote Energization / De-energization, and Flexible Payment Scheme (Prepaid Plan) are currently in development and pilot stage.

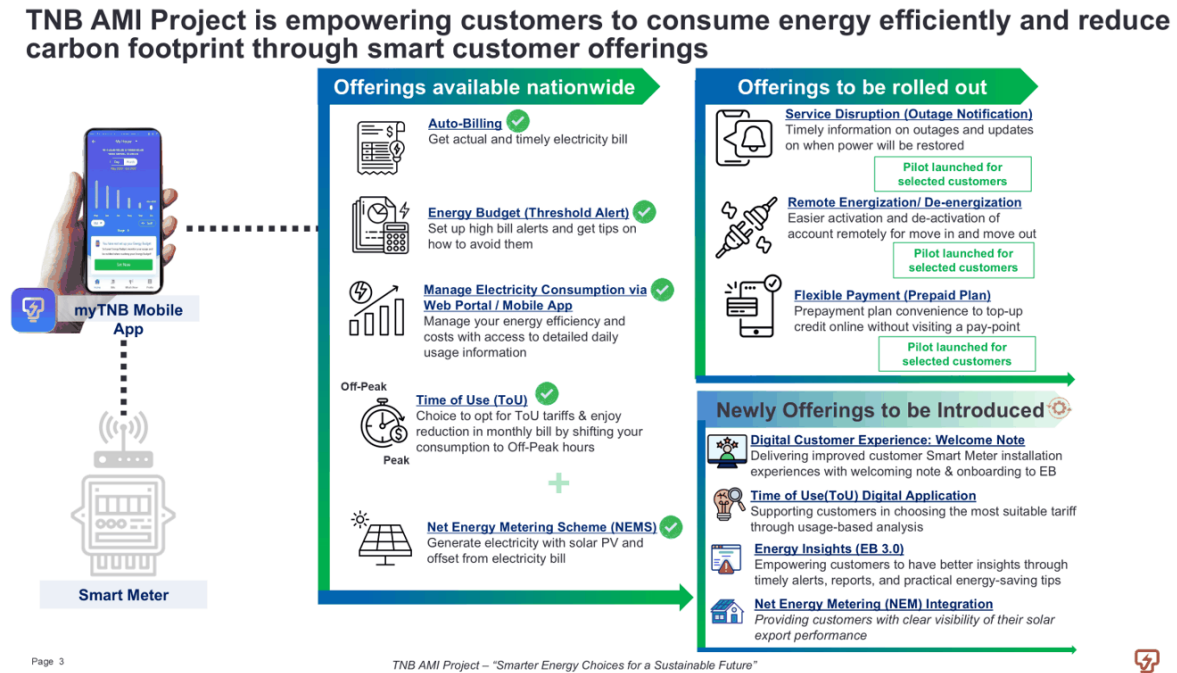


Figure 1.8: Customer Offerings through myTNB App

1.1.2 Online Feeder Pillar (OFP)

The Online Feeder Pillar (OFP), also known as Smart Feeder Pillar, is an advanced distribution feeder pillar that provides near real-time remote monitoring of energy flow within the low-voltage network. By establishing online visibility of feeder loading, energy-related data can be continuously monitored to enhance network visibility, improve load reading efficiency and support more accurate and efficient energy distribution and usage. An example of the OFP is shown in Figure 1.9.



Figure 1.9: Online Feeder Pillar (OFP)

OFP supports diversified sensing use cases, particularly load monitoring for proactive planning & actions, where emerging loading conditions may be identified earlier to support timely assessment and intervention. The same visibility can also support DER integration management by providing better information on power flow and changing network conditions as more distributed energy resources are connected.

For connectivity technologies, OFP uses cellular communication to enable remote transmission of field measurements to TNB's central systems. In terms of data granularity and reliability, OFP provides feeder- and phase-level electrical measurements, including voltage, current, power factor and power-flow information, at frequent intervals. Where OFP is used together with Community Energy Storage System (CESS), charging and discharging data can also be monitored at intervals of up to one minute, providing finer visibility of energy movement and supporting more responsive monitoring of local network conditions.

For integration and accessibility, OFP data is made available through TNB's monitoring and analytics environment, where it can be integrated with other relevant network and asset information for monitoring, analysis and operational decision-making. This provides authorized users with a more consolidated view of low-voltage network conditions and supports applications such as load profiling, anomaly detection, DER monitoring and network planning.

As of July 2026, TNB has installed 4,123 units of OFP nationwide at targeted areas that require online load monitoring towards proactive action and DER-integration management.

1.1.3 Voltage Regulating Distribution Transformer (VRDT)

Voltage Regulating Distribution Transformer (VRDT) is a special-design distribution transformer with a load tap-changing mechanism to automatically manage voltage fluctuation, particularly those associated with DER penetration on the low-voltage network. The intermittent characteristic of DER, particularly solar PV, is expected to have greater impacts as it can cause frequent voltage fluctuation at the distribution level. An increase in voltage is also a key limitation for connecting new DER to the low-voltage network. An example of the VRDT is shown in Figure 1.10.

From a pervasive perspective, VRDT continuously observes network voltage conditions as part of its dynamic voltage regulation function. This provides local visibility of voltage behaviour and enables the transformer to respond to changing load and generation conditions through its built-in on-load tap changer. The resulting sensing and regulation capability supports improved voltage stability and better integration of DER by mitigating high-voltage conditions that could otherwise limit new DER connections or require generation curtailment.

VRDT operational data is transmitted through TNB's intelligent field gateway for integration with the relevant central monitoring environment, enabling authorized users to monitor asset and network conditions remotely.

To date, TNB has installed 9 units at targeted areas.

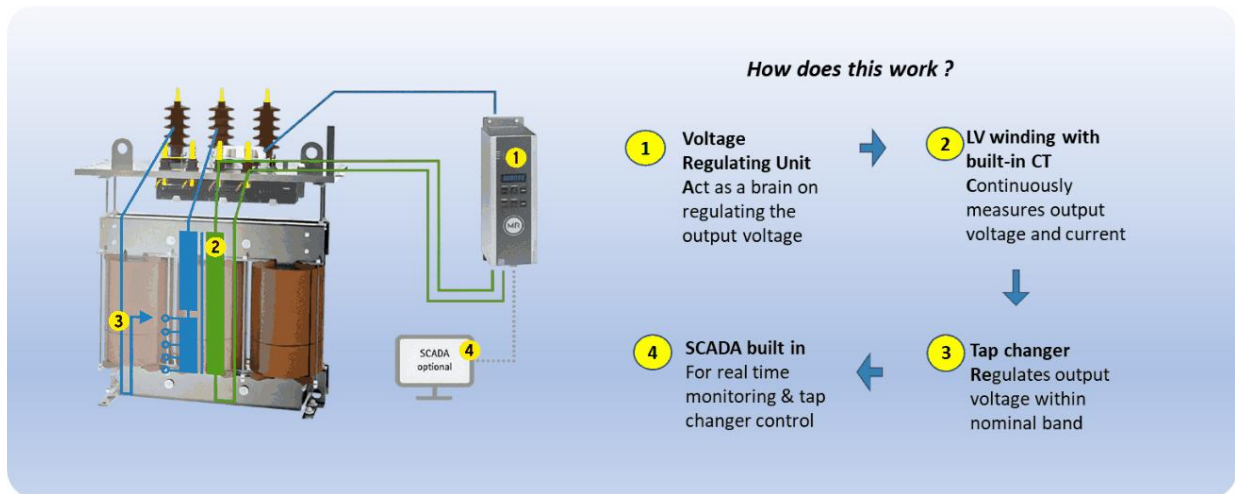


Figure 1.10: Voltage Regulating Distribution Transformer (VRDT)

1.1.4 IoT Sensor Deployment for Switchgear and Power Transformer Health Monitoring

The IoT Sensor Deployment for Switchgear & Power Transformer Health Monitoring initiative leverages Internet-of-Things (IoT) technology to enable near real-time monitoring of critical distribution network assets. The deployment of IoT sensors is strategically prioritized based on asset criticality assessment, incorporating the Condition Network Asset Indices Methodology (CNAIM), technical expertise from TNB subject matter experts, and a weighted prioritization framework. The Substation Criticality Index is used to evaluate the operational and business importance of substations by considering factors such as customer impact, network configuration, strategic importance, and service continuity requirements. This approach ensures that sensor deployment is focused on assets with the highest operational impact and risk exposure.

By continuously collecting operational and condition data from assets such as power transformers and switchgear, the initiative provides accurate and predictive insights into asset health, supporting more informed and proactive asset management.

Traditionally, asset condition monitoring has relied on periodic inspections, scheduled maintenance activities, and manual testing, resulting in limited visibility into the actual operating condition of critical assets between inspection intervals. As a result, developing defects may remain undetected until they progress into failures, leading to unplanned outages, emergency maintenance, and increased operational risks.

The deployment of IoT sensors addresses these challenges by providing continuous condition monitoring and real-time visibility of asset performance. Sensor data is integrated into the Asset Performance Monitoring System (APMS), where advanced analytics are used to generate key asset performance indicators, including the Asset Health Index (AHI) and Asset Risk Index (ARI). These insights enable maintenance teams to shift from time-based maintenance to condition-based and predictive maintenance strategies.

The initiative aims to support data-driven maintenance decisions, reduce maintenance costs and operational risks, and optimize overall network health through continuous monitoring of critical assets. The overall IoT sensor deployment concept is shown in Figure 1.11.



Figure 1.11: IoT Sensors Deployment System Overview

The IoT solution continuously monitors the operating condition of switchgear and power transformers by collecting condition data from critical asset components through connected monitoring devices. The solution enables secure wireless transmission of asset information to TNB's central IoT environment. The collected data is updated at near real-time intervals, enabling timely detection of abnormal conditions and supporting proactive maintenance decisions. The monitoring frequency varies depending on asset type and measurement requirements, ensuring appropriate data granularity for effective asset health assessment. This enables maintenance teams to remotely monitor asset health and identify abnormal operating conditions before they develop into major failures.

By integrating IoT sensor data with the Asset Performance Monitoring System (APMS), the platform generates near real-time Asset Health and Asset Risk insights that support proactive maintenance planning and operational decision-making. The integration of previously isolated monitoring systems into a monitoring platform enables access to asset condition information, allowing engineers to obtain a consolidated view of asset performance, health trends, and potential risks. Early warning notifications alert maintenance teams when asset conditions begin to deteriorate, enabling timely intervention before faults result in equipment failures or customer interruptions.

The solution also supports early detection by identifying anomalies and emerging asset issues that may not be visible through routine inspections alone. This reduces the likelihood of unexpected failures, improves network reliability, and minimizes outage risks.

In addition, IoT-enabled condition monitoring supports asset life extension by enabling maintenance activities to be performed based on the actual condition of equipment rather than

predetermined maintenance intervals. This allows assets to remain safely in service for longer while avoiding unnecessary maintenance activities and optimizing lifecycle costs.

IoT sensors deployed on critical assets, including power transformers and switchgear, collect condition data such as dissolved gas analysis (DGA), partial discharge (PD), thermal imaging, motor current, vibration, and other asset-specific measurements.

The primary outcome of the solution is a consolidated dashboard that provides a unified view of asset condition, alarms, and operational performance across multiple asset types. By bringing together data from IoT sensors, maintenance systems, and analytics platforms into a single interface, the dashboard enables maintenance teams and asset managers to monitor asset health in near real-time, identify emerging issues, and make faster, data-driven maintenance decisions.

The IoT Sensor Deployment initiative is currently being implemented in phases across the distribution network. To date, the deployment of IoT sensors for 12 power transformers has been completed, while IoT monitoring for switchgear has been implemented at five substations. These deployments provide near real-time asset condition monitoring and serve as the foundation for expanding IoT-enabled predictive maintenance capabilities across critical distribution assets that will strengthen real-time asset visibility, enhance predictive maintenance capabilities, and further improve network reliability through data-driven asset management.

1.1.5 Thermodynamic Modelling at Manjung 5

Thermodynamic Modelling is a Digital Twin initiative implemented at TNB Janamanjung's Manjung 5 (M5) power plant. The initiative focuses on Thermodynamic Modelling to enhance operational efficiency, optimize asset performance and support data-driven decision-making. The primary objective of the initiative is to improve plant efficiency by utilizing real-time data analytics. By creating a virtual replica of the physical plant, operators can gain insights into plant performance, identify inefficiencies and implement corrective measures proactively.

The initiative integrates real-time operational data with an advanced thermodynamic model, enabling detailed calculations and in-depth performance analysis of the plant. This supports early detection of performance gaps, identification of underperforming equipment, immediate action to improve plant efficiency and reduce fuel costs. Figure 1.13 shows an example of boiler performance monitoring.

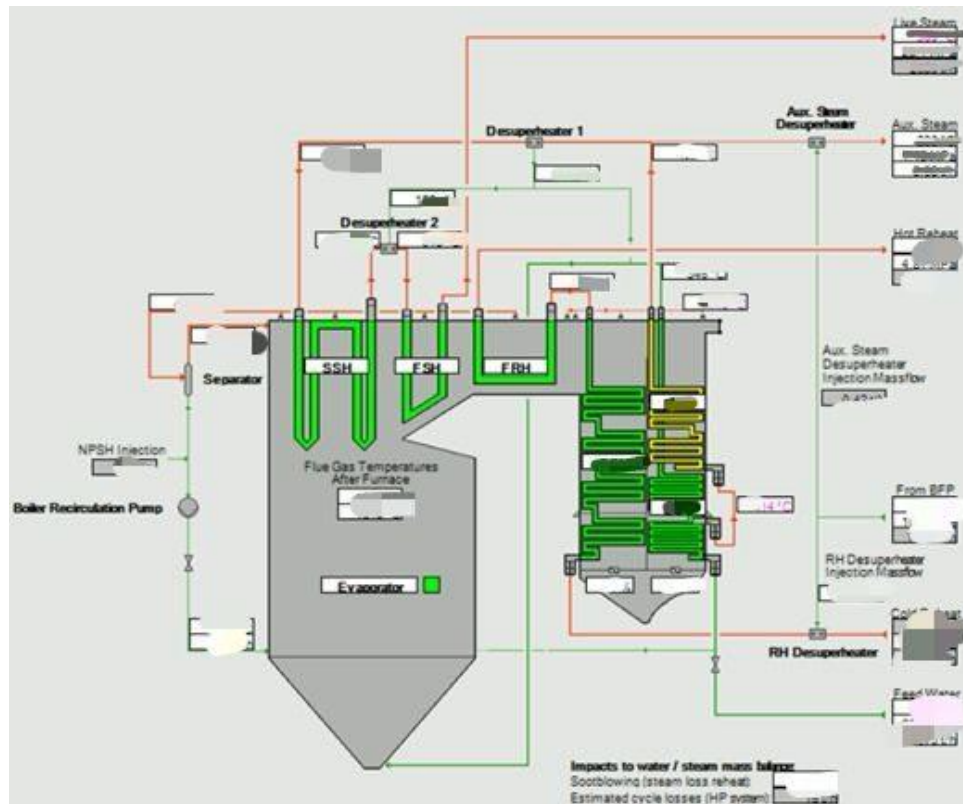


Figure 1.13: Monitoring on Boiler Performance

One of the main capabilities of Thermodynamic Modelling is real-time plant performance monitoring. The system supports the performance team in monitoring plant performance in real-time and improving work efficiency. The data in the application is updated every five (5) minutes. The initiative enables monitoring and assessment of major equipment, including turbines and boilers. By continuously tracking equipment health, the system provides real-time insights, supports timely maintenance, lowers fuel costs, enhances asset longevity and ensures optimal plant efficiency.

The dashboard provides process views for major plant areas including Main Boiler, Boiler Performance Data, Steam Turbine, HP Preheater, LP Preheater, Condenser, Air/Flue Gas Overview, Air Preheater, FD/ID/PA Fans and Coal Mills. The system also supports more efficient identification of underperforming equipment. Colour coding allows immediate attention on equipment shown in red, while the impact to heat rate is calculated instantaneously.

The model represents the plant through thermodynamic modelling, including characteristic curves for each component and T-Q diagrams. The modelling is based on governing principles such as the 1st Law of Thermodynamics, conservation of mass and heat transfer. Cases are raised by HQ to the station when abnormalities are observed, consisting of abnormalities or findings observed and proposed actions.

The workflow for performance monitoring follows Identification, Verification and Execution. The dashboard supports monitoring of component performance and controllable losses, with indicators for Danger, Warning, and Normal conditions. Figure 1.14 shows the dashboard used to monitor major equipment.

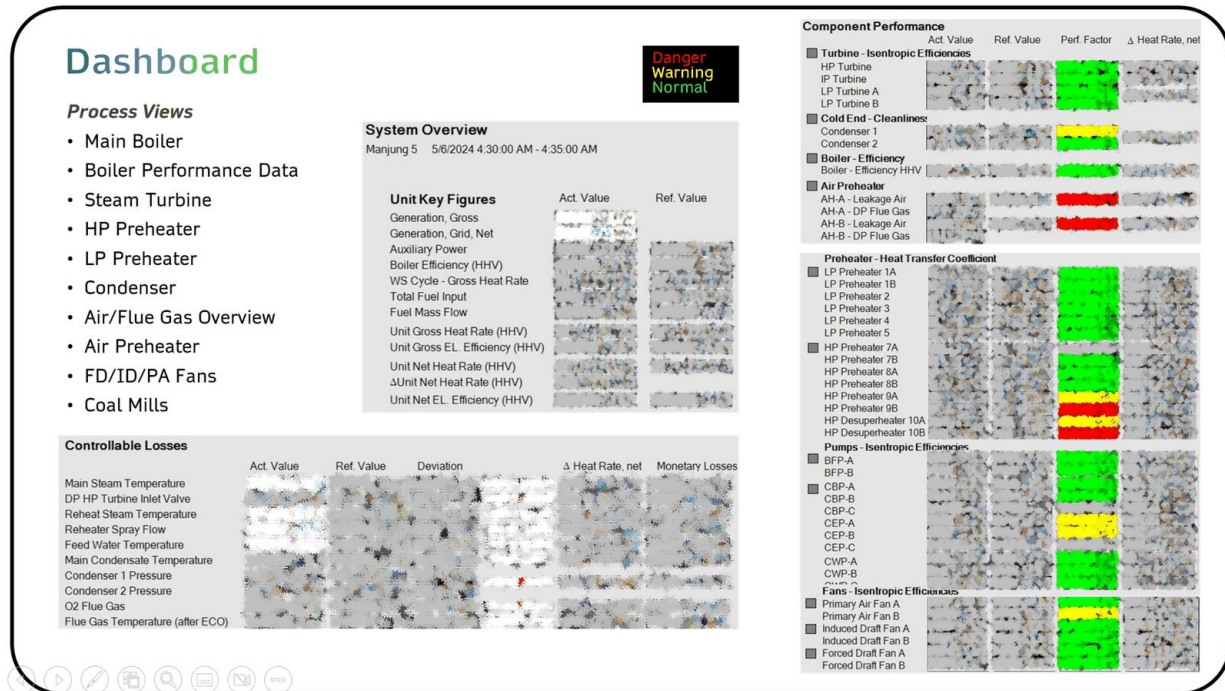


Figure 1.14: Dashboard Monitoring on Major Equipment

The implementation at M5 began in September 2021 and has been continuously implemented to date. The initiative is planned for Tuanku Muhriz Power Station (Unit 1 and Unit 2) in 2026.

The value of Thermodynamic Modelling is seen through real-time insights, enhanced equipment performance and efficiency improvements to optimize power plant operations. The implementation addressed the previous limitations (i.e. manual data extraction, time-consuming and many charts and trends to be observed) and made the identification stage more efficient. The impact of controllable losses on heat rate allows monetary impact to be calculated, supports managerial decision-making and provides a list of potentially suspect sensors for immediate troubleshooting by the station team.

The system also enables verification of soot blowing effectiveness through performance factor monitoring.

1.1.6 HV Grid Field Sensing Technologies

Field Sensing Technologies

To improve visibility across the transmission network, multiple sensing technologies are being deployed at substations based on asset criticality and network requirements. Table 1 summarizes the sensing technologies, deployment scope, information acquired and reporting intervals.

Table 1: HV Grid Field Sensing Technologies

Sensing Technology	Deployment	Information Acquired	Reporting Interval
Wide Area Intelligent System (WAIS)	500 kV, 275 kV and selected critical 132 kV substations	Time-synchronized synchro phasor measurements including voltage, current, phase angle, frequency, MW, MVAR and MVA	1 second
Electrical Transducers	Substations without WAIS	Voltage, current, MW and MVAR measurements	10 seconds
Protection Relay & Substation Alarm Monitoring	All substations	Protection relay operation alarms, relay health status and substation equipment alarms acquired through the appropriate substation monitoring interfaces.	Event-based / Periodic
Transformer Online Monitoring System (OMS)	Selected transformers	RTCC measurements including Oil Top Temperature (OTI), Winding Temperature Indicator (WTI), multi-gas dissolved gas analysis and other transformer condition parameters	Continuous
GIS Online Monitoring System	Selected GIS substations	Partial Discharge (PD) monitoring for insulation condition assessment	Continuous
Cable Monitoring System (<i>Roadmap</i>)	Critical transmission cable circuits	Online cable condition monitoring including temperature and asset condition indicators	Continuous
Transformer Explosion Fire Preventive System (TEFPS) (<i>Roadmap</i>)	Selected power transformers	Early detection and mitigation of transformer internal faults to prevent catastrophic explosion and fire incidents	Event-based / Continuous

Centralized Data Collection and Visualization

Field measurements from multiple sensing and monitoring sources are consolidated through TNB's substation edge platform, which performs communication and edge-computing functions before information is transmitted to the centralized data environment.

1. WAIS synchro phasor measurements
2. Electrical transducers
3. Protection relays
4. RTU
5. IEC 61850 IEDs
6. Online Monitoring Systems

The collected data is securely transmitted to a centralized historian, providing an enterprise repository for operational and asset information across the transmission network.

Engineers and asset managers access this information through the Integrated Centralized Equipment Condition & Online Monitoring System (ICECOMS) dashboards, which provide:

1. Real-time grid operating conditions
2. Synchro phasor visualization
3. Asset health monitoring
4. Protection relay health
5. Online monitoring system status
6. Historical trends
7. Alarm and event notifications
8. Engineering analytics

This centralized platform reduces the need to access individual substation systems and provides consolidated visibility through a common interface.

1.2 Advanced Edge Intelligence

Advanced Edge Intelligence complements TNB's pervasive sensing initiatives through initial deployment and piloting of selected edge-processing capabilities, where certain field data is processed closer to the source before being transmitted to central platforms. This approach is being explored to support more efficient handling of operational data and to convert selected raw measurements into useful engineering information closer to the point of collection.

1.2.1 Edge Intelligence through Enterprise Gateway (EGW)

To further enhance the HV Grid Field Sensing Technologies in Section 1.1.6, the Enterprise Gateway (EGW) acts not only as a communication gateway but also performs edge analytics by processing raw field measurements locally before transmitting value-added information to TNB's centralized historian. This edge computing capability reduces unnecessary network traffic while transforming raw data into actionable engineering information.

Selected edge applications being implemented within the EGW are summarized in Table 2.

Table 2: EGW Edge-Processing Applications

EGW Application	Edge Processing Function	Published Output
SWIS DFR	Merges analogue disturbance waveforms with digital protection and breaker status signals to generate complete disturbance records.	Complete disturbance records
SWIS COMTRADE File Transfer	Filters and automatically transfer disturbance records based on configurable rules (e.g., protection trips only).	COMTRADE files transferred to central repository
SWIS VT Monitoring	Analyses voltage measurements from WAIS phasors, Modbus transducers and IEC 61850 Bay Controllers to detect VT abnormalities.	VT health indicators published to the centralized historian
SWIS-POW	Compiles capacitor bank switching disturbance records for Point-on-Wave switching assessment.	Processed switching events for AFA Platform
SWIS Tripping Alarm	Correlates protection operations, circuit breaker status and feeder operating conditions to identify genuine protection trips.	Validated tripping alarms published to the centralized historian

EGW Application	Edge Processing Function	Published Output
SWIS Chattering Alarm	Detects repetitive digital signal chattering, suppresses duplicate event transmission and generates a single information tag containing chattering statistics.	Chattering statistics and notifications published to the centralized historian
SWIT Transformer Through-Fault Current (TFC) COMTRADE Merger	Compiles transformer disturbance records for through-fault current and thermal energy analysis within the AFA Platform.	Processed transformer disturbance records

1.2.2 Distribution Intelligent Switch (DIS) at LV Network

The Distribution Intelligent Switch (DIS) is introduced as an intelligent field gateway that enables information from smart assets and monitoring devices at the low-voltage network to be consolidated and exchanged with TNB's central digital environment. It provides a common interface between operational field devices and higher-level information systems, supporting upstream and downstream data exchange activities.

DIS performs two key functions. First, it provides station-level communication translation so that information from different smart assets can be standardized for onward integration. Second, it concentrates data from multiple field devices so that information can be transmitted efficiently through a common communication channel. This supports integration of smart assets such as VRDT, OFP, CESS, transformer monitoring devices, weather sensors and other connected field equipment.

By consolidating information from these assets, DIS strengthens accessibility to near real-time field information and supports centralized monitoring through TNB's authorized dashboards and applications. This allows operational and asset information to be presented in a more consistent form for monitoring, visualization and decision-making while providing an edge-intelligence layer within the low-voltage sensing architecture.

DIMENSION 2: PROACTIVE NETWORK MANAGEMENT

2.1 Network Visibility & Response and System Integration

TNB is progressively strengthening network visibility and operational response by integrating field sensing, monitoring and control capabilities with central operational and digital platforms. This enables operating conditions, asset status and network events to be observed more effectively, while supporting faster assessment and coordinated response when abnormal conditions occur.

At the same time, system integration brings together information from field equipment, network models, operational systems and enterprise data sources so that relevant information can be accessed and used in a more coordinated manner. Through initiatives such as ADMS and EIP, TNB is building a more connected operating environment that supports improved situational awareness, operational decision-making and management of an increasingly dynamic grid.

2.1.1 Advanced Distribution Management System (ADMS)

TNB's Advanced Distribution Management System (ADMS) is developed to replace the existing Distribution Management System (DMS). ADMS, a software platform integrating several utility systems applications provides automated capabilities for timely outage restoration and optimization of the distribution grid. This translates into a higher performance, reliability in providing solution for reducing technical losses, enhanced work safety, shortened service restoration time during outages, and increased grid resiliency to natural disasters and other threats that could disrupt the flow of power to the end-user.

Network Visibility & Response

ADMS Functions and Capabilities in TNB

1. The Regional Operation Control Centre offers SCADA and DMS functionalities, along with the ability to process geographic map data (GIS). It furnishes operators with comprehensive operation displays and dispatching details. In the event of an incident, it aids operators in promptly recovering power in affected upstream and downstream sections. The system's expandability accommodates the inclusion of feeders and substations across the entire district within the Distribution Feeder Automation framework.
2. ADMS can monitor various substation information terminal equipment feeder via Remote Terminal Unit (RTU) & Field Terminal Unit (FTU) and other equipment installed on distribution network.
3. SCADA allows TNB to monitor and control of automated switches, and devices within substation through geographic display for electrical network topology.

4. Outage Management System (OMS) is a comprehensive solution designed to efficiently manage and respond to power distribution outages and related issues. It combines advanced technology to streamline outage information, restoration processes, and the coordination of field operations. This integrated system serves as a powerful tool for utilities to enhance their grid management capabilities, minimize downtime, and improve overall service reliability with integrated systems.
5. DER Visibility allows operators to monitor the operation of the distributed energy resources in real-time. It empowers TNB to maximize the benefits of distributed energy resources while ensuring reliability and efficiency in energy delivery. This is illustrated in Figure 2.1.

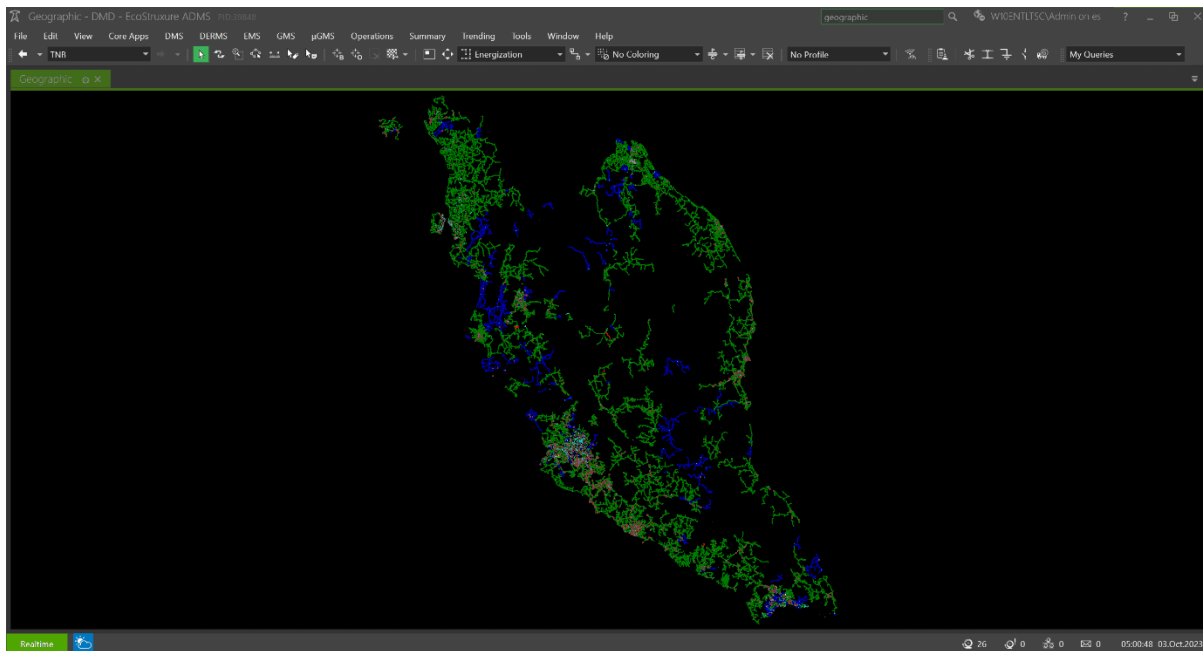


Figure 2.1: Peninsular Malaysia Geographical Distribution Network

A geographic display for operations through GIS CIM integration provides a visual representation of the power distribution network using Common Information Model (CIM) data, enabling operators to monitor and manage the grid with geographic context and real-time information. This is illustrated in Figure 2.2.

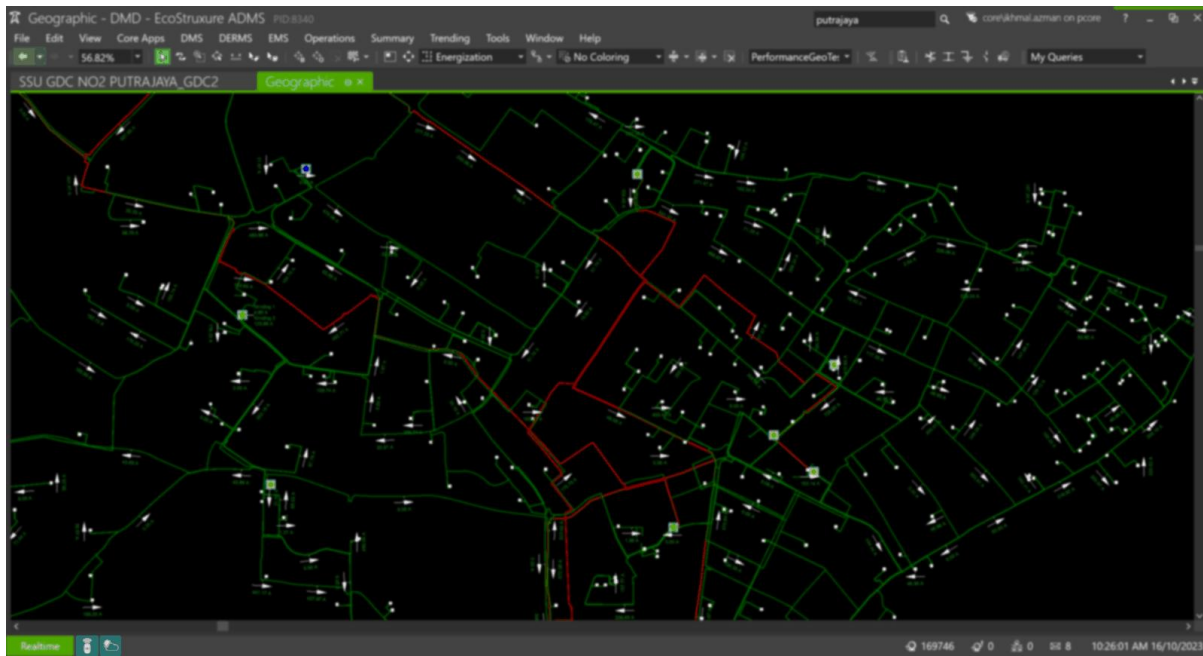


Figure 2.2: Geographical Display in ADMS Medium Voltage

Navigate easily to display from alarm event list, devices, substation, incidents & customers. This is illustrated in Figure 2.3.

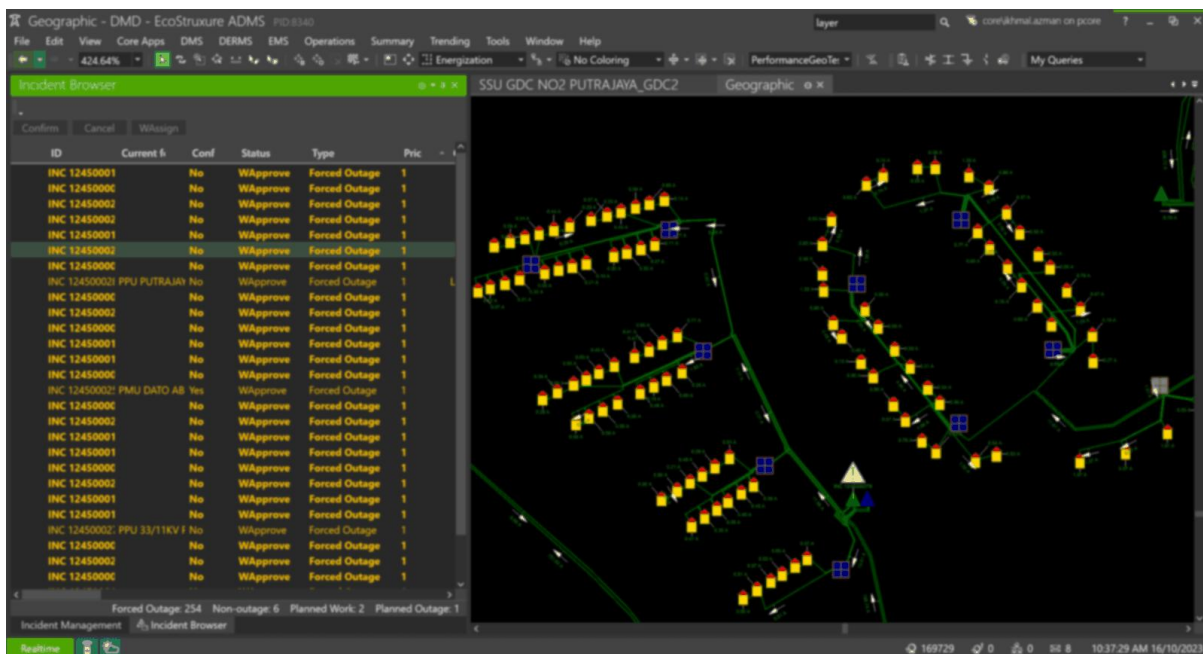


Figure 2.3: Find Functionalities to Locate the Incident

Feeder schematic display based on electrical network topology. This is illustrated in Figure 2.4.

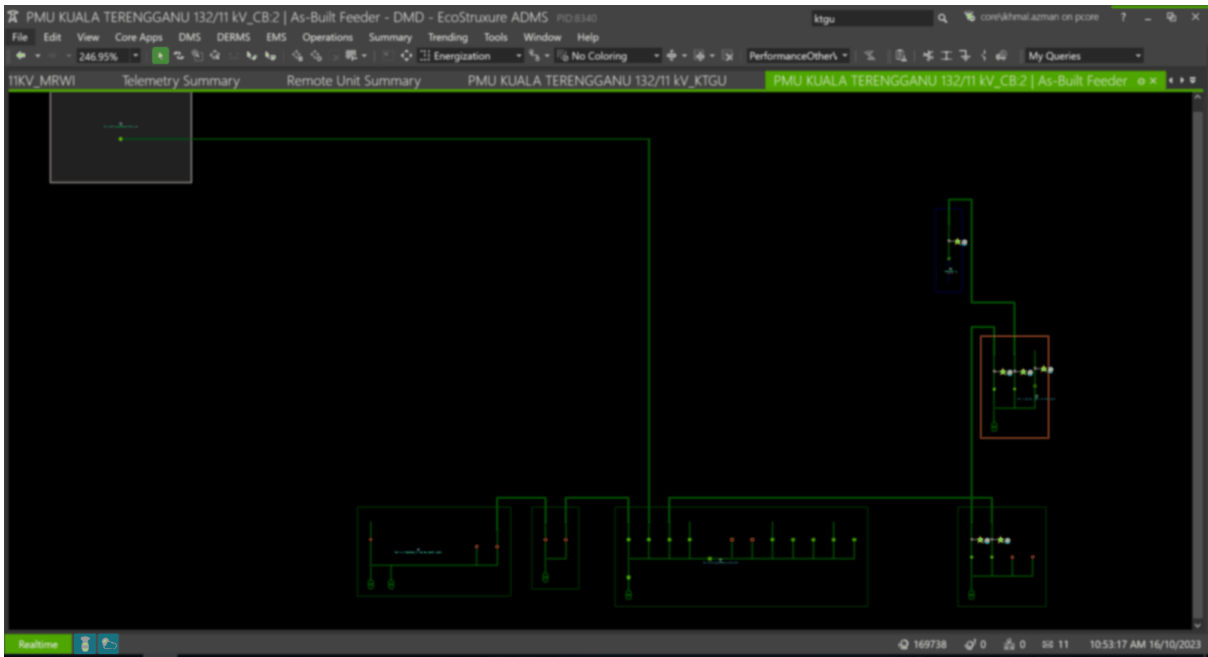


Figure 2.4: Network As-Built View

Circuit Breaker status on feeder level schematic display based on electrical network topology. This is illustrated in Figure 2.5.

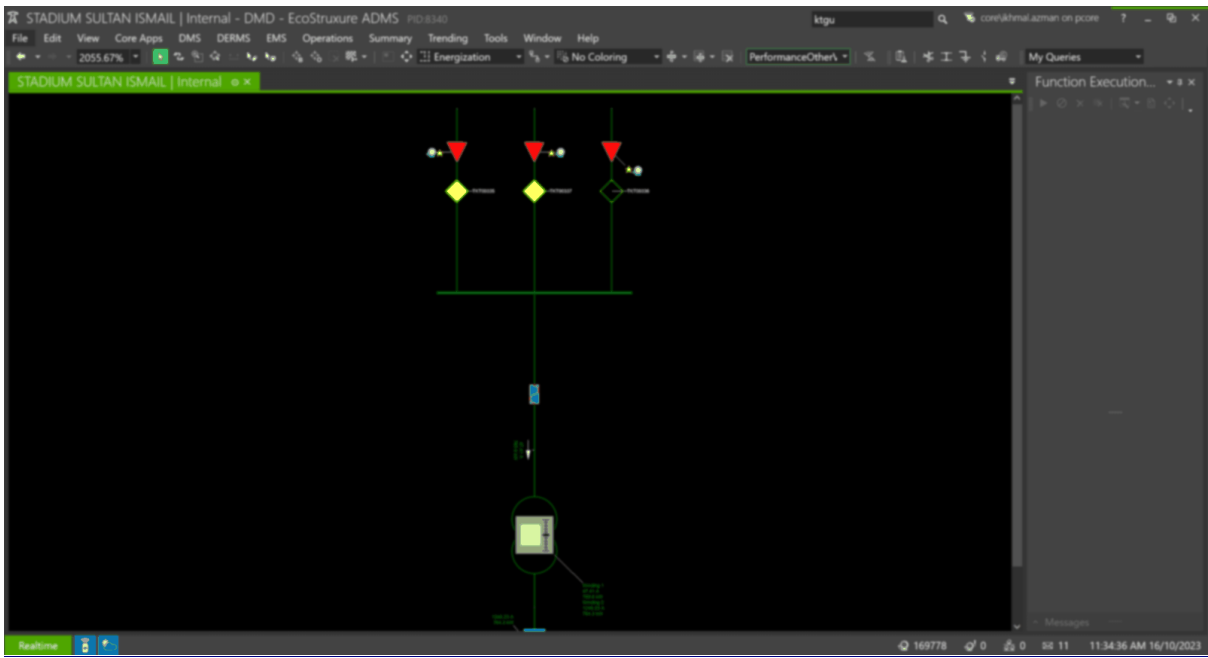


Figure 2.5: Internal View to Observe the Detail in Substation

Enable operator to understand the network status with a glance. This is illustrated in Figure 2.6.

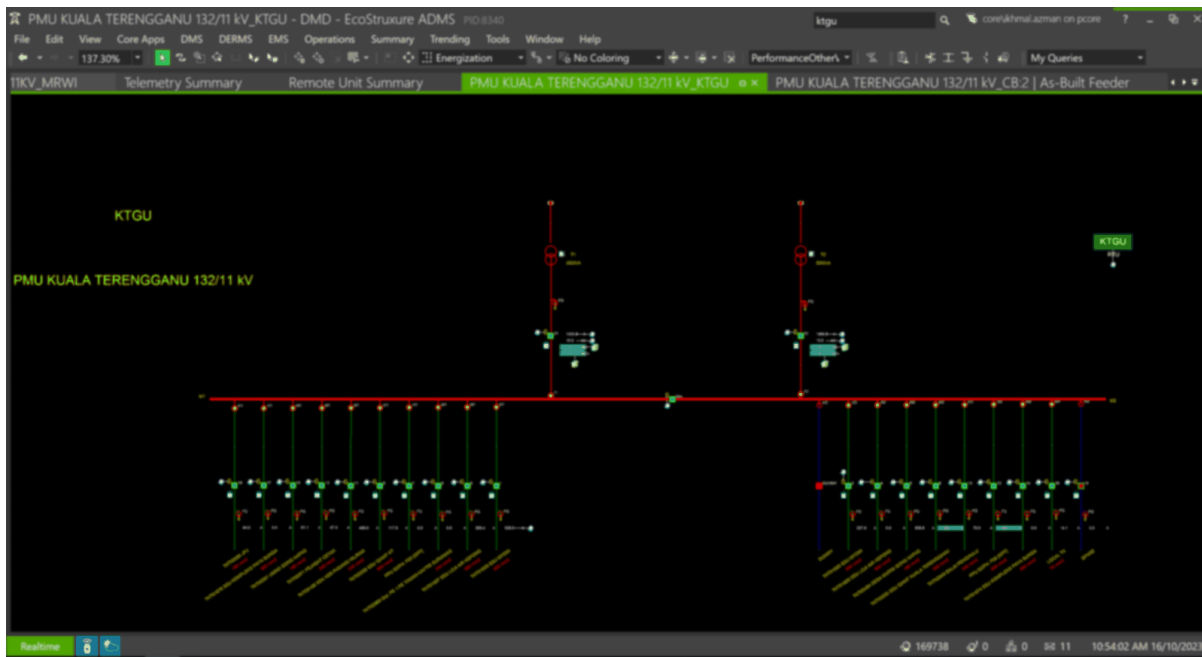


Figure 2.6: Main Intake Substation View in ADMS

SCADA and Distribution Automation in Supporting Network Visibility

Since 2006, TNB has deployed Supervisory Control and Data Acquisition (SCADA) projects within 11kV distribution substations. These initiatives are instrumental in enhancing the availability and reliability of the distribution network through real-time monitoring and control of field equipment. Such efforts support TNB's commitment to establishing a smarter grid and accelerating the integration of Distributed Energy Resources (DER).

With the use of SCADA technology, the Advanced Distribution Management System (ADMS) and Intelligent Electronic Devices (IEDs) installed at substations, TNB Control Centres are able to obtain real-time monitoring data and control network assets, enabling rapid fault-location identification and informed decision-making to restore supply within a shorter period. A control centre is equipped with various capabilities and tools such as:

1. **Real-Time Monitoring:** The control centre continuously monitors the status of the distribution network in real-time. This includes monitoring voltage levels, current flows, equipment status and power quality.
2. **Data Acquisition and Analysis:** It collects and analyses data from various sensors and intelligent electronic devices (IEDs) located throughout the distribution network.
3. **Alarms and Event Management:** The control centre receives alarms and events triggered by sensors and IEDs.

4. **Remote Control:** Operators can remotely control various components of the distribution network, including switches, circuit breakers and reclosers. This capability allows for the isolation of faults and the restoration of services in a shorter time frame as compared to manual switching at site.
5. **Load Management:** The control centre can balance loads within the network to prevent overloading and reduce inefficiencies. It may include load shedding capabilities to maintain grid stability during peak demand.
6. **Outage Management:** The control centre helps in identifying the location and cause of outages, allowing for quicker response and restoration efforts. It can also estimate the number of affected customers.
7. **Asset Management:** It assists in monitoring the condition of distribution network assets and helps schedule maintenance activities to prevent equipment failures.
8. **Network Reconfiguration:** The control centre can reconfigure the network by opening or closing switches to optimize power distribution, reduce losses, and enhance reliability.
9. **Integration with DERs:** As more Distributed Energy Resources (DERs) are integrated into distribution networks, control centres need to accommodate these resources and manage their interactions with the grid effectively.
10. **Cybersecurity:** Implement robust cybersecurity measures to protect the control centre and the distribution network from cyber threats and unauthorized access.
11. **Predictive Analytics:** Use advanced analytics to predict equipment failures, assess the impact of weather events, and optimize network performance.
12. **Customer Interaction:** The control centres also have customer interaction features to communicate with consumers during outages, provide estimated restoration times, and receive outage reports from customers.
13. **Microgrid Control:** For networks with microgrids, the control centre can manage the operation of these smaller grids within the distribution network.

A well-designed control centre with these capabilities is crucial to effectively manage a distribution network, improving power quality, reducing downtime, and enhancing overall grid reliability. The figure below shows the importance of control centre in monitoring and maintaining distribution network at the best level every time overall. This is illustrated in Figure 2.7.

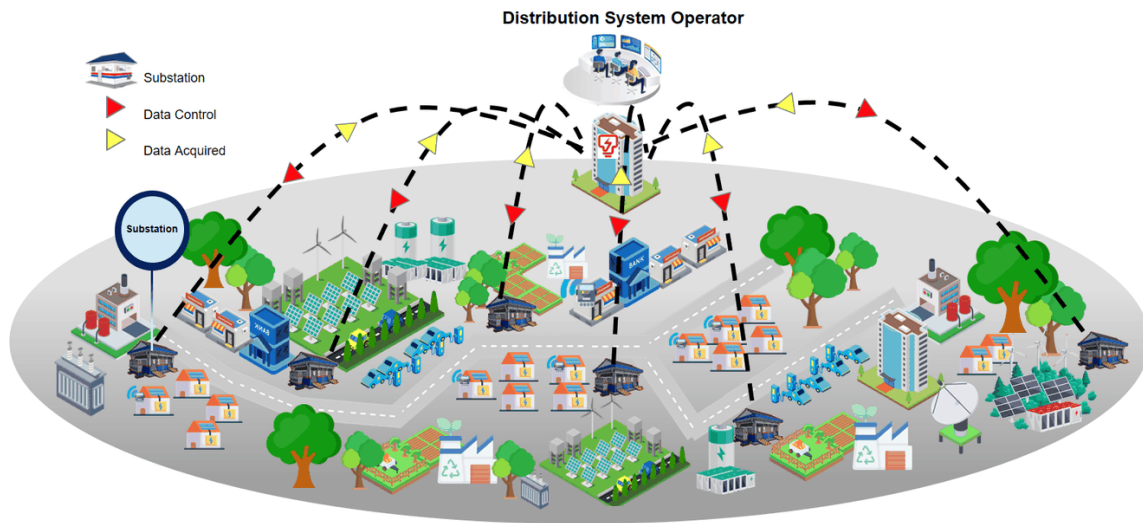


Figure 2.7: Interaction between control centre and distribution network

The Distribution Automation (DA) project continues to drive the strategic expansion of TNB's nationwide Smart Grid rollout. Integrated with the Advanced Distribution Management System (ADMS), the project brings field data into a common operating environment. This empowers operators to make informed decisions, improve feeder visibility and enable remote capabilities, ultimately optimizing operational costs and grid reliability across Peninsular Malaysia.

The strategic deployment of DA project aims to maximize grid resilience and drive long-term cost efficiencies. By enabling real-time monitoring and advanced remote switching, the system facilitates rapid automated fault isolation and accelerated service restoration, drastically minimizing consumer downtime. Furthermore, the solution significantly increases total substation visibility, ensuring that centralized control centres can proactively monitor high-load areas, optimize load distribution, and mitigate potential overloads before they impact the network. Ultimately, this integration of field telemetry unifies grid intelligence into a single ecosystem, allowing operators to make highly informed decisions that optimize ongoing operational and maintenance expenditures. This is illustrated in Figure 2.8.

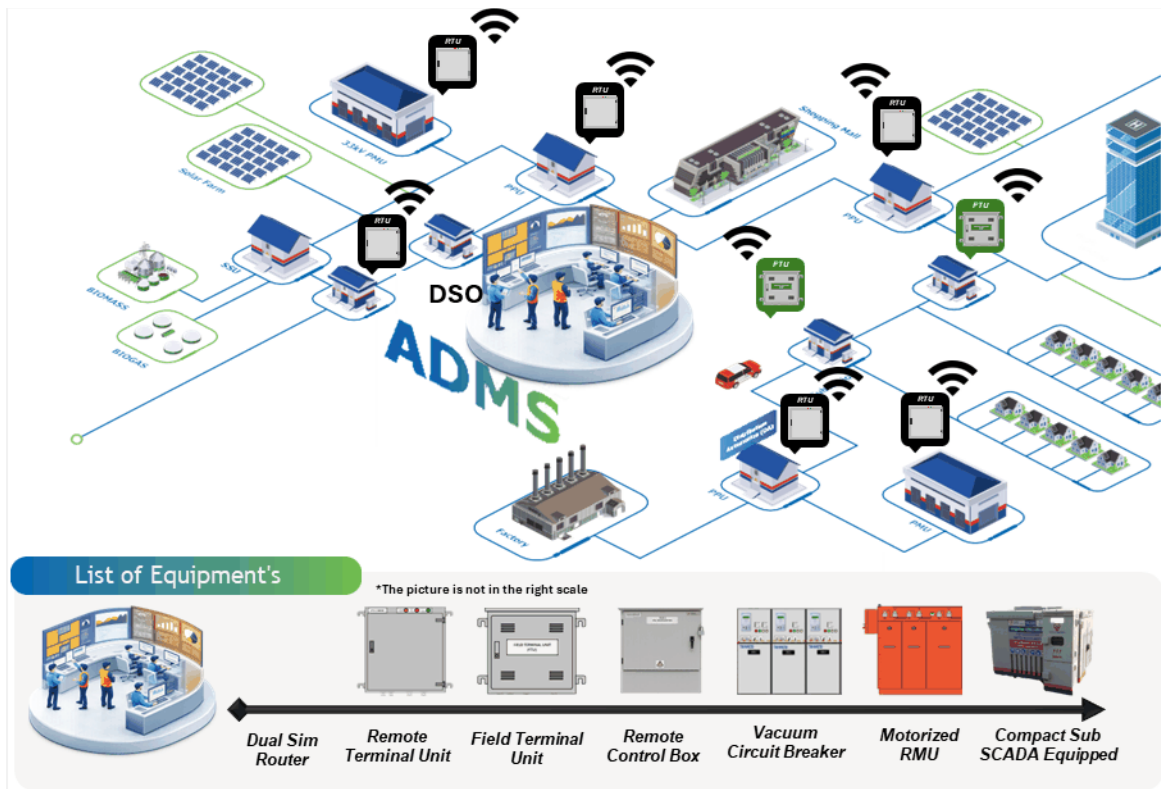


Figure 2.8: DA integration with ADMS and field equipment technologies

The project successfully concluded its FY2025 targets and is actively progressing along its long-term deployment trajectory. At the end of 2025, the DA project continued its nationwide rollout by successfully installing and commissioning 5,102 substations. The cumulative deployment reached approximately 38,007 substations, achieving around a 43% penetration rate in Peninsular Malaysia. Moving forward, the roadmap targets a cumulative installation coverage of 46% of total substations by the end of 2027, with a long-term expansion plan to achieve 85% coverage by the end of 2032. This is illustrated in Figure 2.9.

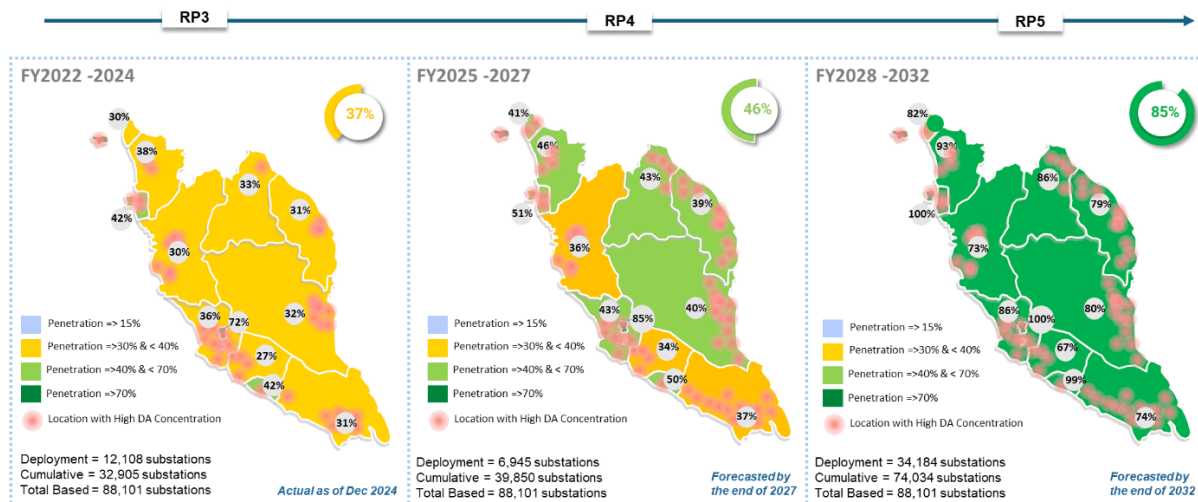


Figure 2.9: DA Penetration Roadmap to 2032

Operational Outcome

Through the implementation of SCADA and Distribution Automation, substations have become intelligent hubs of real-time data. These units continuously collect and analyse data from various parts of the network, detecting fluctuations, overloads and equipment failures. When an issue is detected, the RTUs send automated alerts to network operators for rectification.

TNB observed an average 43% reduction in restoration time for DA-enabled outages compared with non-DA-enabled outages, whereby 32% of DA-enabled outages are restored within 15 minutes. This is illustrated in Figure 2.10.

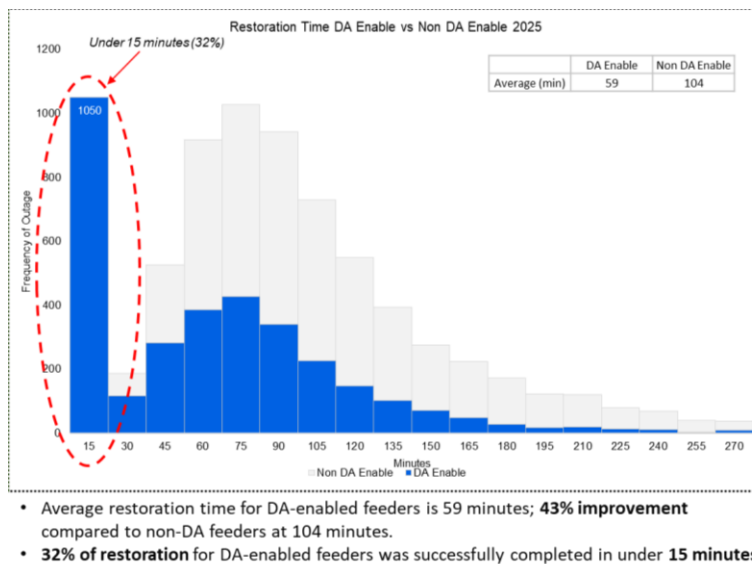


Figure 2.10: Reduction of restoration time with DA

Since operators can remotely monitor equipment health and performance, detect issues or anomalies, and take corrective actions without physically visiting the site, this minimizes the need for frequent site visits and reduces traveling costs. It also enables allocation of resources more efficiently i.e. field crews can be dispatched based on actual need, rather than following a rigid schedule, further reducing travel and crew costs.

System Integration

ADMS power applications like Fault Calculation, Relay Protection, and Volt Var Optimization rely on estimated current derived from the State Estimation (SE) function. The SE is used to assess (estimate) the distribution network state considering:

1. Remotely monitored data (SCADA) such as breaker status, current & voltage measurements, tap changer positions, etc.
2. Initial load data which is derived from the load curves given in the model or from the previous estimated state

The model incorporates various measurements, including voltage magnitudes of MV busbars, current, and real and reactive power measurements from distribution transformers. These measurements also encompass results from EMS State Estimation (from TNB's transmission system) for boundary nodes between EMS and DMS networks, such as estimated voltage magnitude and phase angle, as well as injected real and reactive power. These estimation procedures rely heavily on real-time telemetry redundancy and the availability of switchgear statuses provided by SCADA systems.

Through SCADA signals, the Outage Management System (OMS) receives reports on forced outages, leveraging SCADA information such as breaker status to pinpoint faulted sections of the network. Additionally, the OMS provides estimated power loss based on Distribution Management System (DMS) analytics, offering comprehensive reports detailing affected transformers, customers, load loss, and other pertinent information.

This integrated service shares information with TNB's work management system i.e. MVORR, empowering crews with incident details. Crews can then provide updates on the incidents as they work on restoration efforts. Furthermore, the OMS generates restoration switching sequences for Fault Location, Isolation, and Service Restoration (FLISR) and force outages. This collaborative ecosystem enhances the restoration process significantly.

- Integration with Geospatial Information System (GIS) for network model & topology.
- Integration with Advance Metering Infrastructure (AMI) for smart meter information.
- Integration with Smart Work and Asset Total Solution (SWATS) for crew model & crew status. This is illustrated in Figure 2.11.

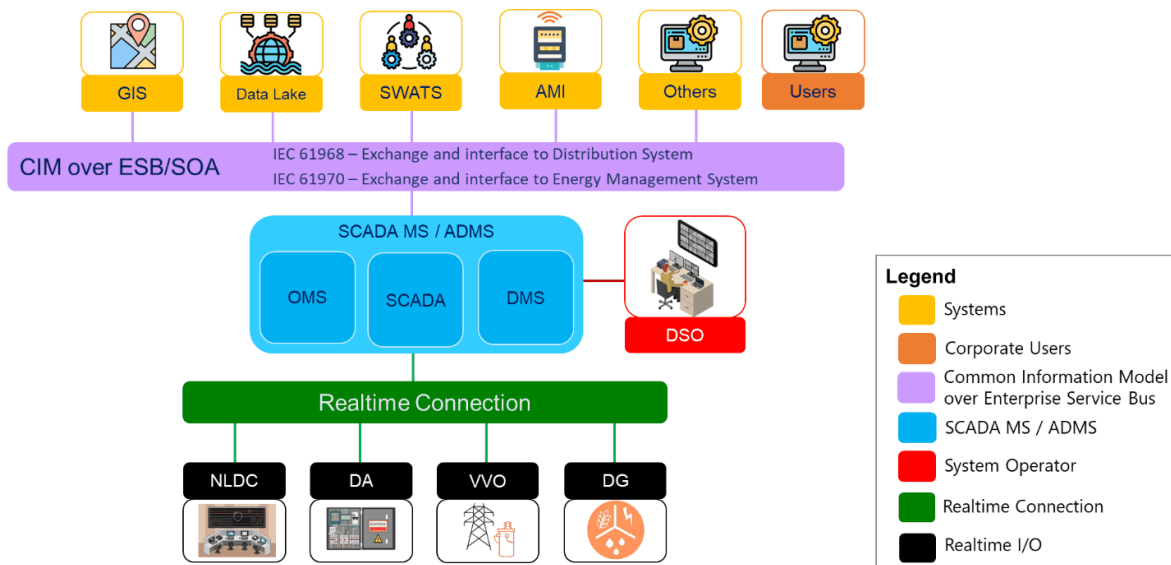


Figure 2.11: End-to-end System Interface for TNB Operations

In the ADMS setup, DERMS plays a crucial role in actively monitoring Distributed Energy Resources (DER) within the MV network such as solar panels, energy storage system and electric vehicles. DERMS enables TNB operators to monitor the operation of these distributed energy resources in real-time. By balancing supply and demand, integrating renewable energy sources, and improving grid stability, DERMS plays a pivotal role in the transition towards a more sustainable and resilient energy system. With features such as monitoring, control, grid integration, optimization, and forecasting, DERMS empowers TNB to maximize the benefits of distributed energy resources while ensuring reliability and efficiency in energy delivery.

DERMS in ADMS provides valuable insights into power flow, with connectivity extending up to the circuit breaker level. ADMS analyses data received from the DERMS at the circuit breaker connected to the MV substation. Leveraging this data, ADMS predicts energy production based on power flow and the rated power of Distributed Generation (DG) resources. This predictive capability enables a comprehensive understanding and efficient management of electricity flow from these distributed energy resources into neighbouring networks. With DERMS in place, opportunities for implementing controllability and optimization measures may emerge with revision in the Distribution Code in progress.

GIS-ADMS integration was established, with substations and medium-voltage feeders successfully imported into ADMS from the GIS data model. GIS-ADMS integration is one of the critical paths, as Operational Data Model Integration poses significant challenges in converting a static data model into a dynamic operational model within the Common Information Model framework. This success makes TNB the first in the world to establish Operational GIS-ADMS Integrated Network Model Automation using the Common Information Model integration standards IEC 61968/61970 and 62325. This is illustrated in Figure 2.12.



Figure 2.12: World's First Operational GIS-ADMS Integrated Network Model Automation

Dynamic Network Operation capability within ADMS

Fault Location, Isolation, and Service Restoration (FLISR), a critical functionality within ADMS is designed to automatically detect, pinpoint the location of faults or disruptions in the distribution network, isolate the affected areas, and quickly restore service to minimize outage durations.

It is represented by a set of applications used for locating and isolating faults, as well as restoring power supply to de-energized customers. The applications are as below:

1. Fault Location (FL) - this application is used to quickly pinpoint a group of feeder sections where an electrical fault may have occurred. The number of sections identified as potentially containing the fault depends on the extent of fault measurement equipment installed in the network. If there are many, it can pinpoint the issue to a specific section; otherwise, it gives a broader section of where the fault might be.
2. Fault Localization (FLL) – this application provides location and isolation functionality for feeders with fewer fault location equipment installed. The FLL application feeds the Switching Sequence (SS) module with a proposed switching procedure, enabling remotely and/or manually controlled switching operations to pinpoint and isolate the faulted section.
3. Fault Isolation (FI) – the FI application provides the SS module with the faulted element or set of elements resulting from the FL/FLL analysis and isolation.
4. Supply Restoration (SR) – The SR application furnishes an optimal operational plan to reinstate service to the unaffected section of the feeder following the isolation of the faulty element. The outcome of the SR application is a series of switching sequences, prioritized based on the user's selected criteria.
5. Restore to Normal State (RN) – The RN application generates the switching sequence, detailing the operations necessary to restore the network to its normal or pre-fault state—the state it was in before the fault occurred. This is illustrated in Figure 2.13.

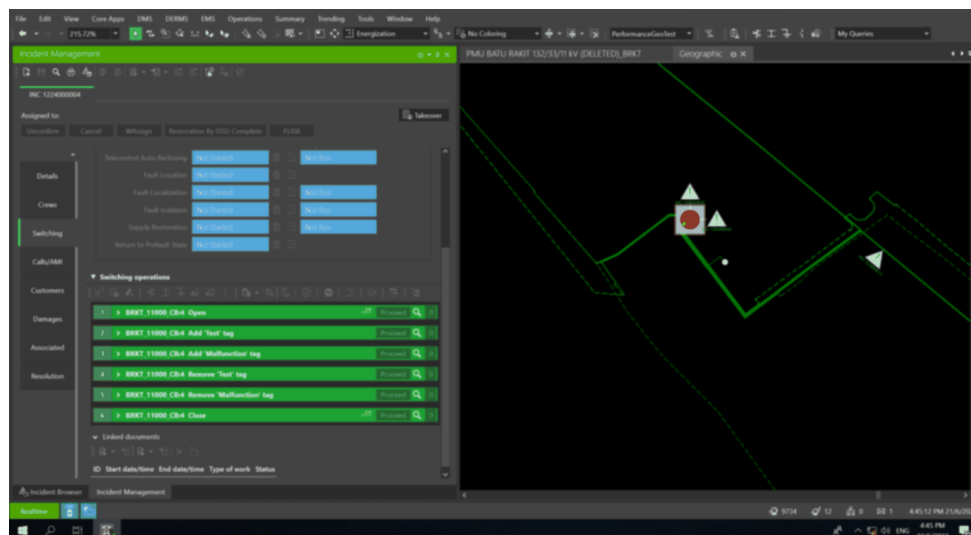


Figure 2.13: FLISR Status in ADMS

2.1.2 Smart Energy Management Infrastructure (SEMI) – Energy Integration Platform (EIP)

The Smart Energy Management Infrastructure (SEMI) project plays an important role in supporting TNB's commitment towards Malaysia's Energy Transition objectives. With its central objective focused on serving as an Energy Transition Facilitator within TNB's distribution network, SEMI supports the development of energy management capabilities to enable better visibility, planning and management of Distributed Energy Resources (DERs).

Under the SEMI project, the Energy Integration Platform (EIP) is designed to elevate the effectiveness and intelligence of energy distribution. By implementing a diverse array of technologies and capabilities, EIP extends its influence not only to the distribution network, but also actively engages customers and pertinent stakeholders in the energy transition process. It provides tangible advantages, including heightened reliability, cost-efficiency, and a steadfast commitment to sustainability.

As illustrated in Figure 2.14, EIP functions as an energy management system, entrusted with the tasks of receiving, analysing, and processing data sourced from Distributed Energy Resources (DERs). Moreover, it delivers valuable insights and foresight concerning DER connectivity, generation, and availability. This process includes an evaluation of TNB's distribution network, supporting system stability and reliability.

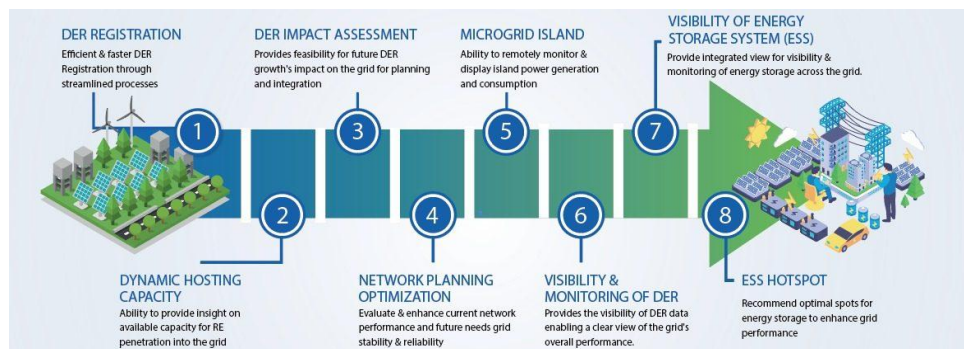


Figure 2.14: SEMI Functionalities Supporting DER Planning and Operations

Network Visibility & Response

EIP enhances the visibility and monitoring of the off-grid and on-grid DERs. Through off-grid DERs, initiatives such as Pulau Tenaga Hijau (PTH) covering Pulau Perhentian, Pulau Redang, and Pulau Tioman are established. It integrates near real-time data from PTH assets with analytics on DER operations, energy consumption, and system performance to improve energy management and enable faster operational response. For on-grid DERs, data integration from various DERs and Energy Storage System (ESS) to EIP contributes to improved monitoring and management capabilities.

EIP also develops the intelligence and visibility network by introducing DER impact assessment to evaluate the effects of increasing DER integration on the power grid. Using DER output forecasting, network simulations, and power flow analysis, the assessment predicts potential impacts and provides data to support asset planning. It identifies and quantifies grid constraints and violations, including voltage deviations, excessive current loading, and abnormal active and reactive power fluctuations across different DER integration levels, enabling improved grid efficiency and system stability. This is illustrated in Figure 2.15.

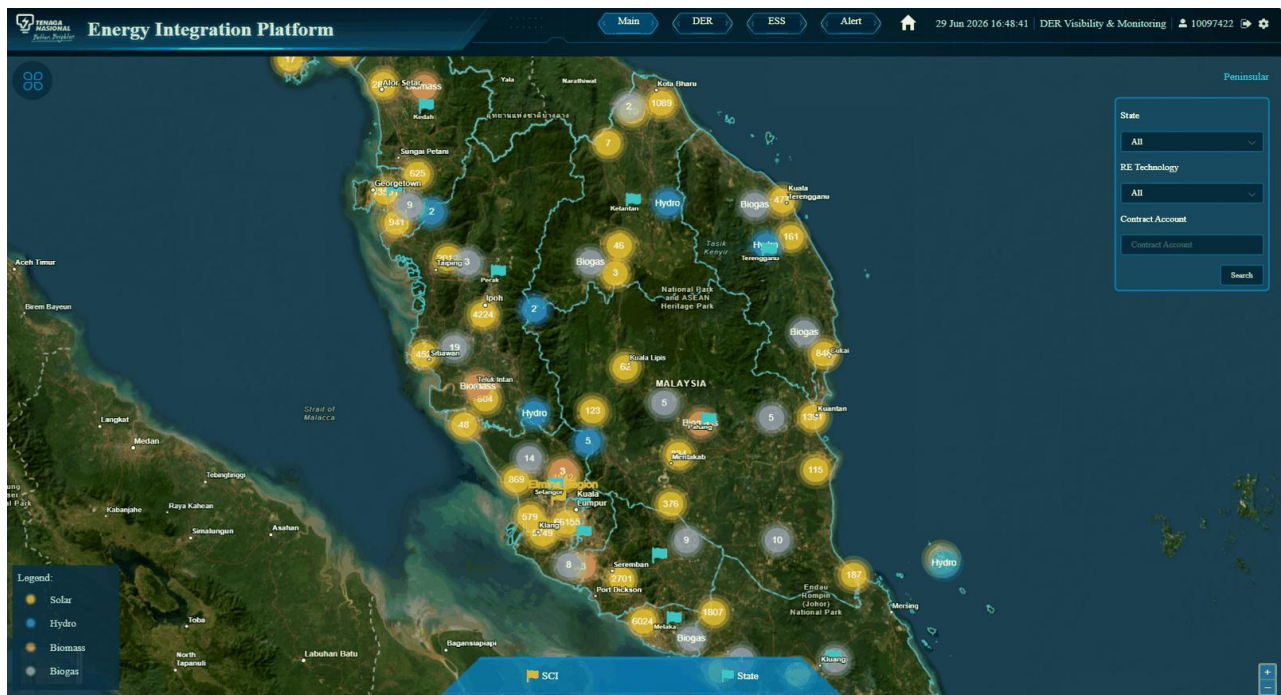


Figure 2.15: Visibility of DERs in EIP

EIP offers comprehensive visibility of Distributed Energy Resources (DERs) connected to the distribution network. This encompasses relevant information, including the connected feeder, location, energy generation and load profiles, and an aggregated perspective of DER profiles. This information is made accessible through dashboards and topology views. EIP also incorporates a Distributed Energy Resources (DER) registration capability to streamline the DER registration process and support the capture of data for new DER installations.

The EIP capability has been implemented across strategic use cases including the Elmina Residential Solar Community and the Green Island projects. Located in a residential area with high rooftop solar penetration, the Elmina site focuses on low-voltage network performance. EIP consolidates data from Smart Meters, Voltage-Regulated Distribution Transformers (VRDTs), Online Feeder Pillars, and Energy Storage Systems, enabling near real-time monitoring and analytics. The platform is used to observe reverse power flow conditions, battery state of charge, and voltage profiles at feeder level. This showcases EIP's ability to enhance visibility into distributed energy flows and support system reliability.



Figure 2.16: Home Page for Elmina Residential Solar Community

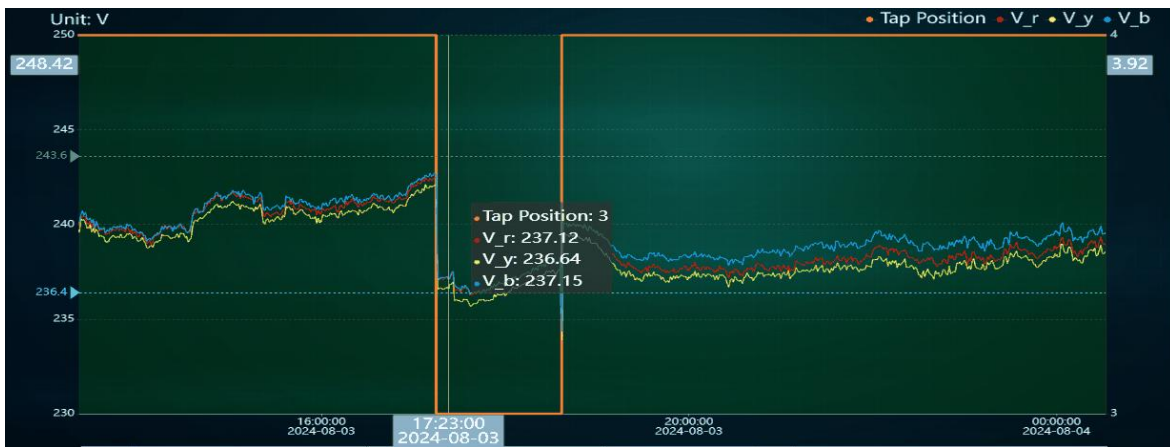


Figure 2.17: Dashboard Monitoring in Elmina

The Green Island projects at Pulau Perhentian, Pulau Redang, and Pulau Tioman serve as pilot sites for hybrid and renewable microgrid systems. Pulau Perhentian and Pulau Redang operate as off-grid hybrid systems integrating solar photovoltaic (PV), vertical-axis wind turbines (VAWT) and diesel generators. Pulau Tioman, while connected to the mainland grid, incorporates significant renewable generation and localized energy assets. EIP supports monitoring and planning for these diverse energy mixes, improving situational awareness and strategic decision-making for microgrids.

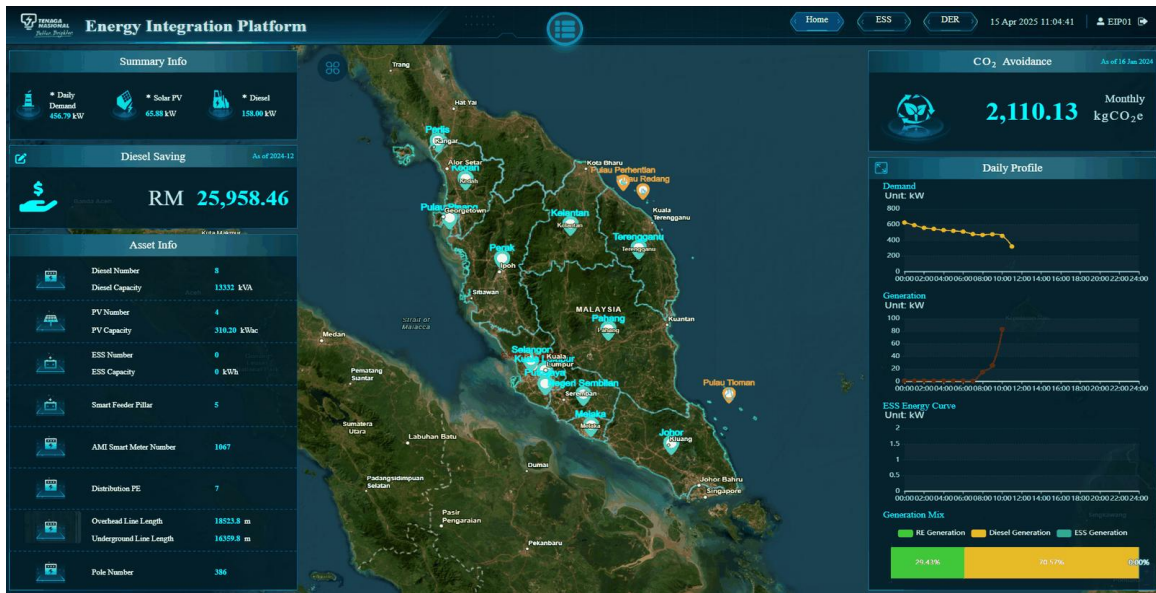


Figure 2.18: Home Page for Smart Green Island

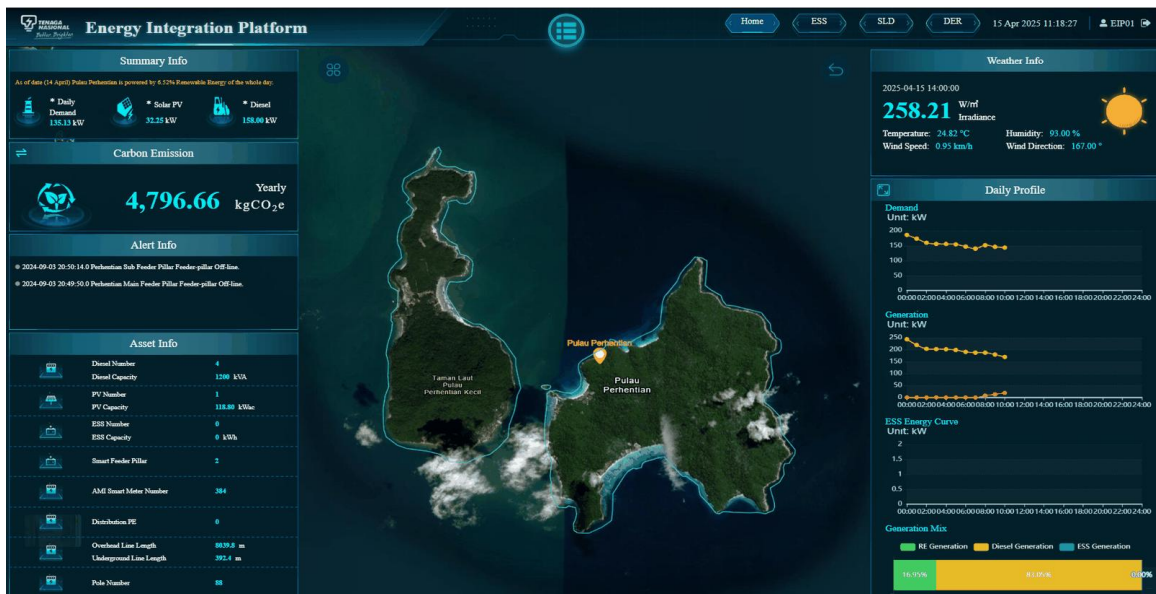


Figure 2.19: Energy Status in Smart Green Island

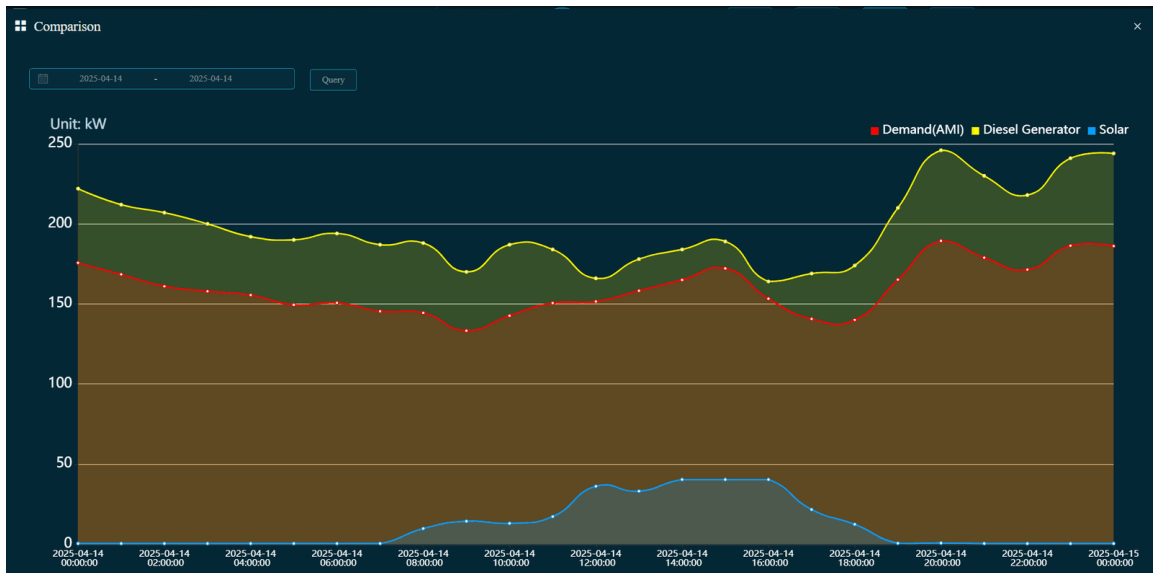


Figure 2.20: Supply and Demand Status in Smart Green Island

System Integration

EIP functions as a centralized platform that collects, exchanges, and manages data between enterprise applications, geospatial systems, and operational data sources. By leveraging standard communication protocols, the platform enables seamless interoperability, centralized data access, and supports enterprise-wide monitoring, analytics, and operational decision-making. The figure below illustrates the high-level system integration architecture of the EIP. This is illustrated in Figure 2.21.

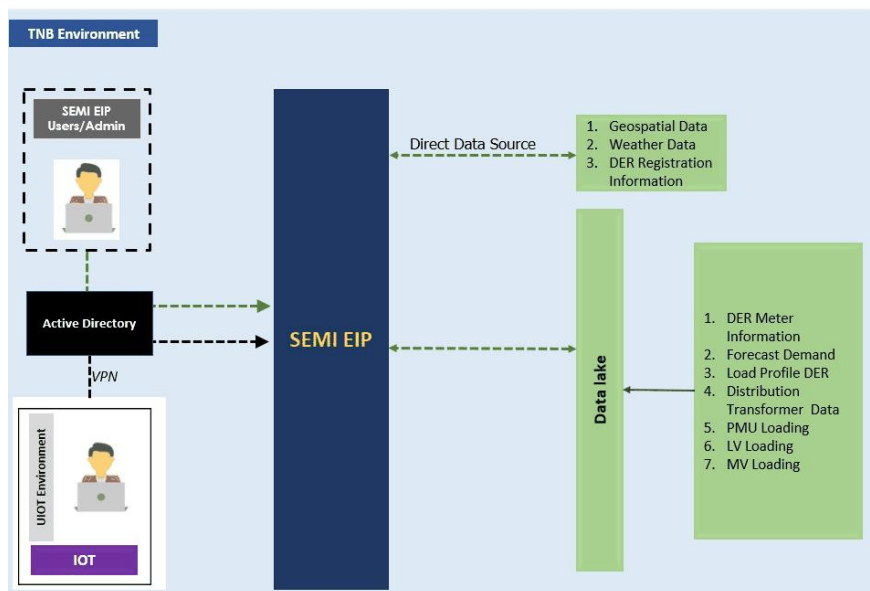


Figure 2.21: System Integration Architecture of EIP

For DER planning and operations, EIP offers a comprehensive suite of tools and features that streamline various activities. The Energy Integration Platform (EIP) serves as a central hub, consolidating data sources and providing visibility, monitoring and planning capabilities for DER assets at all levels. EIP also consolidates information such as customer DER meter information. The DER registration capability in EIP simplifies the RE registration process and supports the capture and streamlining of relevant information. To mitigate gaps in visibility for unregistered DER such as solar PV, TNB also employs LV Analytics. This is illustrated in Figure 2.22.

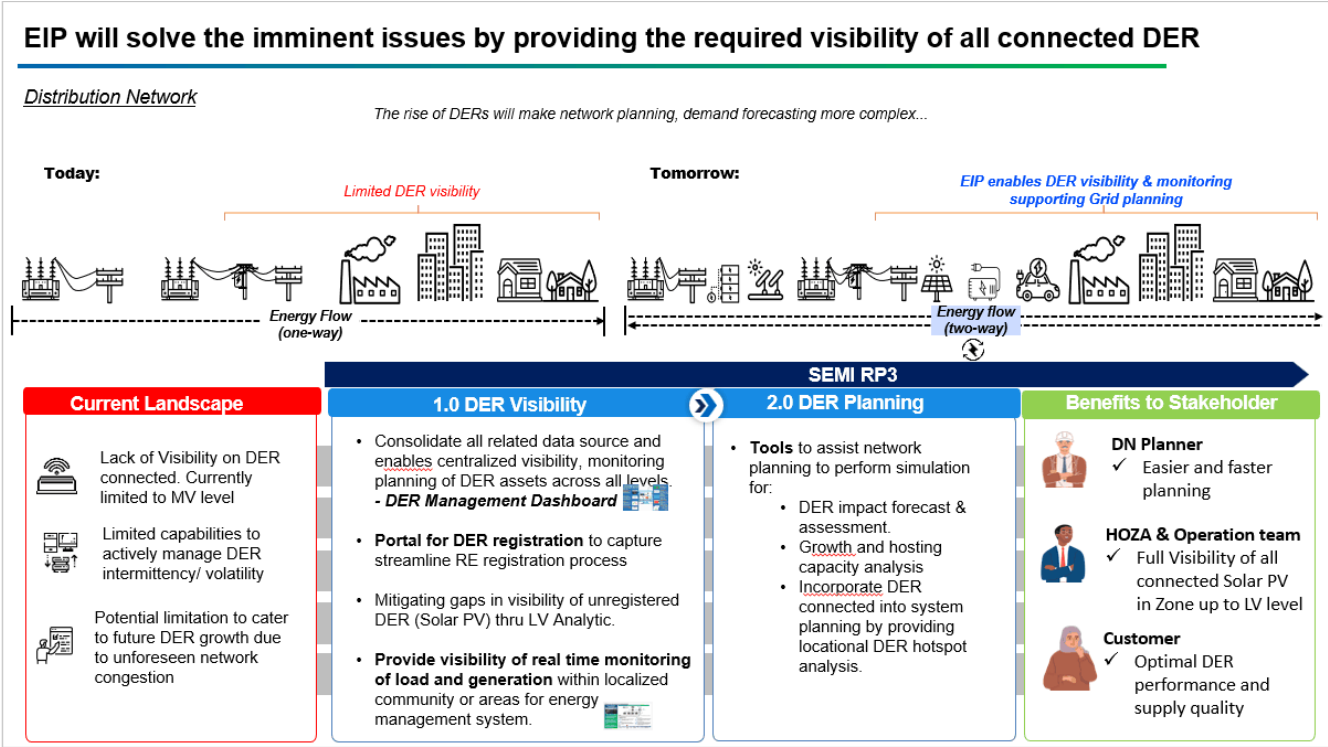


Figure 2.22: SEMI Key Functions

One of the main features is the near real-time monitoring of load and generation within localized communities or areas. This empowers energy management systems and enhances the decision-making process. Furthermore, we provide planning tools that enable network planning, offering capabilities for DER impact assessment, growth and hosting capacity analysis. These tools cater for a variety of stakeholders.

Incorporating these tools into DER planning and operations supports more informed decision-making, enhancing operational efficiency and benefiting a wide range of stakeholders. These capabilities are illustrated in Figures 2.23 and 2.24.



Figure 2.23: Energy Integration Platform (IIP)



Figure 2.24: IIP Dashboard for CESS monitoring

Forecasting & Predictive Capability

Network planning optimization in IIP supports this component by evaluating the operational condition of the distribution network and identifying potential constraint violations such as voltage deviation and overloading, including N-1 Element Analysis and an overview dashboard for studies carried out nationwide. Through advanced grid modelling, load-flow analysis and scenario simulation, IIP enables users to assess both the current network condition and future planning scenarios. Based on the analysis results, the system provides optimization recommendations to improve network stability and operational efficiency and to support hosting capacity.

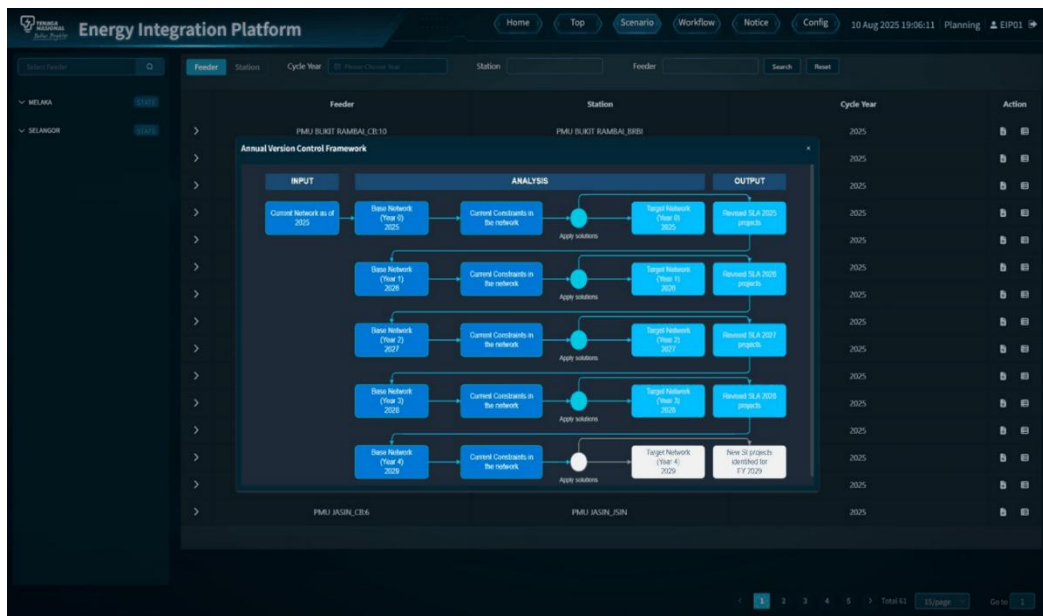


Figure 2.25: Five-Year Network Analysis in EIP

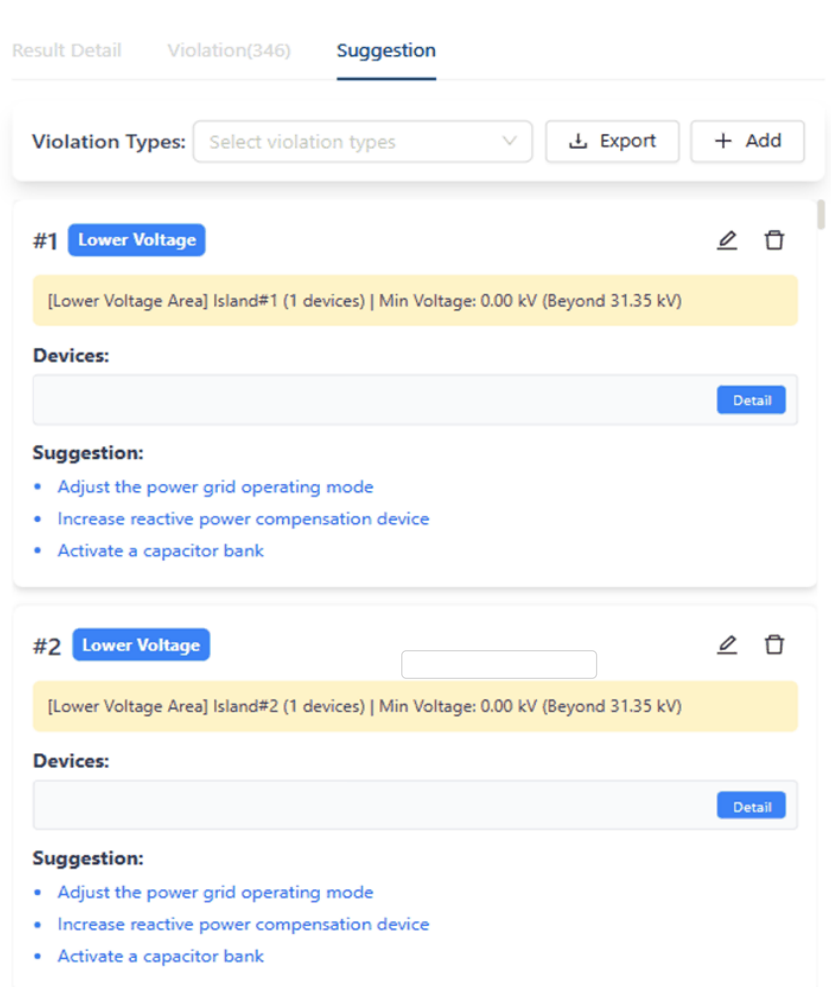


Figure 2.26: Suggested Network Improvements for Identified Violations

To support network planning, EIP provides a suite of essential tools that enable simulation for assessing and forecasting the impact of DERs. This includes Power Flow simulations and hosting capacity, and the seamless integration of DERs into system planning.

EIP provides visibility into potential Energy Storage System (ESS) deployment opportunities across the distribution network. By forecasting load growth within the Medium Voltage (MV) network, EIP can identify transformers that are at risk of becoming heavily loaded or overloaded. This early identification enables users to assess suitable ESS installation locations within the MV network to enable effective peak shaving and load optimization. These capabilities contribute to enhanced grid stability and reliability while facilitating the strategic and sustainable integration of Renewable Energy (RE) resources.

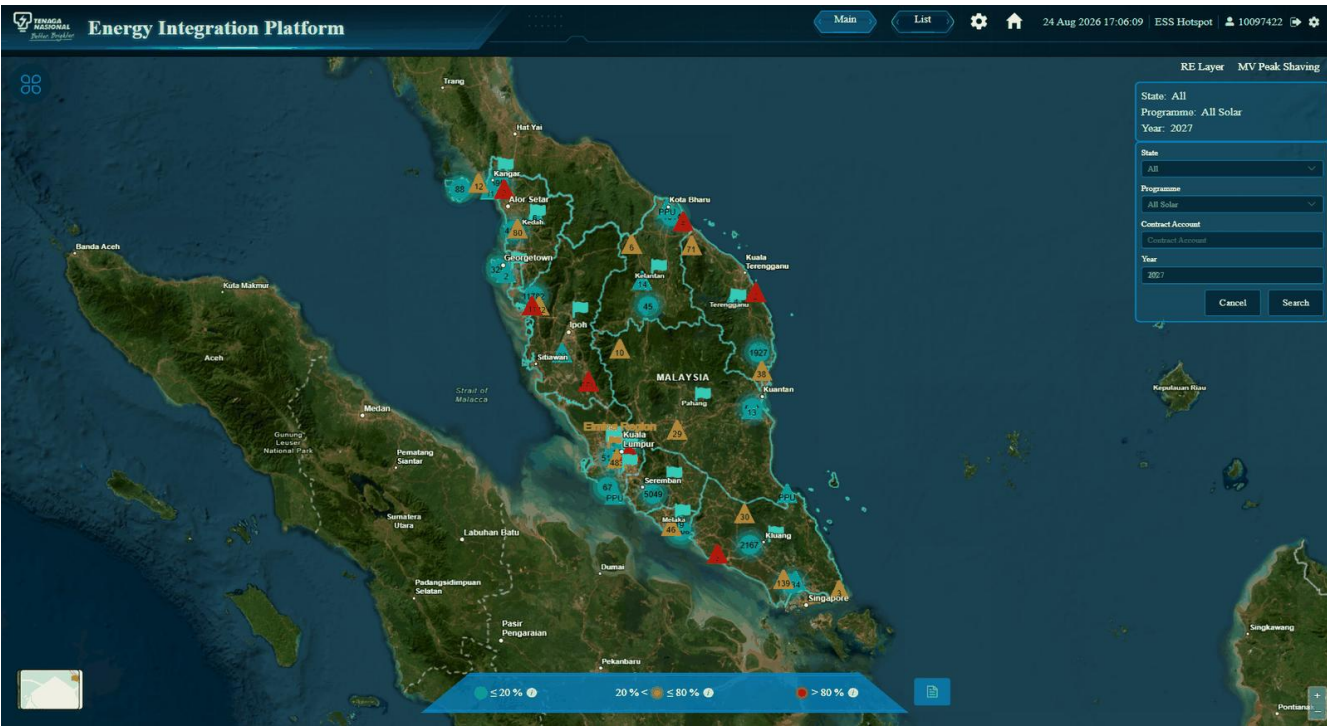


Figure 2.27: ESS Hotspot at MV level in EIP

Flexibility Management

At the core of our smart energy management infrastructure, the DER integration component stands as a pivotal foundation, drawing inspiration from globally successful models such as the Active Network Management (ANM) project in UKPN.

This innovative system navigates the complexities of modern energy management, effectively balancing the energy flow (intermittency) of renewable energy sources, adapting to shifting demand patterns, and dynamically orchestrating energy flows. The outcome is a reduction in energy wastage and the maximization of efficiency. Moreover, EIP opens the door to RE hosting

capacity, providing users with a better overview of substation capacity for RE installation and actively fostering the expansion of Renewable Energy (RE). This commitment to innovation extends to addressing grid congestion, with SEMI introducing trials for Demand & Supply Side Flexibility, ensuring the harmony and efficiency of the energy network.

The combined benefits of these features are profound:

1. Enhanced Grid Stability: Through its dynamic approach to supply and demand, DER integration significantly minimizes grid instability and power fluctuations.
2. Promote Growth of Renewable Energy: By incorporating renewable sources like solar PV, a higher penetration of clean energy into the grid without compromising network performance is ensured. This not only promotes sustainability but also advances our collective transition towards a greener energy landscape.

TNB's DERMS MONITORING CAPABILITIES OF MICROGRID IN ELMINA TOWNSHIP

The capabilities described above are demonstrated through practical use cases, including the Elmina Residential Solar Community, where EIP supports the monitoring and management of distributed energy resources within a low-voltage network environment.

To address challenges and unlock full potential of renewable energy integration in Malaysia, innovative solutions and investments in robust grid modernization infrastructure upgrades are essential. A pioneering initiative by TNB through its Smart Utility Program, developed Malaysia's first interconnected Smart Utility Infrastructure, aims to encourage the adoption of DERs, enhancing local energy generation and consumption. Leading this effort is Elmina Ilham Residence in Shah Alam, exemplifying sustainable living by seamlessly integrating technology, sustainability, and green energy. With 513 houses equipped with solar 2kW capacity under Net Energy Metering (NEM), alongside an additional 6kW for 223 houses through rooftop leasing, exporting excess energy to the grid, the residence demonstrates a strong commitment to renewable energy adoption. This holistic approach is supported by End-to-End Smart Utility Infrastructure deployment comprising Community Energy Storage Solutions (CESS), Voltage Regulated Distribution Transformers (VRDT), Online Feeder Pillars (OFP), Distribution Intelligence Switch (DIS), SCADA-Distribution Automation (DA), and Smart Meters, all integrated through Energy Integration Platform (EIP), an Energy Management Platform. This is illustrated in Figure 2.28.

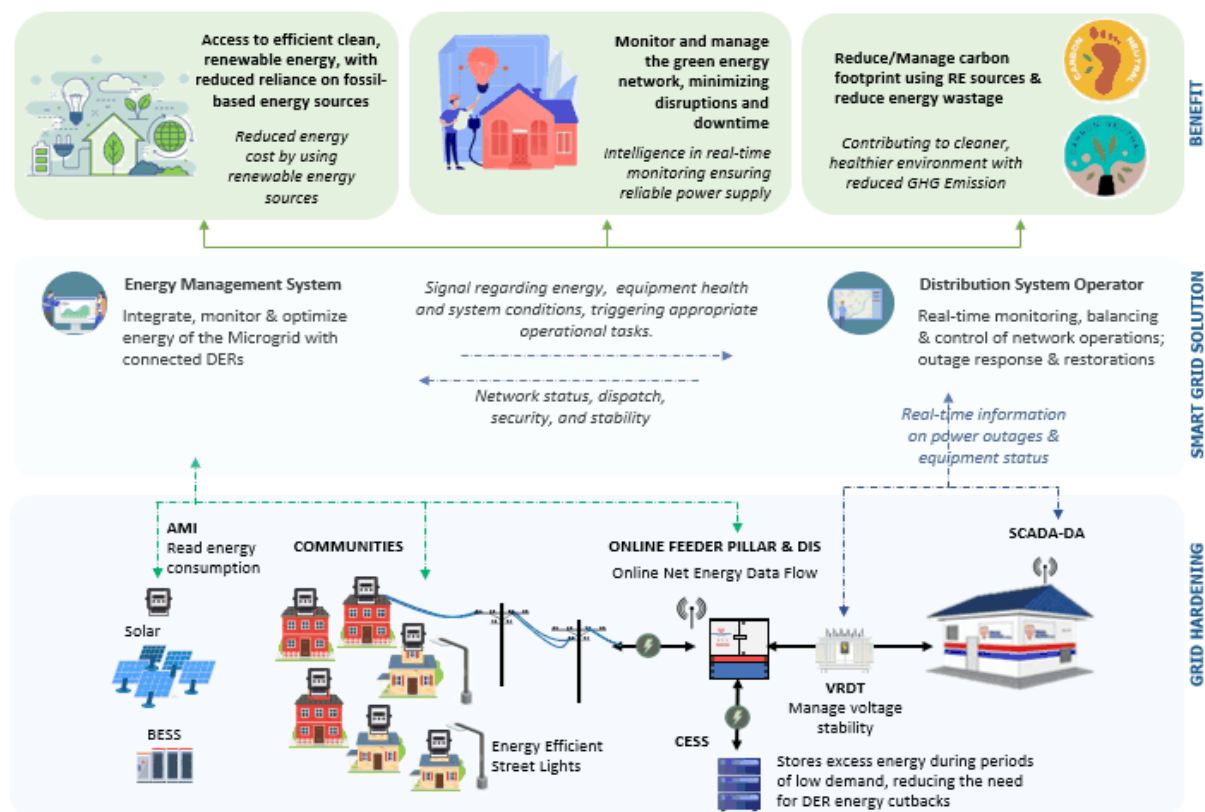


Figure 2.28: Offerings & Benefits of TNB's Smart Community Infrastructure (Microgrids)

In this smart community energy system, electricity is supplied from the grid to users through transformers, online feeder pillars, LV cables and AMI meters. During peak solar hours, surplus energy generated from rooftop solar flows to nearby users, while excess energy is stored in the CESS to support efficient utilization. When generation exceeds local demand, voltage may rise, allowing the VRDT to regulate voltage within allowable limits. During periods of low sunlight, stored energy from the CESS is redistributed to users to supplement grid supply when demand rises. At night, when RE supply is unavailable, the system switches to full grid supply while the VRDT continues to regulate voltage. These functions operate automatically and interoperate through DIS and IoT technology, with monitoring supported through EIP. This is illustrated in Figure 2.29.

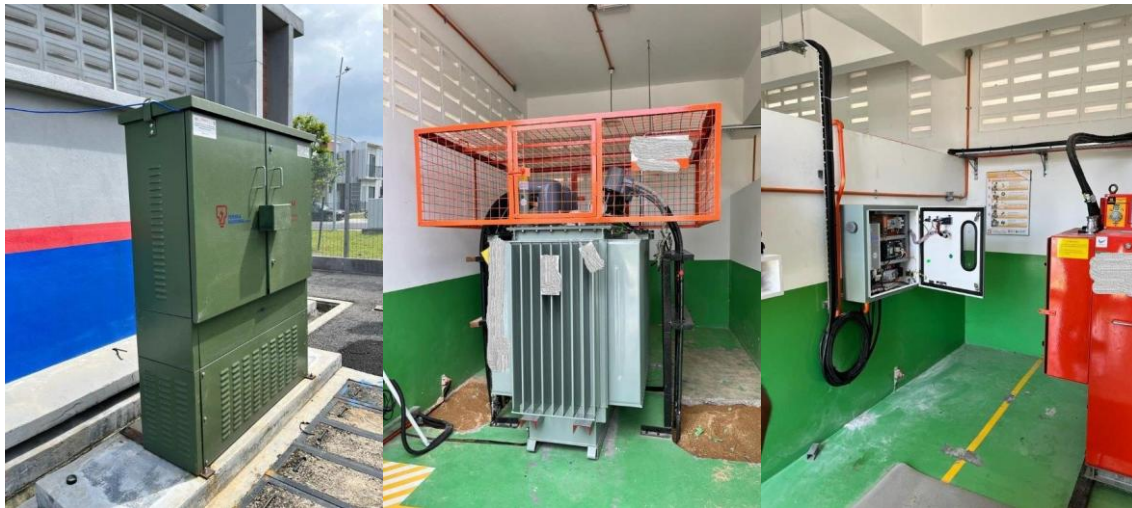


Figure 2.29: Online Feeder Pillar, Voltage Regulated Distribution Transformer & DIS

TNB's Smart Community Infrastructure, or microgrids, offers a solution to challenges posed by increased renewable energy integration, particularly within local communities. Implementing smart utility infrastructure offers various benefits, including access to clean energy, reduced reliance on fossil fuels, enhanced efficiency, lower emissions, and increased savings. TNB is taking this effort by embracing smart technologies, laying the foundation for a sustainable and resilient energy future in Malaysia. With the motto "PRODUCE LOCALLY, USE LOCALLY" and a commitment to fostering an energy-sharing community, TNB aims to lead Malaysia towards a brighter and sustainable future for generations to come. This is illustrated in Figure 2.30.



Figure 2.30: The commissioning of TNB's Microgrid in Elmina

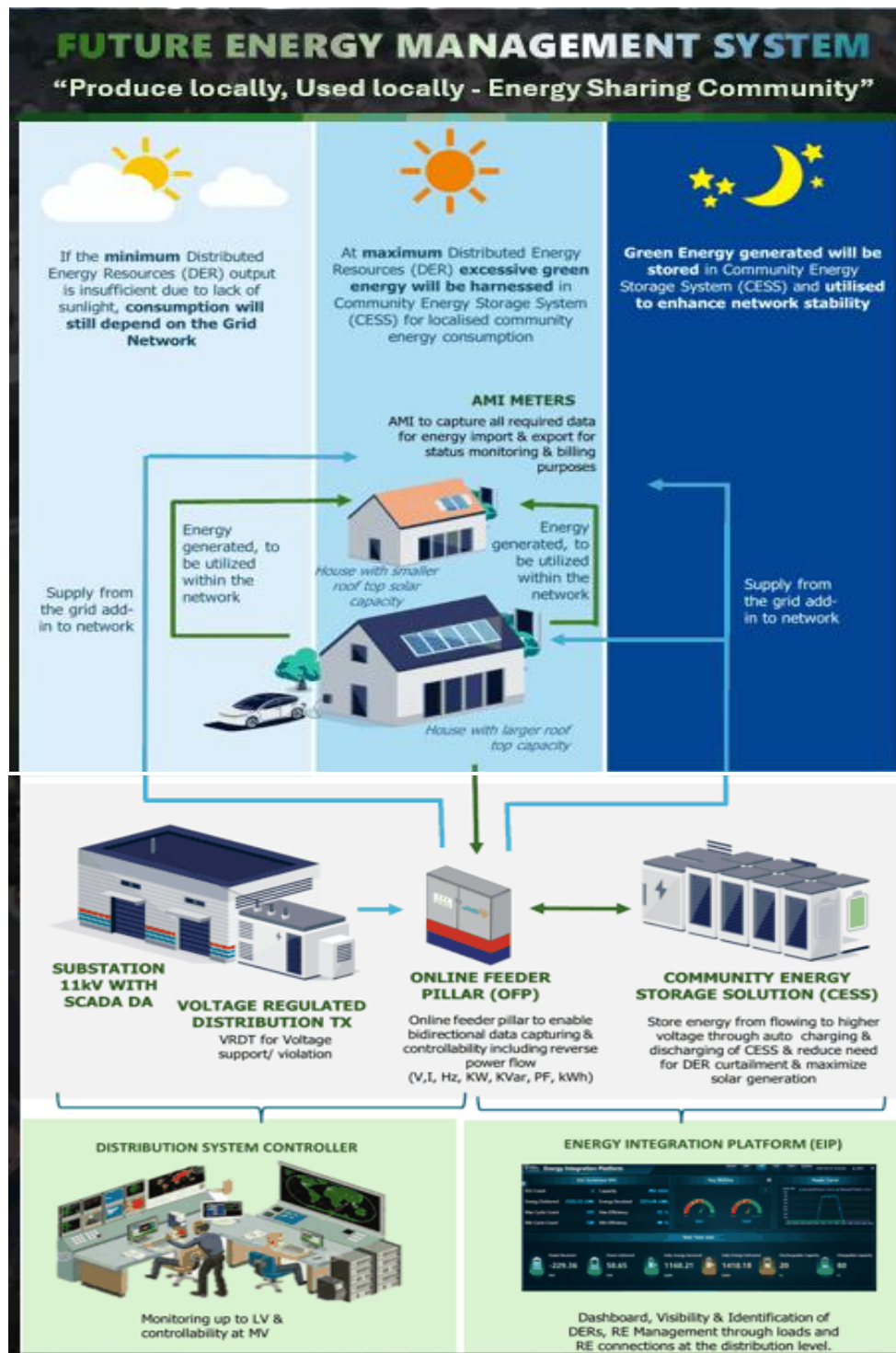


Figure 2.31: TNB's Smart Community Infrastructure (Microgrids) Scenario & Ecosystem

RECOGNITION

TNB has also achieved recognition through SEMI project as ‘Energy Advocate of the Year’ award winner in the ENLIT Asia event in Bangkok in September 2022 for Uplifting TNB towards Energy Transition. This is illustrated in Figure 2.32.

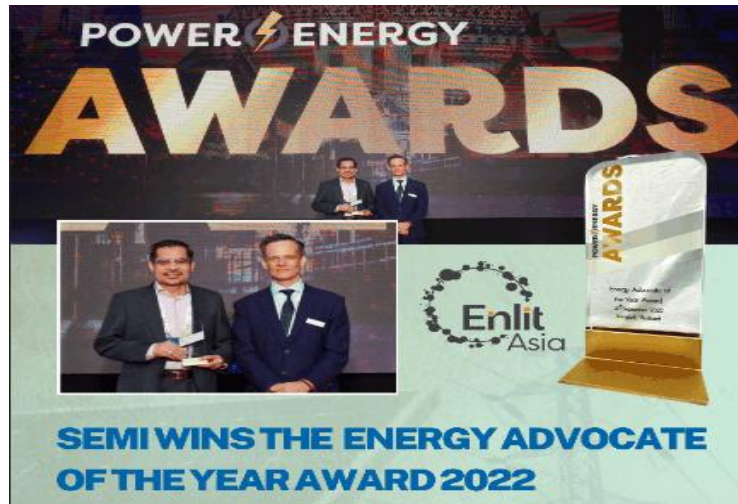


Figure 2.32: SEMI Award – Energy Advocate of the Year Award 2022

Besides that, TNB also won the Gold Award for "Energy Integrated Platform (EIP) as an enabler towards Energy Transition of TNB Distribution Network" through Asian Power Award 2023 under category Transmission & Distribution Project of The Year. Another recognition achieved by SEMI is being Energy integration Pioneer in Southeast Asia from State Grid Electric Power Research Institute in CEPSEI 2023. This is illustrated in Figure 2.33.



Figure 2.33: SEMI recognition as Energy integration Pioneer in Southeast Asia

2.1.3 Special Protection Scheme (SPS) for Automated System Integrity Protection

System Integration

Unlike conventional protection, which primarily isolates individual faulty equipment, SPS assesses conditions across a wider area of the power system. It combines electrical measurements, equipment status and predefined system logic to determine whether a major contingency has occurred or whether the network is approaching an unacceptable operating condition. Depending on the scheme design, SPS may initiate corrective actions such as selective generation tripping or de-loading, load reduction, transmission-line tripping, transfer switching or network reconfiguration.

TNB has progressively developed multiple SPS applications since 2010 to manage system-specific risks across different parts of the transmission network. As the grid expanded, the schemes evolved from relatively independent applications into a more interconnected network of detection, communication and mitigation functions. Changes to generation dispatch, transmission topology, renewable-energy connections and other grid facilities may therefore affect how an existing SPS performs.

Because SPS is required to remain available for system security, complete end-to-end testing on the live network is difficult and may not be operationally acceptable. Testing only the modified portion of a scheme may also leave hidden logic, communication or system-interaction issues undetected. To strengthen SPS testing and assurance, TNB developed an integrated SPS Digital Twin and real-time simulation capability in 2022. The platform reproduces the electrical network, SPS devices, control logic and communication behaviour in a controlled environment so that existing schemes, modifications and new system conditions can be tested without exposing the operational grid to unnecessary risk. This is illustrated in Figure 2.34.

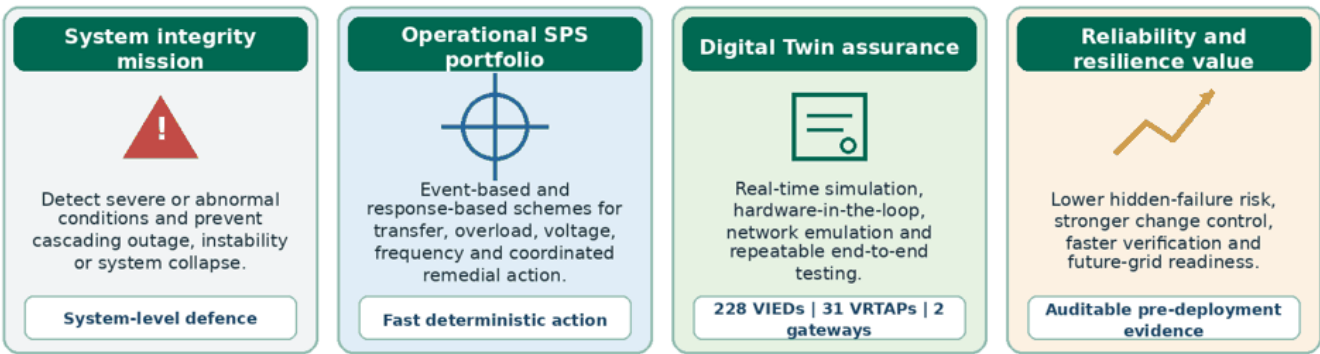


Figure 2.34: Overview of SPS capability and Digital Twin assurance

The principal capability of SPS is its ability to respond automatically to a major system event within a timeframe that cannot be achieved through manual control-room intervention. Measurements and equipment-status information are collected from selected locations across the network and

processed through coordinated SPS logic. When the predefined operating criteria are satisfied, remedial commands are issued to the appropriate field equipment.

This provides a system-level self-healing capability. Rather than waiting for the disturbance to propagate or for an operator to manually assess and respond, SPS takes immediate and coordinated action to arrest the event and maintain the remaining power system within a stable operating condition.

SPS also integrates protection and control functions across transmission lines, substations, generation facilities and other critical network interfaces. This allows a single scheme to consider the combined condition of several geographically separated assets rather than relying only on local measurements.

The coordinated approach is particularly important for contingencies involving multiple outages, excessive power transfer, generation loss, voltage instability or other events where the consequence extends beyond a single item of equipment. SPS therefore strengthens the grid's ability to withstand abnormal system conditions and prevents local disturbances from developing into larger system events.

The SPS Digital Twin provides a controlled environment for testing the complete operating chain—from the initial network contingency, through SPS detection and communication, to the final corrective action. The acceptance programme verified the operation of 228 virtual protection and control devices, 31 virtual SPS processing platforms and two virtual acquisition and control gateways. It also compared the responses of physical and virtual devices and verified several operational SPS representations under simulated system conditions. This capability allows engineers to repeat tests under controlled conditions, vary system parameters, introduce communication delays and reproduce complex contingencies that would be difficult or unsafe to create on the live network.

The simulation environment can also represent emerging power-system technologies and changing network characteristics. Models developed for the platform include renewable generation, battery energy storage, HVDC systems, flexible AC transmission devices, load variation and other future-grid elements. This enables TNB to assess how new generation sources, inverter-based resources and changing power-flow patterns may interact with existing SPS functions before actual implementation. The capability therefore supports renewable-energy and BESS readiness while maintaining appropriate system-integrity protection.

The operational SPS acquires real-time electrical measurements and equipment-status signals from selected substations, transmission lines and generation interfaces. These inputs are processed through coordinated SPS logic to detect predefined high-impact contingencies. When the required conditions are confirmed, the scheme automatically issues remedial commands

such as generator or load reduction, circuit-breaker operation or network reconfiguration to prevent instability, cascading tripping or widespread supply interruption.

The SPS Digital Twin reproduces the same end-to-end operating chain in a controlled real-time simulation environment. Validated network models generate realistic disturbances, while virtual or physical SPS devices, processing platforms, gateways and communication models respond as they would in the live system. The resulting corrective actions are returned to the simulated network so that their timing, effectiveness and overall system impact can be assessed.

Beyond monitoring and post-event analysis, the Digital Twin supports new scheme development, modification testing, hardware-in-the-loop verification, troubleshooting, regression testing and assessment of future-grid conditions. It enables TNB to evaluate renewable generation, BESS, changing power flows, communication delays and equipment unavailability before implementation, thereby reducing hidden failure risk and strengthening confidence in SPS performance. This is illustrated in Figure 2.35.

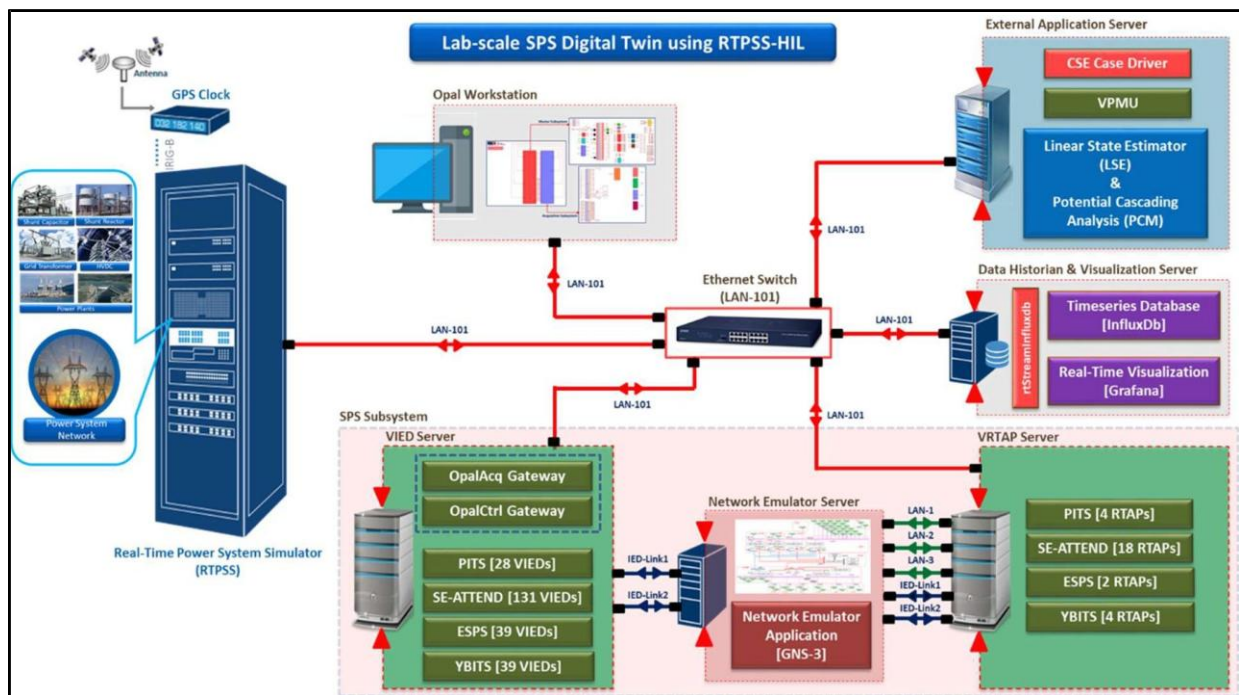


Figure 2.35: SPS Digital Twin real-time simulation environment

SPS applications are operational at selected strategic transmission areas to manage defined high-impact contingencies and prevent instability, cascading tripping or major supply interruption. The schemes are supported by established protection, control, communication and monitoring infrastructure across the relevant substations, transmission corridors and generation interfaces.

The SPS Digital Twin and real-time simulation platform were completed and formally accepted in 2022. The platform has since been used for pre-installation simulation, testing of new and modified schemes, hardware-in-the-loop verification, troubleshooting and assessment of changing network conditions.

Overall, SPS is an established operational grid-protection capability, while the Digital Twin provides the supporting engineering environment for scheme development, validation and performance assurance. Together, they strengthen TNB's ability to maintain reliable SPS operation as the transmission network evolves.

In the near term, the SPS Digital Twin models will be updated to reflect the latest operational schemes and network conditions. A structured library of credible contingency scenarios will be developed to support consistent validation of existing SPS and proposed modifications before field implementation.

In the mid-term, the capability will be enhanced through greater integration of high-speed measurements, SCADA data and system-stability indicators. Automated regression testing and response comparison will be introduced, together with expanded assessment of renewable generation, BESS, changing power flows and communication delays.

In the long term, SPS will progress toward adaptive wide area protection and control, with corrective actions selected according to prevailing system conditions. This may include coordinated use of generation control, BESS, demand response, renewable curtailment and network switching to strengthen system integrity and support secure integration of future energy resources. This is illustrated in Figure 2.36.

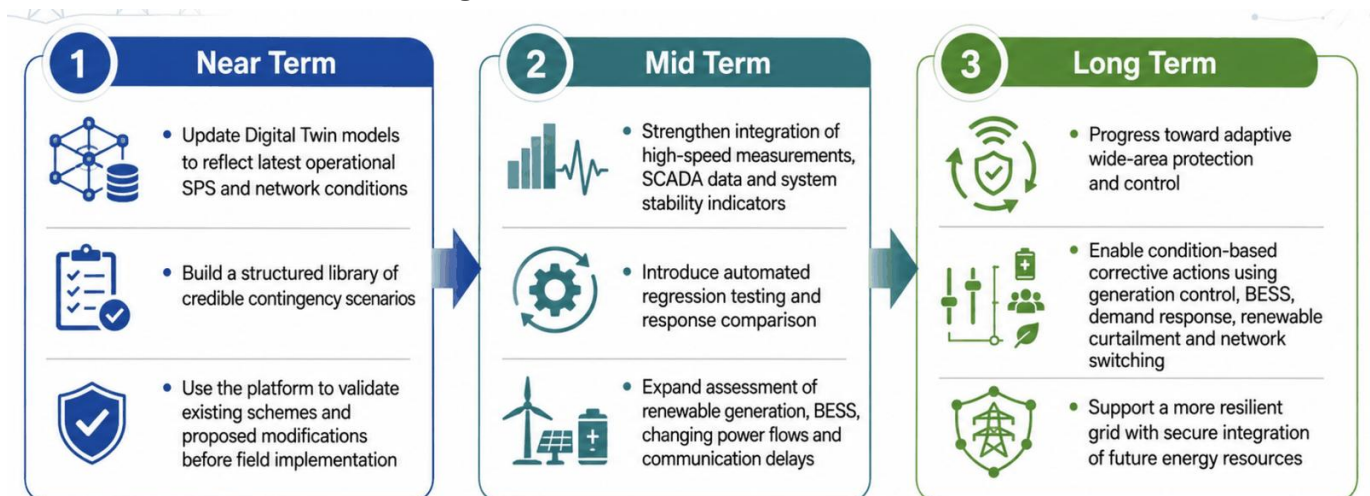


Figure 2.36: SPS Digital Twin development roadmap

SPS improves supply reliability and resilience by detecting severe system contingencies and executing coordinated corrective actions faster than manual intervention. This reduces the risk of instability, cascading tripping and widespread supply interruption, while helping the remaining network continue operating securely.

The Digital Twin strengthens SPS performance by enabling end-to-end testing under realistic and repeatable conditions without exposing the live grid to unnecessary risk. It supports earlier detection of logic errors, communication issues and unintended system interactions, reduces dependence on partial field testing and provides clearer evidence for design acceptance, commissioning and troubleshooting.

The combined capability also improves readiness for renewable generation, BESS and other future-grid technologies by allowing their impact on existing SPS to be assessed before implementation. Previous assessments estimated potential cost avoidance of approximately RM4.46 million per major scheme through more efficient design and optimization.

2.1.4 AI-Driven Predictive Maintenance for 11kV Underground Cable (UGC)

Network Visibility & Response

TNB has introduced an AI-driven predictive maintenance capability for 11kV underground cable (UGC) to support more proactive identification of cable assets with higher potential risk of failure. The initiative applies predictive analytics to historical asset and maintenance information to provide additional insights for maintenance planning and asset-management decisions.

The predictive capability, including its data inputs, analytical approach, implementation status and development direction, is described in Section 3.1.1.

2.1.5 IoT Sensor Deployment for Switchgear and Power Transformer Health Monitoring

IoT-enabled condition monitoring also contributes to network visibility and operational response by providing near-time condition information from selected critical distribution assets i.e. 33kV Switchgear and Power Transformer. The sensing deployment, data collected, and monitoring approach are described in Section 1.1.4, while the application of this information for predictive asset analytics is further discussed in Section 3.3.1.

2.2 Forecasting & Predictive Capability

TNB has implemented several initiatives to strengthen forecasting and predictive capability for network planning and investment decision-making. The key initiatives presented in this section include i-NET and Asset Investment Planning and Management (AIPM), together with DG Hosting Capacity to support forward-looking network and capacity assessment. The Energy Integration Platform (EIP) also contributes to this capability through its network planning optimization and DER impact assessment functions, as described earlier in Section 2.1.2.

2.2.1 i-NET (Integration Network Expansion Tool) and Asset Investment Planning & Management (AIPM) for MV Assets

Advance asset analytics projects also encompass network management to enhance the overall resiliency of the grid. This comprehensive approach ensures that the network is robust enough to cater to a wide range of operational challenges and external factors. By continually monitoring the performance of grid assets and analysing network data, these initiatives empower grid operators to respond effectively to adverse conditions such as extreme weather events, cyber threats, and changing load patterns. Through proactive measures as highlighted in the project below, real-time insights, and dynamic adjustments, the grid can adapt and maintain its dependable service, ultimately delivering sustainable, reliable electricity to meet the ever-growing energy demands of our modern society.

i-NET is an analytical solution custom built for distribution network planners to facilitate Centralized Planning and Capacity Allocation Management. It was a digitalization initiative to enable effective realization of TNB Smart Utility Master Plan which demands accurate network planning of dual power flow system, centralized governance of efficient planning, overall optimization of CAPEX planning and management as well as productivity improvement to cater for job enhancement of planning unit to take up additional tasks related to grid modernization.

Figure 2.44 below illustrates the high-level solution framework of i-NET implementation for distribution planning as a part of Enterprise Asset Management System (EAMS). Traditionally the architecture of EAMS consists of Enterprise Resource Management System (ERMS), Asset Performance Management System (APMS), Asset Investment Planning and Management (AIPM) and Project Portfolio Management (PPM).

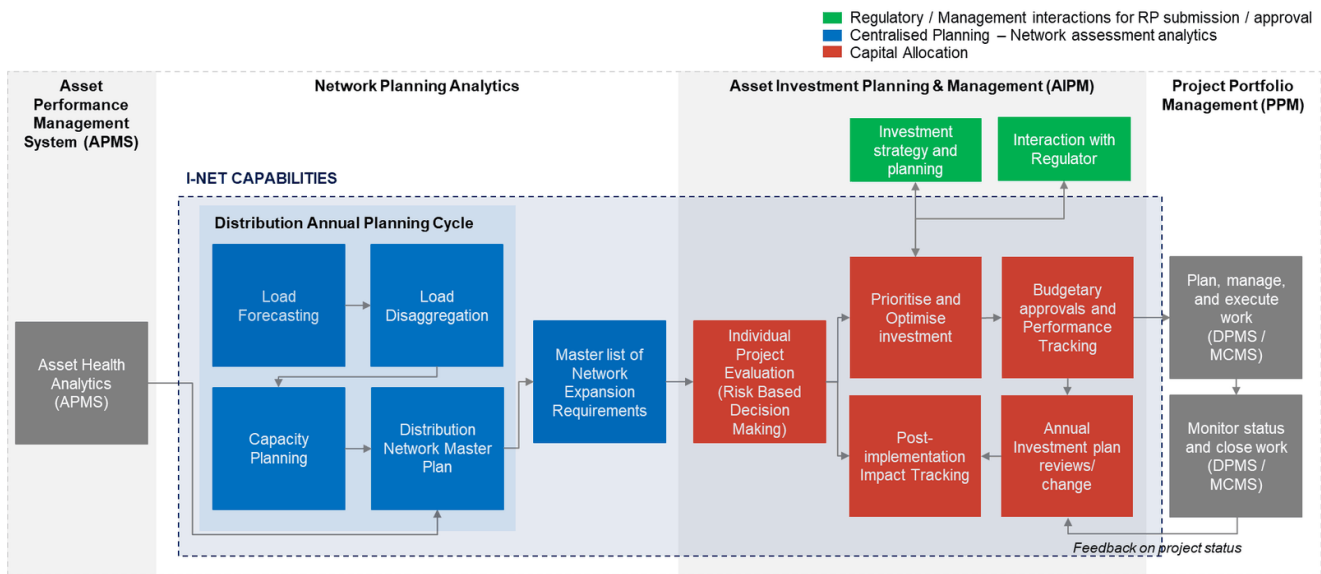


Figure 2.44: High level solution framework of i-NET Capabilities

While completing the traditional building blocks of EAMS, i-NET goes beyond the basic requirements of EAMS i.e. capabilities of Network Planning Analytics is coupled with AIPM as a total solution for planners sandwiched between APMS and PPM.

i-NET is embedded with the customised methodology of Distribution Annual Planning Cycle analysis which generates network expansion requirements and becomes an input to AIPM where annual capital allocation is prioritized and optimized according to strategic objectives of the organization.

Hence, besides process automation, i-NET is a decision support system (DSS) and single source of truth for centralized planning and capital allocation with below features:

1. A unified Platform for distribution annual planning cycle studies conducted by nationwide planners
2. Centralized capex portfolio planning and management through risk-based evaluation and mathematical optimization
3. Automated data collection and result generation based on admin specified logics and user-friendly Graphical User Interface (GUI)
4. Ad-hoc result simulation for unique scenario planning
5. Convenient interactive analytical tool with custom built Visual Analytics Reporting

As a total solution for distribution planners, the capabilities of i-NET can be segmented into 2 major parts i.e. Centralized Network Planning Analytics and Asset Investment Planning and Management.

The forecasting methodology adopted in i-NET allows advanced load forecasting capabilities. It is a progressive migration from simple time series forecast to a much-advanced multi-variant time series analysis which encapsulates time series as well as regression models. Time series analysis searches for recent trending as well as seasonal or recurrent relationship of demand with respect to time parameter. The multi-variant parameters used in this forecast model considers the influence of Peninsular Malaysia's economic factors such as population, Gross Domestic Product (GDP), weather and others.

With demand by main intake substation as the dependent variable and the respective econometric factors (Weather, GDP, Population, Nos. of Household, Electricity price & Commercial floor space) as the independent variables, i-NET automatically identifies the best statistical fit by comparing against unlimited models. Any irregularities are automatically detected which produces forecasting result that is free from human error. Besides, in i-NET there are functionalities to configure impact of recurring or non-recurring events such as festive season, natural disasters, high profile event and sudden spike of industrial step load.

As a result, i-NET generates high accuracy forecast which will basically determines the accuracies of consecutive studies of DAPC i.e. Load Disaggregation, Capacity Planning and Distribution Network Master Plan.

Upon finalization of Load Forecasting, i-NET allows automated Load disaggregation, where forecasted demand is disaggregated to distribution primary and secondary substations to generate 20-year demand forecast by asset. All demand transfers between assets to optimize asset utilization are handled within i-NET properly recorded on a geospatial unified platform.

The AIPM establishment in i-NET focuses in achieving end to end Core CAPEX lifecycle management with automated project evaluation, CAPEX portfolio optimization as well as post implementation impact tracking. It comprises of 5 main capabilities as deliberated below:

1. Project Life Cycle Management and Tracking which provides single source of truth for CAPEX lifecycle management.
2. Project Assessment & Risk Management which enables automated identification of "effective" CAPEX to avoid potential OPEX evaluated by unique needs of local area characteristics leveraging on concept of risk or value-based decision making.
3. CAPEX Portfolio Planning & Optimization which can be broadly classified as mathematical optimization of CAPEX portfolios against constraints or targets i.e. short term / medium term strategic objectives of the organization, allowable CAPEX allowances specified by regulators, availability of resources and elements of related nature. This allows agile optimization of CAPEX portfolios for optimum value creation within Regulatory Period targets.
4. Periodic Revision of Budgetary Requirements allows centralized CAPEX lifecycle management by distribution planners to ensure optimal utilization of CAPEX adjusted against constraint faced during implementation to avoid prolonged stagnation of CAPEX or project.

5. Interactive Dashboards for Performance Monitoring provides easy performance tracking by middle management

In a nutshell, digitalization of abovementioned capabilities is expected to yield enhanced process efficiencies, enhanced risk management, enhanced investment evaluation, enhanced portfolio evaluation, improved system project outcomes and overall bullet proofing of TNB's CAPEX proposal accompanied by risk monetization and proven value creation.

For AIPM for HV Assets, refer to section 3.4.2.

2.2.2 Intelligent Grid Planning for Renewable Energy Integration

To support the National Energy Transition Roadmap (NETR), TNB continues to strengthen its transmission-level planning capability to accommodate increasing renewable energy penetration while maintaining system security, reliability and operational flexibility. This is particularly relevant for the connection of utility-scale renewable energy developments, including Large Scale Solar (LSS), Battery Energy Storage Systems (BESS) and other inverter-based resources, which can have a significant impact on the high-voltage transmission network.

TNB has established an integrated planning capability that combines Renewable Energy Hosting Capacity Assessment with advanced power system simulation and planning tools, particularly PSS®E. Using detailed transmission network models, planners assess the capability of the network to accommodate additional renewable generation under different future operating conditions, including changes in electricity demand, generation dispatch, transmission outages and planned network development.

The assessment covers technical studies such as load flow, contingency analysis, voltage performance, fault level and transient stability in accordance with applicable Grid Code and Transmission System Reliability Standards (TSRS) requirements. Through these studies, TNB can identify available network capacity at relevant substations or regions, evaluate potential technical constraints and determine where network reinforcement may be required before new generation projects are connected.

Rather than relying solely on network reinforcement after constraints occur, this capability supports a more proactive and forward-looking planning approach by assessing future network conditions and the cumulative impact of multiple renewable energy developments. It also supports renewable energy programmes such as LSS, CRESS and BESS initiatives, enabling connection decisions to be supported by consistent and technically justified engineering assessments.

By combining hosting capacity assessment with advanced network simulation, TNB is able to make more informed transmission development and investment decisions, optimize the utilization of existing infrastructure and prepare the high-voltage network for increasing renewable energy penetration. This strengthens TNB's predictive planning capability while supporting the development of a secure, reliable and future-ready electricity system.

2.2.3 Distributed Generation (DG) Hosting Capacity for DER

Towards promoting the proactive integration of Distributed Energy Resources (DER), TNB introduced the Distributed Generation (DG) Hosting Capacity web portal in 2022 and continues to provide hosting-capacity visibility to support prospective renewable energy developers and stakeholders in identifying potential connection points within the Medium Voltage distribution network. This innovative platform, equipped with a map-based view, allows potential DER developers and stakeholders to effortlessly identify available DER connection points and assess the associated capacity visibility within the Medium Voltage distribution network for Distributed Generation. The user-friendly DG Hosting Capacity map is made accessible to both internal TNB users and external parties, including RE developers, through a Geographic Information System (GIS) platform.

The first phase of the DG Hosting Capacity Map project was initiated in March 2021 and successfully completed in October 2021. During this initial phase, the system was exclusively designed for internal use within TNB. Subsequently, the project proceeded to its second phase, commencing in November 2021, and reaching completion on June 27, 2022, making it accessible to the public.

Since 2023, TNB in collaboration with the Sustainable Energy Development Authority Malaysia (SEDA), embarked on an initiative to streamline the process of connecting to Renewable Energy (RE) sources. A central aspect of this initiative is the release of a comprehensive list outlining the hosting capacity of available substations, termed Nodal Points. These Nodal Points play a pivotal role as reference points for new RE projects looking to connect to TNB's distribution network, specifically at medium voltage levels (33kV and 11kV). They play a crucial role in facilitating connections for projects operating under the Feed-in Tariff (FIT) and Net Energy Metering (NEM) programs (Refer to Figure 2.45).

Table 1: Nodal points for DG is publicly available in tabular format

No	Substation Name	State	Connection Point (kV)	Allowable Connected Capacity (MW)
1	Bakri	JOHOR	11	4.45
2	Bandar Penawar		11	4.06
3	Batu Pahat		11	5.84
4	Bukit Kepong		11	2.57
5	Gerisek		11	11.12
6	Kangkar Tebrau		11	5.62
7	Kluang (New)		11	7.20
8	Kota Tinggi		11	2.20
9	Parit Jamil		11	5.16
10	Parit Yusof		11	2.53
11	Renggam		11	3.13
12	Rengit		11	7.85
13	Senai		11	14.50
14	Sri Sulong		11	2.50
15	Tangkak		11	5.24
16	Tangkak Industrial		11	7.00
17	Batu Pahat East		33	17.39
18	Bukit Siput		33	3.30
19	Financial Center (Gis)		33	19.07
20	Kangkar Tebrau		33	28.77
21	Mersing		33	3.49
22	Pasak		33	10.62
23	Pasir Gudang Town Centre		33	49.35
24	Perling		33	27.83
25	Permas Jaya		33	7.06
26	Pontian		33	4.47
27	Pusat Bandar Johor Bahru		33	22.39
28	Saling		33	16.83
29	Senai		33	20.62
30	Skudai		33	49.38
31	South Key Jb (Gis)		33	9.38
32	Sungai Abong		33	12.13
33	Tampoi Industri		33	25.54
34	Tanjung Kupang		33	14.42
35	Tanjung Langsat		33	30.85
36	Tebrau		33	30.60
37	Teluk Ramunia		33	2.44
38	Ulu Tiram		33	31.36
1	Bona Vita	MELAKA	11	5.71
2	Kampung Gede		11	4.86
3	Masjid Tanah		11	6.51
4	Zarina		11	4.81
5	Bukit Rambai		33	4.70
6	Cheng		33	22.78
7	Hicom Pegoh		33	3.62
8	Jasin		33	13.12
9	Metacorp		33	16.63
10	Pulau Gadong		33	5.35
11	Tangga Batu		33	7.55
12	Ujung Pasir		33	25.01



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TNB NODAL POINTS



GUIDELINES

- FEED-IN TARIFF (FIT) GUIDELINES
- GUIDELINES FOR ELIGIBILITY OF THE S02 BONUS
- NEM GUIDELINES
- POWER SYSTEMS STUDY GUIDELINE
- GUIDELINE FOR SURUHANJAYA TENAGA LICENSES
- TNB PV INTERCONNECTION
- PROCEDURE FOR THE T&C OF GCPV

TNB NODAL POINTS FOR FEED-IN TARIFF SYSTEM

The list of Nodal Points can be used as a preliminary guide for any new Renewable Energy (RE) projects to be connected to TNB's distribution network at medium voltage levels (33kV and 11kV). These nodal points can be used as a reference for new RE projects in the TNB distribution network under the Feed-in Tariff (FIT) system as well as projects under the Net Energy Metering (NEM) scheme. The list of nodal points were established based on the following criteria: -

- Distribution substations with short circuit fault levels of not more than 90% of the switchgear rating, to meet the requirement stated in clause 5.4.9.1. of the Distribution Code; and
- There is sufficient load at the substation:
 - For FIT projects (direct connection), the maximum capacity of connections that are allowed is based on 85% of the average minimum load at the Main Intake Substation (PMU).
 - For NEM projects (indirect connection), the maximum allowable connection capacity is based on 75% of the average Maximum Demand (MD) of the NEM applicant.

Please take note that the list of nodal points can only be used as a preliminary check before conducting the NEM Assessment Study (NEMAS) or Power System Study (PSS) and the final decision on the interconnection and approved capacity will be solely based on the results of the actual NEMAS and PSS.

Figure 2.45: SEDA website shows TNB Nodal Points info

The introduction of an advanced and interactive tool, the Distributed Generation (DG) Hosting Capacity Map, represented a significant milestone in mid-2022. Integrated into the Geographic Information System (GIS) platform, it transitioned from a simple list of Nodal Points to a dynamic visual representation on a geographical map, covering the medium voltage network.

The Nodal Points serve as the foundational elements for evaluating the hosting capacity of the TNB grid for prospective renewable energy (RE) connections. Additionally, in mid-2022, TNB introduced a more advanced and interactive analysis tool called the Distributed Generation (DG) Hosting Capacity Map as part of the GIS Distribution Network (GISDN) Project. This DG Hosting Capacity Map is integrated into the Geographic Information System (GIS) platform, which represents a transition from the previous list of Nodal Points to a visual representation on a geographical map, now encompassing the medium voltage network.

This GIS-based platform offers enhanced visibility and facilitates the identification of the nearest potential substation for connecting new RE sources. For instance, it assists in determining which substation has the capacity to accommodate a specific amount of RE development at a given location and time, all while adhering to the existing network conditions and operational criteria. This ensures that critical factors such as safety, fault levels, voltage, power quality, and reliability are not adversely affected by the introduction of new renewable energy resources.

Using the DG Hosting Capacity Map, the public such as renewable energy developers have the ability to pinpoint Nodal Points by entering specific parameters, including the desired capacity in megawatts (MW), the prospective location for their new renewable energy project, the radius from that location, and the type of distributed generation (DG) they plan to employ. In the illustrative scenario, as depicted in Figure 2.46 and Figure 2.47, RE developers or members of the public can readily search for and access information regarding the hosting capacity for solar-type DG systems within the boundaries of the Langkawi district or within a 30-kilometer radius of a given coordinate or address, serving as an initial connection point for their proposed DG facility.

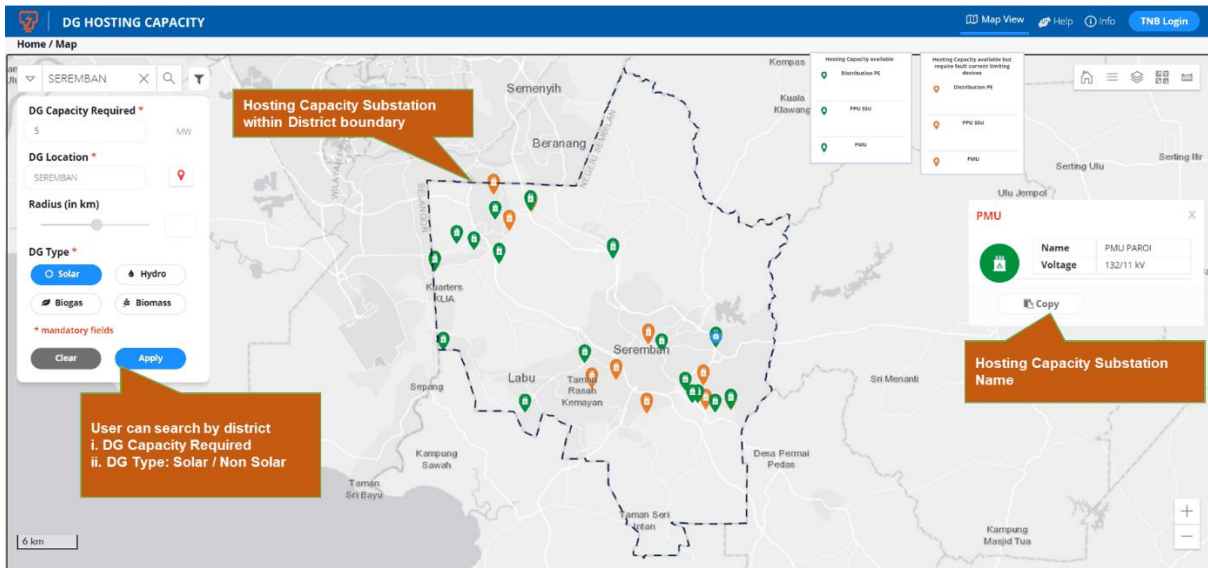


Figure 2.46: The searching functionality of the Hosting Capacity Map by district selection for the public

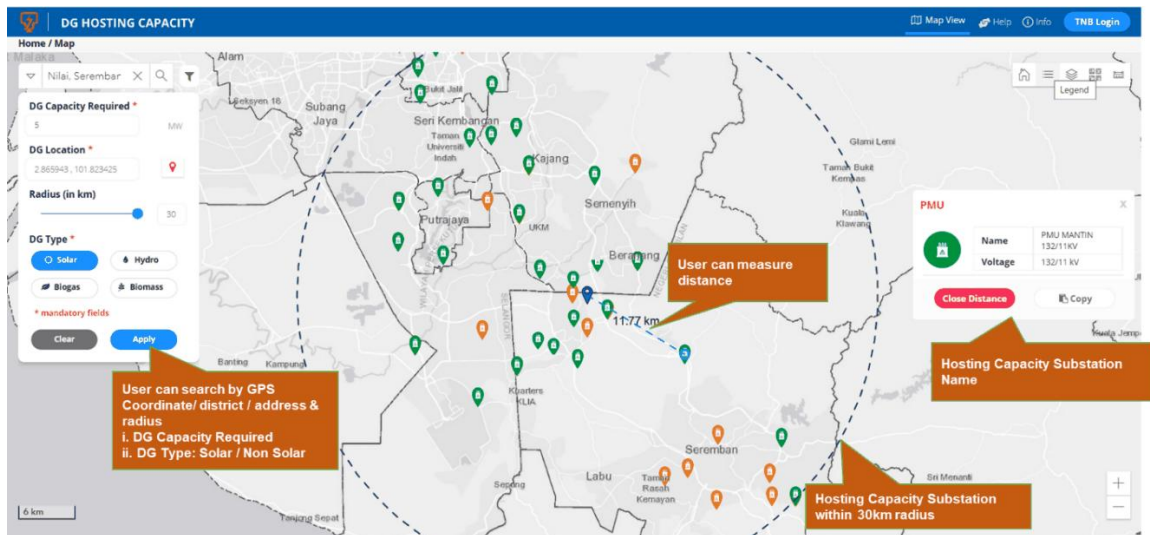


Figure 2.47: The searching functionality of the Hosting Capacity Map by coordinate / address for the public users

The DG Hosting Capacity Map offers several advantages:

- Facilitates swift and efficient DG interconnections, aligning with the Malaysian Government's goal to accelerate RE deployment.
- Supports TNB's commitment to achieving net-zero emissions by 2050, in line with the Government's ambitious targets.
- Addresses environmental, social, and governance (ESG) risks related to assets and integrates advanced ESG measures into operations.
- Targets improved financial performance through reduced on-site visits and minimized reliance on TNB personnel.
- This initiative enhances data transparency and boosts DG systems' productivity through automated data extraction, processing, and analytics.

To explore the hosting capacity map for Distributed Generation via the GIS platform, click [here](#). It is now also accessible through mobile devices.

TNB has also achieved recognition as the winner of Power Energy Awards for Transmission and Distribution Network Project of the Year Category in the ENLIT Asia Conference in November 2023 based on a paper submission entitled “Large-Scale Low Voltage Asset and Network Mapping in Malaysia by Embarking on the Technology of Mobile Mapping System”.

Moving forward, this capability can be expanded to provide visibility within the Electric Vehicle (EV) ecosystem, offering insights on EVCS hosting capacity to identify supply availability for proposed charging location. Thus, the EVCS capability assists in ensuring a seamless supply application process for EV chargers.

RECOGNITION



Figure 2.48: Winner for Power Energy Awards in Transmission and Distribution Network Project of the Year Category

2.3 Flexibility Management

TNB is progressively exploring flexibility management to better coordinate distributed energy resources, energy storage and flexible demand in response to changing network conditions. This capability is being supported through the Energy Integration Platform (EIP) and its integration with Smart Community Infrastructure (SCI), including assets such as CESS and VRDT, as described in Section 2.1.2. TNB is also developing Demand Response capabilities to further support system balancing and operational flexibility.

2.3.1 Demand Response with Customer Participation

Demand Response (DR) is envisioned to be an ancillary service for grid, aiding in frequency control and energy balancing. Moreover, it serves as a valuable mechanism to offset the inadequacies in generation ramping during the ongoing energy transition. By dynamically adjusting electricity consumption in response to grid conditions, DR effectively contributes to maintaining grid stability and reliability.

TNB has embarked on a pilot project for Demand Response with the goals of ascertaining the technical requirements that would be required for the deployment of a DR system and, as a sandbox, gauging customers' experience. The technical development was done in collaboration with TNB research partners to create a system that would be able to securely convey information and command signals between participant sites and the TNB control centre. The DR system was developed to be scalable as interested participants can install a DR-box at their sites and can leverage existing wireless networks for interfacing with TNB.

The diagram below provides an overview of the connection path between participants and the TNB control centre. This is illustrated in Figure 2.49.

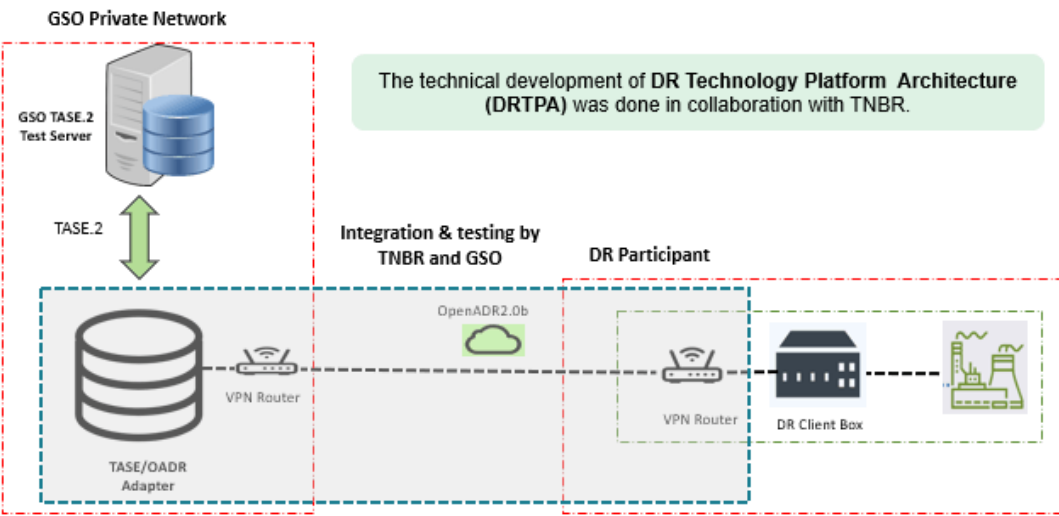


Figure 2.49: Architecture of DR Technology Platform

The Demand Response Management System (DRMS) user interface for the control centre allows the operators to select different levels of power quantum and duration for each DR event execution for manual execution. Currently, an automated feature is being developed that would allow these DR resources to respond to frequency excursion events in the system. This is illustrated in Figure 2.50.

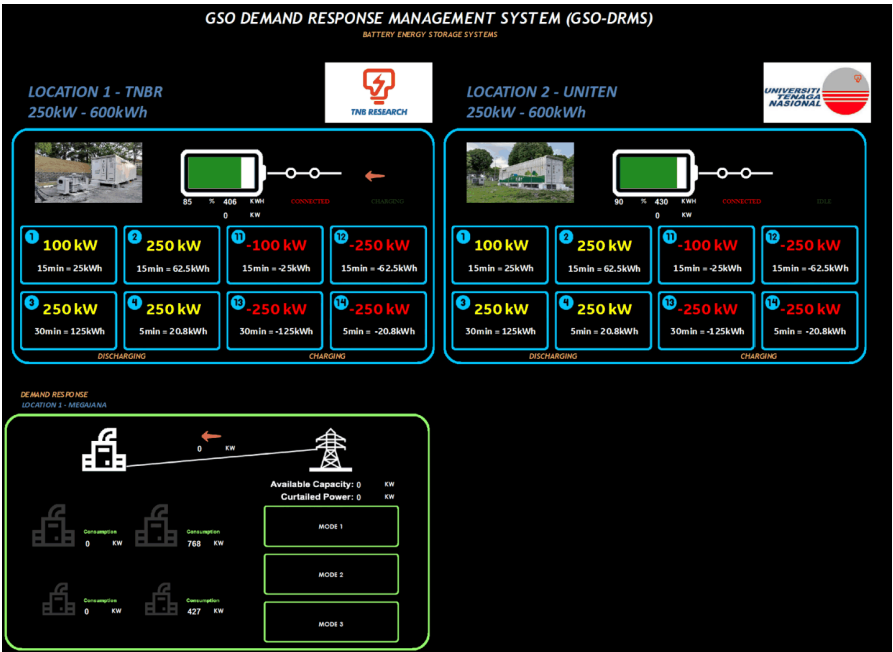


Figure 2.50: TNB Demand Response Management System (DRMS)

The following are the targeted customer segments involved in the DR pilot project:

1. **Industrial or Large Power Consumers:** Customers would have the capability of nominating equipment within their installation that would be available for DR events activation.
2. **District Cooling System:** The consumer would allow TNB to turn off their pumps which they would nominate based on their cooling water reserves and their customer consumption.
3. **Battery energy storage systems (BESS):** BESS systems can be discharged and recharged according to system requirements.
4. **EV charging stations:** Development in-progress. The increasing number of EVs and charging stations could present a challenge to the system however if it can be leveraged as a DR resource it can be an opportunity to secure the grid. Currently, TNB is in the process of developing the conversion adapter between OADR (DR system protocol) and OCPP (charging station protocol) to enable remote control of EV charging stations. This is illustrated in Figure 2.51.

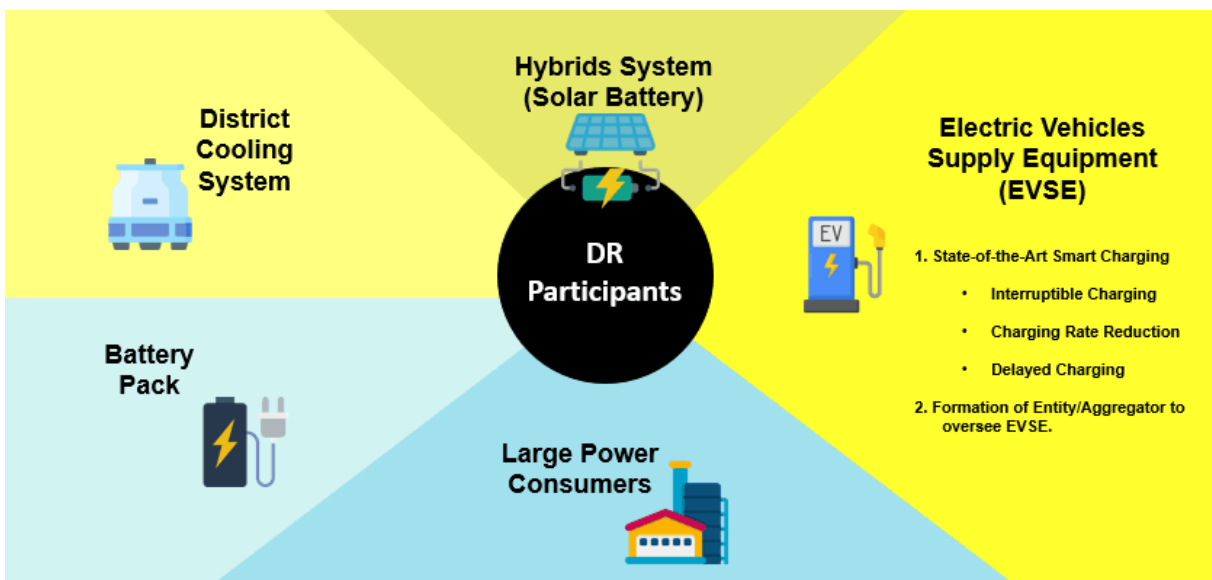


Figure 2.51: Demand Response Participants

The Value Creation from the Demand Response Pilot Project encompasses several key aspects:

1. **Workforce Development:** The project aims to cultivate a skilled and knowledgeable workforce capable of effectively scaling up the DR program. This involves training personnel in the technical and operational aspects of demand response implementation.
2. **Technology Identification:** Through rigorous analysis, the project identifies the technological requirements necessary for the successful implementation of a viable DR system. This includes assessing the compatibility of existing technologies with DR objectives and identifying areas for innovation and improvement. The adapter that converts the protocol from OADR to TASE.2 for integration with the TNB control centre was developed internally by TNBR.
3. **Cost Optimization:** The pilot project aims to be realized leveraging on existing TNB investments in talent and assets. Furthermore, assets such as battery storage systems that were procured for research can be utilized to provide an additional use case for DR. The pilot's plan to

integrate EV chargers can enhance the value derived by both the customers in remuneration also the utility with additional flexibility in managing system stability.

4. **Economic Opportunities:** The DR program when fully implemented would create new economic opportunities while at the same time empowering consumers to be an active participant in the energy industry. By incentivizing participation in demand response initiatives, the program stimulates innovation and entrepreneurship, driving economic growth and diversification.
5. **Standardization:** Developing standardized technical and commercial requirements through a Standard Term Sheet facilitates streamlined implementation of DR initiatives in the future. This promotes consistency and interoperability across different DR projects, reducing complexity and enhancing scalability.

With the completion of the DR architecture development phase, TNB is poised to operationalize the system. By harnessing the capabilities of Demand Response, the grid becomes more resilient, responsive, and adaptable to the evolving energy landscape, ensuring a sustainable and reliable energy future.

2.4 Dynamic Network Operation

This component covers capabilities that adjust operating limits or network configuration based on actual system conditions. ADMS Fault Location, Isolation and Service Restoration (FLISR) is described within the complete ADMS story in Section 2.1.1. Dynamic Line Rating is presented below.

2.4.1 Dynamic Line Rating

As electricity demand continues to rise and renewable energy integration accelerates, power grids face increasing pressure to maximize efficiency, reliability, and capacity. Long-established methods of managing transmission lines by Static Line Ratings (SLR), use safe operating capacity as power transfer limits, often leading to underutilization of potential capacity such as lower transfer limits for 500kV backbone network to account for the risk of overloading the remaining lower-kV network if the backbone trips. This assumption-based approach limits grid flexibility and results in needs for development of new transmission infrastructure. There is also a scenario of sudden rise in supply applications, such as the influx of data centres, which requires the fast-tracked development of new infrastructure amid challenges.

To address these challenges TNB in December 2024 has successfully piloted Dynamic Line Rating (DLR) at its 132kV and 275kV in southern part of the peninsular. The DLR is an advanced grid technology that enhances real-time monitoring and optimizes transmission capacity based on actual operating conditions. The DLR is a real-time grid optimization technology that dynamically

forecasts power transfer limits based on actual environmental and conductor conditions, such as wind, temperature, and line sag. Unlike SLR, which applies static limits, DLR leverages on real-time data to determine a line's true ampacity, allowing grid system operator to increase power transfer limit without compromising grid stability and system reliability.

The implementation has increased the transfer limits of selected existing lines by 20-40%, allowing grid system operator to transfer more power, reduce congestion if needed, and provide dynamic rating forecasts for up to 72 hours. This is illustrated in Figures 2.52 and 2.53.

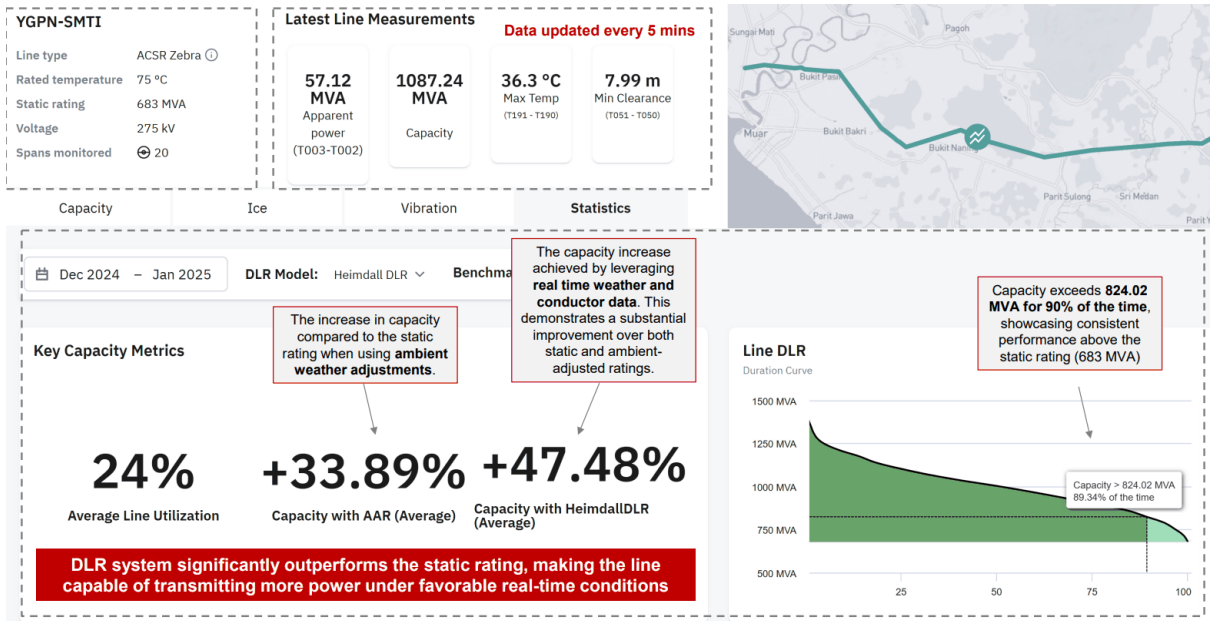


Figure 2.52: DLR Dashboard Forecasting Dynamic Capacity Based on Weather and Conductor Data up to 72 Hours

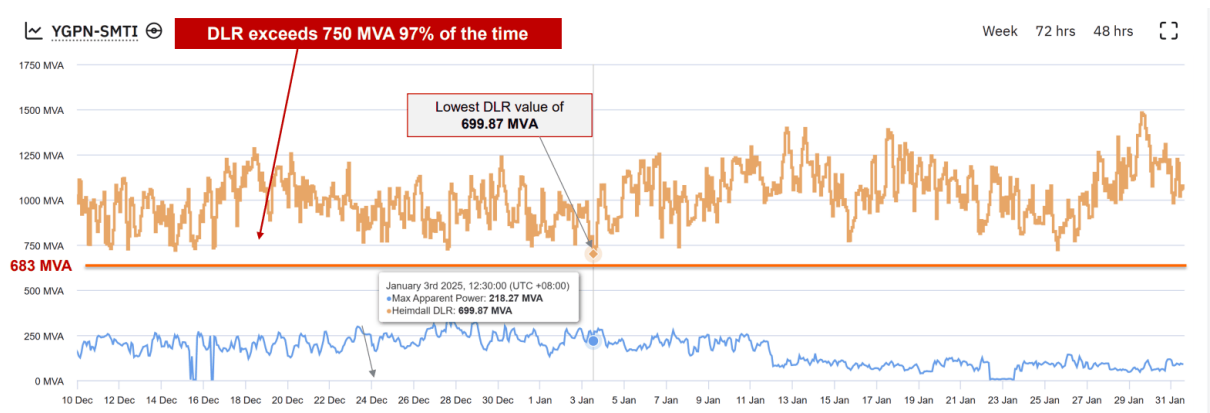


Figure 2.53: DLR Dashboard Showing Line Capacity Higher Than Static Rating

By embracing real-time digital solutions like DLR, TNB is better equipped to make flexible dispatching decisions and accommodate new infrastructure development.

2.5 Advanced Grid Technologies

This component covers next-generation grid technologies that improve capacity, control, flexibility and interoperability. TNB's Smart Community Infrastructure combines smart network assets and energy-management capabilities to support higher DER penetration and reinforce the low-voltage network.

2.5.1 Smart Community Infrastructure (SCI)

Smart Community Infrastructure (SCI) is defined as advanced electrical grids that use advanced technologies and systems to enhance the efficiency, reliability, and functionality of electrical distribution networks to monitor, manage, and optimize the flow of electricity incorporated with DERs, with smart assets as its main components. SCI combines network and non-network elements and is particularly critical to reinforce the LV network interconnected with residential areas with high DER penetration.

1. The Online Feeder Pillar (OFP), also known as Smart Feeder Pillar, is an advanced distribution feeder pillar that provides near real-time remote monitoring of energy flow within the low-voltage network. By establishing online visibility of feeder loading, energy-related data can be continuously monitored to enhance network visibility, improve load reading efficiency and support more accurate and efficient energy distribution and usage. An example of the OFP is shown in Figure 2.54.



Figure 2.54: Online Feeder Pillar (OFP)

OFP supports diversified sensing use cases, particularly load monitoring for proactive actions, where emerging loading conditions may be identified earlier to support timely assessment and intervention. The same visibility can also support DER integration management by providing

better information on power flow and changing network conditions as more distributed energy resources are connected.

For connectivity technologies, OFP uses cellular communication to enable remote transmission of field measurements to TNB's central systems. In terms of data granularity and reliability, OFP provides feeder- and phase-level electrical measurements, including voltage, current, power factor and power-flow information, at frequent intervals. Where OFP is used together with Community Energy Storage System (CESS), charging and discharging data can also be monitored at intervals of up to one minute, providing finer visibility of energy movement and supporting more responsive monitoring of local network conditions.

For integration and accessibility, OFP data is made available through TNB's monitoring and analytics environment, where it can be integrated with other relevant network and asset information for monitoring, analysis and operational decision-making. This provides authorized users with a more consolidated view of low-voltage network conditions and supports applications such as load profiling, anomaly detection, DER monitoring and network planning.

2. Voltage Regulating Distribution Transformer (VRDT): This special-design distribution transformer has a load tap-changing mechanism to automatically manage voltage fluctuation (particularly caused by DER penetration) on the LV network (Figure 2.55).

The intermittent characteristic of DER, particularly solar PV, is expected to have greater impacts as it will cause instability in the network through frequent voltage fluctuation at the distribution level. In addition, an increase in voltage is the main limitation for connecting new DER to the LV network and forces the reconstruction of the network with higher capital costs.

Currently, the voltage at the LV network can only be regulated at the distribution transformer (11/0.433kV), mainly via the load tap changing mechanism, in which shutdown requires manually changing its tap position, resulting in supply interruptions to customers. Hence, the VRDT is introduced to manage voltage fluctuation by regulating its output voltage dynamically via its built-in on-load tap changer. Some of the key benefits of VRDT are:

- Improved Voltage Stability: VRDTs continuously regulate the output voltage to maintain stable voltage levels, regardless of fluctuations in load or generation.
- Better Integration of DERs: VRDT is the solution to comply with voltage regulation in the case of a high penetration with DER as it mitigates the risk of limited DER being connected to the LV network or DER generation curtailment due to high voltage issues.
- Lower Operational Costs: Enhanced efficiency and reduced losses in the distribution network translate to lower operational costs for utilities.

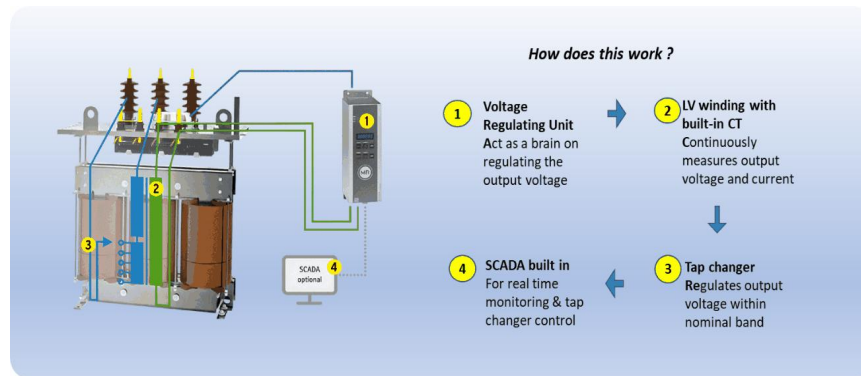


Figure 2.55: VRDT operation scheme

3. Community Energy Storage System (CESS): An LV-connected battery energy storage system stores excess energy (mainly generated from RE sources, particularly solar rooftops) during low demand and supplies it back to the network when required (during high demand). This will avoid high reversed power flow and support voltage stability and network resilience.

CESS allows excess electricity generated by customers' rooftop PV systems to be stored at the distribution LV level, reducing the reverse energy flow to a higher voltage level. The stored energy can then be exported into the network when needed (e.g., when the sun goes down). CESS is controllable and can balance the load and ensure network stability and resilience. Thus, it enhances distribution grid flexibility to promote higher utilization of renewable energy resources.

The higher cost of DER is prevailing, especially when the solar is generated by a prosumer with an NEM offset mechanism at a higher energy tariff. When this DER cannot be consumed locally within the same community but consumed by other tariff categories of customers at neighbouring communities or further down the distribution network, the DER cost will be higher than the energy tariff paid by other consumers, besides incurring network cost when transporting the energy to a higher voltage level of distribution network.¹

CESS is crucial in managing energy storage and distribution at a community level, particularly among houses and small and medium-scale commercial or industrial lots with a high penetration of clustered solar. Some of the benefits are as follows:

- Energy Balancing: Store excess energy generated during low-demand periods and release it during peak demand, ensuring a balanced energy supply, particularly among communities of houses with highly clustered solar installations.
- Grid Stabilization: Enhance grid stability by providing a buffer against fluctuations in supply and demand while promoting a higher share of clean energy sources.
- RE Integration: Facilitate the integration of RE sources by storing intermittent RE and supplying it when needed. This is illustrated in Figure 2.56.

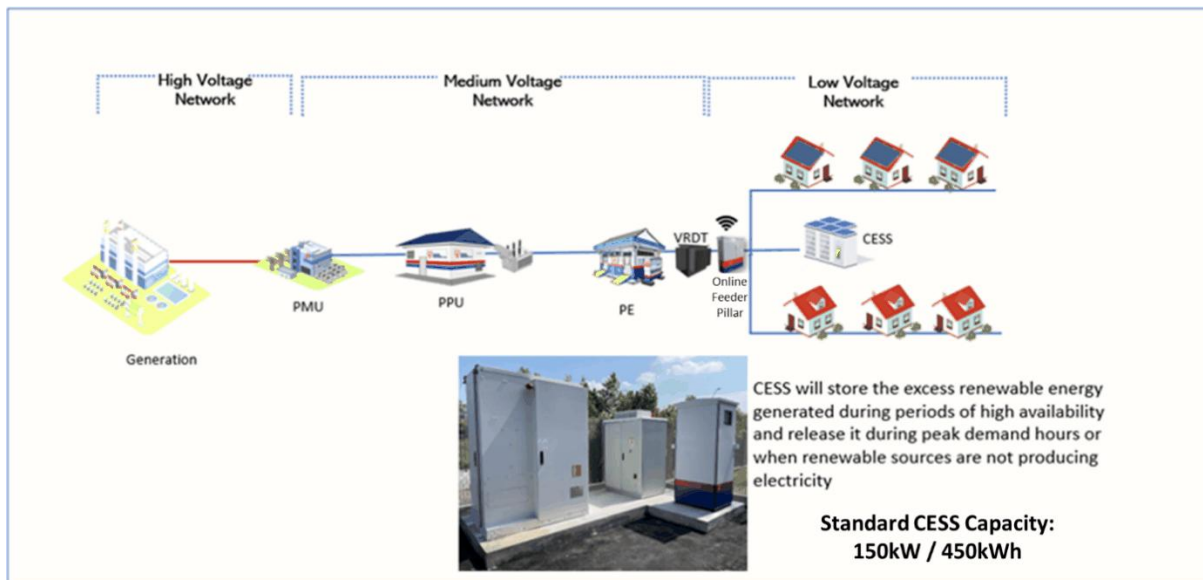


Figure 2.56: Example of CESS connected to Online Feeder Pillar

BESS/ CESS also plays a vital role in supporting and enhancing the capabilities of modern electricity grids. Other benefits include:

- **Peak Shaving:** Batteries can store electricity during periods of low demand (off-peak) and release it during periods of high demand (peak). This reduces the need for additional generation capacity during peak periods and can defer or eliminate the need for grid upgrades.
- **Load Levelling:** By charging during times of excess generation and discharging during high demand, batteries can smooth out electricity generation and consumption fluctuations, optimizing power plant operation and reducing wear on infrastructure.
- **Reducing Distribution Network Congestion:** By storing energy locally, BESS/ CESS can reduce the need to transmit power over long distances, thus alleviating congestion on transmission lines.
- **Black Start Capability:** Some BESS/ CESS can help restart power plants or parts of the grid after a complete blackout, known as a "black start."
- **Backup Power & Resilience:** BESS/ CESS can provide backup power to critical facilities or communities, enhancing grid resilience against natural disasters or other disruptive events.
- **Deferred Infrastructure Investment:** Instead of immediately investing in new infrastructure like power lines or transformers, power utilities can use BESS/ CESS as an interim solution to meet increasing demand, thus saving money and time.
- **Voltage Support:** BESS/ CESS can help maintain voltage levels within the desired range on distribution networks, which is crucial for the safe and efficient operation of electrical devices.
- **Emissions Reduction:** BESS/CESS can reduce greenhouse gas emissions by enabling greater integration of renewable energy sources and optimizing the operation of conventional power plants.

- Supporting DERs: BESS /CESS, in combination with other DERs like solar panels, can be used in microgrids to provide power to remote areas or in community-level grids that can operate independently from the main grid.

4. Smart Energy Management Infrastructure (SEMI): An integrated data analytics platform to manage DERs and support data required in an energy exchange via energy management capabilities to enable DER orchestration between CESS & VRDT. Figure 2.57 shows the functionalities and features of smart assets. This is illustrated in Figure 2.58.

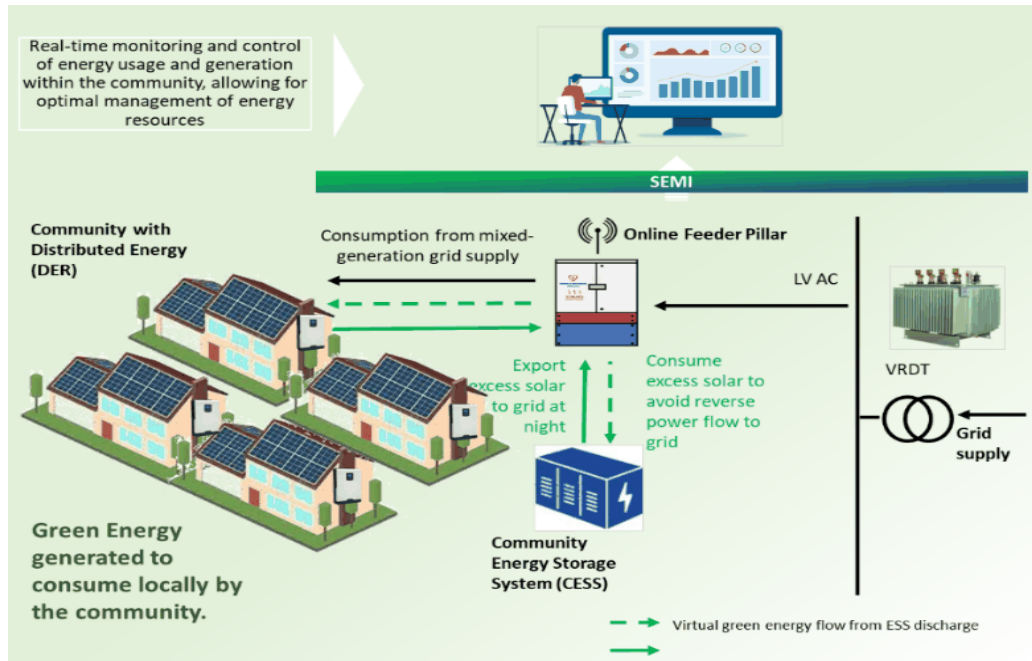


Figure 2.57: Smart Assets – OFP, CESS & VRDT as reinforcement to LV Network to accelerate DER integration



Figure 2.58: Smart Energy Management Infrastructure (ESS Summary)

SEMI is a comprehensive IT platform that monitors and manages all energy data received from OFP, VRDT, CESS and other smart assets. The graphical user interface for SEMI is shown in Figure 2.58. SEMI provides:

- **Visibility:** Offers a near real-time view of energy generation, distribution, and consumption across the entire network.
- **Data Analytics:** Analyses data from various sources to optimize energy usage, predict demand, and enhance operational efficiency.
- **Control and Automation:** Enables automated control of grid components based on real-time data, improving responsiveness and reliability.
- **Parameter Monitoring:** Tracks key parameters such as voltage, current, real and reactive power, and energy dynamic profiling, ensuring optimal grid performance.

2.5.2 Digital Substation

The Digital Substation initiative is a strategic modernization program by TNB to transform conventional substations into intelligent, digitalized facilities using the IEC 61850 communication standard. The project replaces conventional hardwired communication with a standardized Ethernet-based network, enabling seamless integration between protection, control, monitoring, and automation systems. This approach simplifies engineering, enhances interoperability between Intelligent Electronic Devices (IEDs), and provides a reliable platform for future digital technologies.

The initiative was successfully demonstrated through the Digital Substation Pilot Project at PPU Nada Alam, which validated the technical feasibility and operational benefits of IEC 61850-based communication in the TNB distribution network environment. Building on the pilot's success, the project establishes standardized architecture for future Greenfield substations while supporting the modernization of secondary systems across the distribution network. This is illustrated in Figure 2.59.

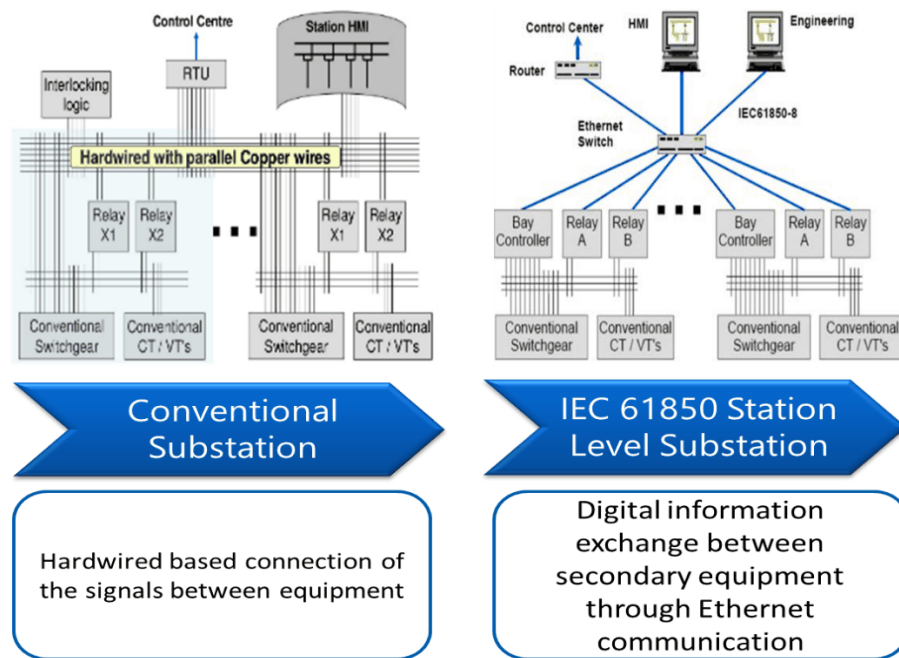


Figure 2.59: Digital Substation Pilot Project Focusing on Station Level

The Digital Substation delivers an integrated platform that enhances protection, control and monitoring substations through standardized digital communication. By enabling real-time information exchange between station-level and bay-level devices, the system improves operational efficiency, reliability and visibility.

Key capabilities include:

- High-speed protection communication using GOOSE messaging.
- Centralized monitoring and control through the Station HMI and SCADA Gateway.
- Accurate event recording and disturbance analysis through synchronized time stamping.
- Reduced hardwiring and simplified engineering design.
- Remote engineering, diagnostics, and maintenance.
- Scalable architecture for future expansion.
- Support for cybersecurity and Smart Grid integration.

The Digital Substation supports TNB's digital transformation by improving operational performance, simplifying engineering and enhancing maintenance efficiency. It enables better protection, monitoring and control, supports faster fault identification and restoration, and reduces reliance on extensive conventional wiring and complex configurations. The digital approach also facilitates easier troubleshooting, remote diagnostics and more efficient maintenance, while improving interoperability and helping reduce lifecycle costs. Overall, it provides a more flexible and future-ready platform to support TNB's Smart Grid development.

The Digital Substation successfully demonstrated the practical application of IEC 61850 within the distribution network. It achieved reliable communication between protection IEDs, Station

HMI and the SCADA Gateway using standardized IEC 61850 protocols. It validated high-speed GOOSE messaging for protection functions, MMS communication for monitoring and control and accurate time synchronization across all devices. Also, the interoperability between equipment from different manufacturers is established.

The Digital Substation initiative represents a significant milestone in the modernization of TNB's secondary systems. By adopting IEC 61850-based digital communication, TNB establishes a standardized, interoperable and future-ready platform that enhances protection, control, monitoring and maintenance while reducing engineering complexity and lifecycle costs. The Digital Substation provides a proven foundation for the future rollout of Digital Substations, supporting greater network reliability, operational efficiency and Self-healing Grid in the Smart Utility's objectives.

2.5.3 Smart Eco-Design High Energy Efficient Transformer with Biodegradable Oil

TNB is exploring Smart Eco-Design High Energy Efficient Distribution Transformers as part of its ongoing efforts to improve the sustainability, safety and efficiency of distribution assets. One area being assessed is the potential use of biodegradable ester-based insulating oil as an alternative to conventional mineral oil. The initiative is currently at the feasibility and research stage, where its technical performance, environmental benefits, safety and lifecycle considerations are being evaluated before wider deployment is considered.

Further details on the feasibility study and TNB's exploration of biodegradable transformer oil are available here: <https://www.tnb.com.my/sustainability/esg-stories-tnb-green-transformer-oil-solutions/>.

DIMENSION 3: AI-DRIVEN OPERATIONS

TNB is progressively applying Artificial Intelligence (AI) to strengthen decision support across planning, operations, maintenance, field activities and system optimization. These initiatives demonstrate how AI and advanced analytics are being used to anticipate future conditions, support asset and workforce decisions, improve inspection and maintenance practices, and provide employees with more accessible knowledge and decision support.

3.1 Predictive Forecasting & Scenario Analysis

TNB is applying AI-driven forecasting and predictive analytics to anticipate asset failures and emerging operational risks before they materialise. The initiatives presented in this section include predictive maintenance for 11kV underground cables and AI-driven forecasting of potential energy-theft hotspots, supporting more proactive planning, investigation and operational readiness.

3.1.1 AI-Driven Predictive Maintenance for 11kV Underground Cable (UGC)

TNB has introduced an AI-driven predictive maintenance capability for 11kV underground cable (UGC) to support more proactive identification of cable assets with higher potential risk of failure. The initiative applies predictive analytics to historical asset and maintenance information to provide additional insights for maintenance planning and asset-management decisions.

Underground cables present maintenance challenges as many assets are located beneath roads, rivers, densely populated areas and other locations that are difficult to access. Conventional maintenance approaches therefore rely significantly on historical performance, inspection and diagnostic activities. As the underground cable population continues to grow, a more data-driven approach is being adopted to complement existing engineering and maintenance practices.

The predictive capability uses available information including historical cable failures and outage records, maintenance history, asset demographic and cable information, and relevant operational data. These datasets are processed using machine-learning models to identify patterns associated with cable failures and generate a prioritized list of assets for further assessment.

The output is intended to support maintenance teams in identifying assets that may require greater attention. Rather than replacing existing engineering assessment and diagnostic testing, the predictive results provide an additional input to support the prioritization of inspection,

testing, repair and replacement activities. The overall predictive-maintenance concept is illustrated in Figure 3.1.

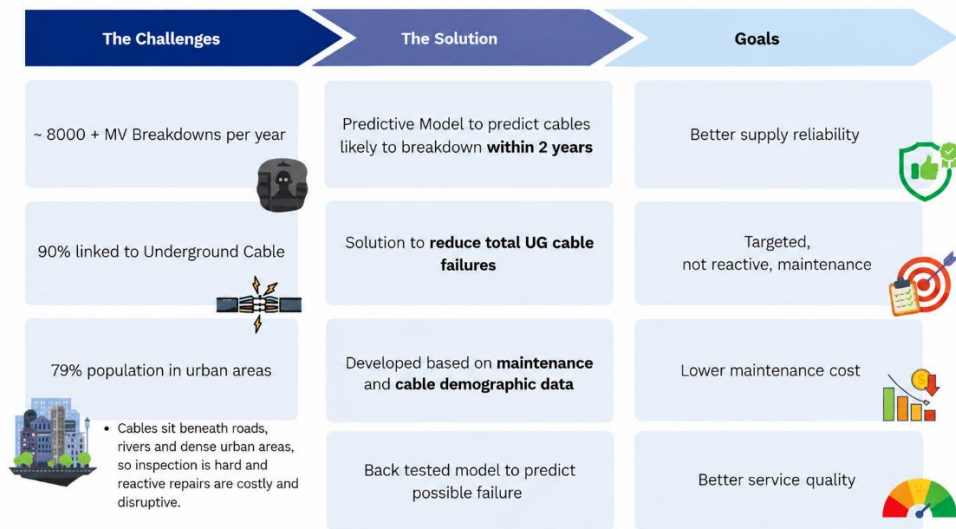


Figure 3.1: AI-Driven Predictive Maintenance for 11kV UGC overview

The current capability supports several areas of asset management, including early identification of potentially higher-risk cable assets, prioritization of maintenance activities and improved visibility of underground cable condition and performance. This allows available maintenance resources to be directed more effectively towards assets requiring further assessment. The predictive output is subsequently reviewed together with relevant engineering information and, where required, validated through field inspection or diagnostic testing. Assets confirmed to require intervention may then be prioritized for appropriate maintenance, repair or replacement activities. The overall process is illustrated in Figure 3.2.

TNB has implemented the predictive model to support underground cable maintenance planning and asset-management activities. The capability provides an initial foundation for moving from predominantly reactive maintenance towards a more proactive and risk-informed approach.

As the capability matures, further enhancement is required to improve the breadth, quality and timeliness of input data, strengthen predictive performance and expand its application across underground cable asset-management activities. Future development may include refinement of the analytical models using additional operational and maintenance information, enhanced

visualization and decision-support functions, and closer alignment with maintenance workflows and other asset-management platforms.

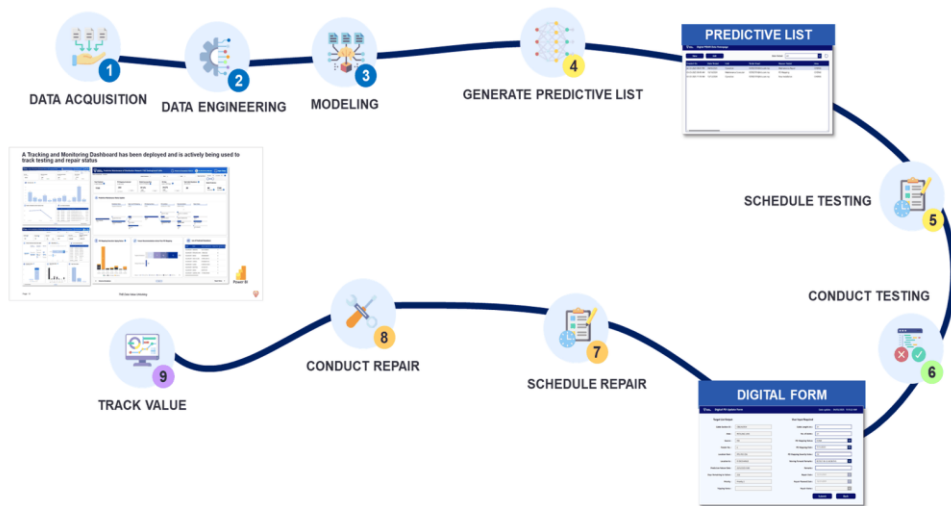


Figure 3.2: AI-Driven Predictive Maintenance for 11kV Process flow

These enhancements are expected to improve the ability of maintenance teams to interpret predictive information, validate emerging asset risks and prioritize interventions more consistently. The development direction is illustrated in Figure 3.3.



Figure 3.3: AI-Driven Predictive Maintenance for 11kV Roadmap

Overall, the initiative demonstrates the potential of AI and predictive analytics to complement existing engineering practices for underground cable management. By progressively improving the availability and use of asset information, TNB aims to strengthen proactive maintenance planning, improve asset-risk visibility and support the long-term reliability of the distribution network.

The initiative has also received industry recognition for its application of data and AI in utility asset management as below:

- Enlit Asia Awards 2025
 - 2nd Place – Power Utility Project of the Year
 - 2nd Place – Transmission & Distribution Network
- AIBP ASEAN (Malaysia) Innovation Award 2025

- Winner – Data & AI Category
- Asian Power Awards 2025
 - Winner – Innovative Power Technology of the Year – Malaysia
 - Winner – Smart Grid Project of the Year – Malaysia



Figure 3.4: AI-Driven Predictive Maintenance for 11kV Awards

3.1.2 AI-Driven Forecasting and Prevention of Energy Theft in Crypto Mining Hotspots

TNB is exploring the use of Artificial Intelligence (AI) and advanced analytics to support the identification of potential electricity-theft risks associated with illegal cryptocurrency mining activities. The initiative is intended to complement existing investigation and enforcement processes by providing additional data-driven insights to help prioritize locations for further assessment.

Electricity theft associated with illegal cryptocurrency mining can contribute to abnormal load patterns, non-technical losses and localized network stress. Conventional investigation activities may require significant manual effort and field verification, particularly where potential cases are dispersed across a wide geographic area. The initiative therefore explores how AI-assisted analysis can be used to support more focused and proactive investigation.

The analytical capability combines relevant internal and external information, including historical confirmed cases, electricity consumption and load patterns, customer and premise information, geospatial information, publicly available information and other relevant operational indicators.

These data sources are analysed to identify patterns and characteristics that may indicate locations requiring further assessment.

Rather than automatically determining that electricity theft has occurred, the AI-generated output provides a prioritized list of potential risk locations for further review. The results are subsequently assessed by the relevant operational team and, where appropriate, validated through field investigation before any enforcement or preventive action is taken. The overall process is illustrated in Figure 3.5.

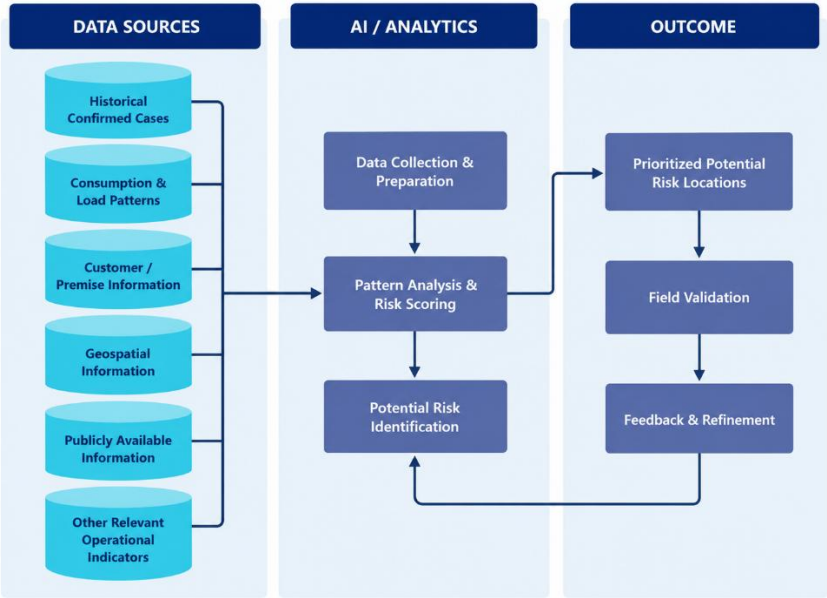


Figure 3.5: AI-Driven Forecasting and Prevention Energy Theft in Crypto Mining Hotspots System Architecture

The initiative provides an additional decision-support capability for prioritizing investigation activities. By focusing attention on locations with higher risk indicators, the approach has the potential to reduce broad screening activities, improve the allocation of field resources and support earlier identification of abnormal consumption behaviour.

The project is currently being developed through a Proof of Concept (PoC) approach. Initial phases have demonstrated the ability to combine multiple data sources, generate potential target locations and validate selected outputs through field assessment. The capability continues to be refined based on operational feedback and validation results.

Further development is required before broader implementation. Areas for enhancement include improving the quality and coverage of input data, refining analytical models, strengthening validation methodologies, improving the interpretability of AI-generated outputs and enhancing the workflow between analytical results and field investigation activities.

The longer-term development direction may also explore the applicability of the analytical framework to other forms of electricity-loss detection and abnormal consumption patterns, subject to further assessment and validation. The development roadmap is illustrated in Figure 3.6.

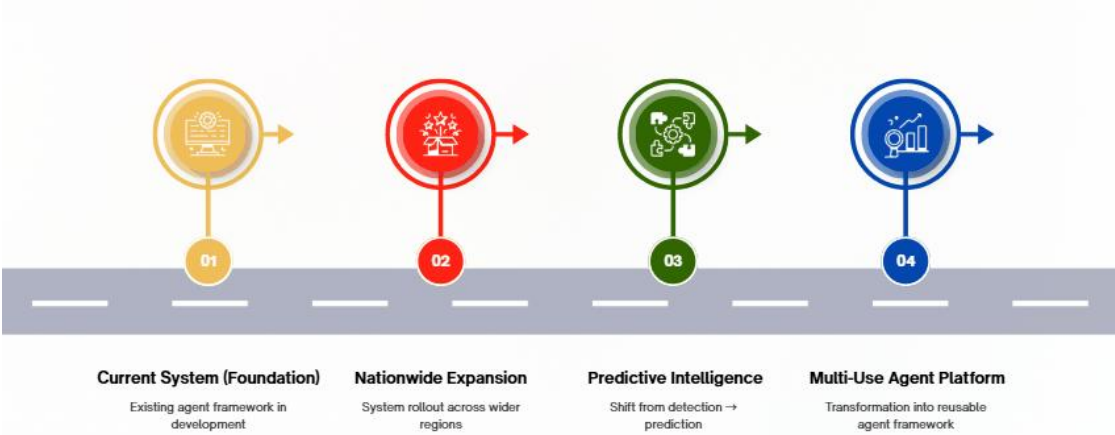


Figure 3.6: AI-Driven Forecasting and Prevention Energy Theft in Crypto Mining Hotspots Roadmap

Overall, the initiative demonstrates the potential of AI-assisted analytics to complement existing revenue-protection and network-management activities. As the capability matures, continued refinement of data, models and operational workflows will be important to improve the consistency and reliability of the insights generated and to support potential wider application. This initiative has also received industry recognition through the AIBP Enterprise Innovation Award – Malaysia 2026, Data & AI Category, reflecting its application of emerging AI capabilities within the utility environment.



Figure 3.7: AI-Driven Forecasting and Prevention of Energy Theft in Crypto Mining Hotspots AIBP Award Ceremony

3.2 Robotics & Computer Vision

TNB is using drones, cameras, remote-sensing technologies and AI-based image analytics to improve inspection, defect detection and vegetation assessment. These technologies complement conventional field inspection by providing additional visibility, supporting access to difficult locations and enabling more consistent analysis of visual information.

3.2.1 Visual Intelligence Assistant (VIA)

Visual Intelligence Assistant (VIA) is an Artificial Intelligence (AI)-assisted solution being developed by TNB to strengthen the quality-assurance process for underground cable jointing works. The initiative responds to the need for greater consistency and visibility in workmanship verification, as installation quality can influence the long-term performance and reliability of underground cable joints.

VIA applies Computer Vision and Large Language Model (LLM) technologies to analyse videos and images captured during underground cable jointing activities. The capability is intended to complement existing engineering supervision by providing an additional digital assessment of whether selected work activities have been carried out in accordance with established procedures.

The solution analyses submitted visual evidence against predefined engineering checklists and identifies activities that may require further review. The resulting assessment provides supervisors with additional information to support workmanship verification and follow-up actions where necessary. Final engineering assessment and corrective decisions remain subject to review by the relevant personnel.

The assessment process uses images and videos of cable-jointing activities, relevant project information and established jointing procedures or engineering checklists as its primary inputs. These inputs are processed using AI-based visual analysis to generate structured assessment results that can be reviewed by engineering supervisors.

VIA also provides a digital environment for recording and reviewing assessment information, enabling relevant users to monitor submissions, review findings and maintain a structured record of workmanship assessments. Over time, these records may also provide useful information to support quality trends, contractor-performance assessment and further improvement of the AI capability.

The overall VIA assessment process may be illustrated at a high level in Figure 3.8.

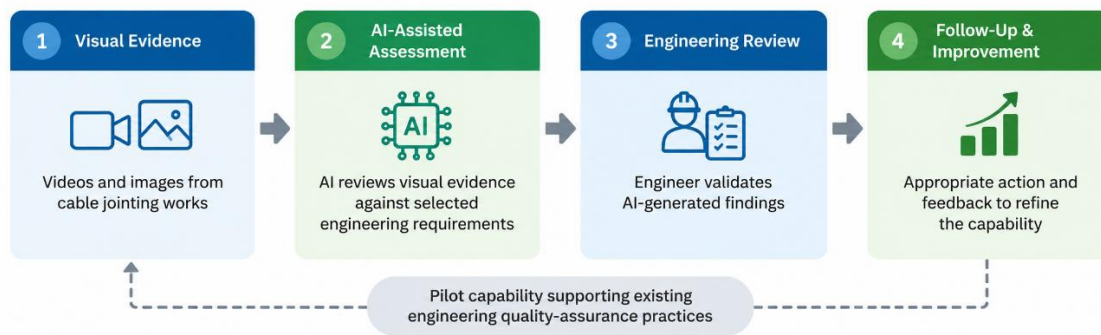


Figure 3.8: VIA High Level Process

Rather than replacing existing engineering inspection and supervision practices, VIA is intended to provide decision support by helping supervisors focus attention on activities that may require further verification. This can improve the consistency of quality-assurance activities while reducing reliance on fully manual review of visual submissions.

VIA has progressed into pilot implementation, where the capability is being evaluated using actual underground cable jointing submissions. Initial deployments have enabled TNB to assess the practicality of AI-assisted workmanship verification and gather operational feedback on model performance, usability and the suitability of the assessment workflow.

The pilot is being progressively evaluated across different operational environments to further understand the performance and applicability of the solution. Findings from these deployments will be used to refine the AI models, assessment criteria and user experience in the later phase.

Further development is required before broader implementation. Areas for enhancement include improving the diversity and quality of training and validation data, refining AI assessment accuracy, strengthening the consistency of workmanship scoring, improving user interfaces and decision-support functions, and enhancing alignment with existing engineering and asset-management workflows.

As the capability matures, VIA may provide a stronger digital foundation for quality assurance of underground cable jointing works and potentially support wider applications of AI-assisted visual inspection. Continued development will be important to ensure that the technology remains reliable, practical and appropriately aligned with engineering governance requirements.

Overall, VIA demonstrates the potential of AI-assisted visual analytics to complement conventional quality-assurance practices. By combining digital evidence, standardized engineering requirements and AI-based analysis, TNB can strengthen workmanship visibility and support more proactive quality management while continuing to develop the capability for broader future applications.

3.2.2 Unmanned Aerial System (UAS) for Medium Voltage Overhead Line Maintenance

Unmanned Aerial System (UAS) is an initiative deployed in TNB to enhance Medium Voltage (MV) overhead line maintenance through digital inspection, condition monitoring and data-driven asset management. Technology improves inspection visibility, defect detection capability and supports proactive maintenance planning.

Conventional MV OHL inspection using ground patrol and binocular observation has limitations due to restricted viewing angle, accessibility issues and challenging terrain. UAS enables aerial inspection, infrared thermography (IRT), image capture and data collection to provide comprehensive asset condition visibility.

The implementation transforms inspection information into actionable insights by integrating visual data, CBM information, defect records and analytics platforms. This supports the transition from conventional maintenance practices towards predictive and condition-based maintenance. This is illustrated in Figure 3.9.



Figure 3.9: UAS application in MV overhead line inspection and maintenance regime.

UAS improves operational efficiency by providing 360° visual inspection capability and reducing the possibility of missing critical defects on overhead line components.

UAS enhances productivity by enabling inspection of assets located in difficult terrains such as hilly areas, river crossings and remote locations while reducing dependency on manual access methods.

Advanced analytics and Artificial Intelligence (AI) enable automated image processing, defect identification and thermal analysis including hotspot evaluation to support faster decision-making.

Digital platforms consolidate inspection outputs including pole information, coordinates, defect images and asset criticality status, creating an integrated workflow from inspection to maintenance action. This is illustrated in Figure 3.10.

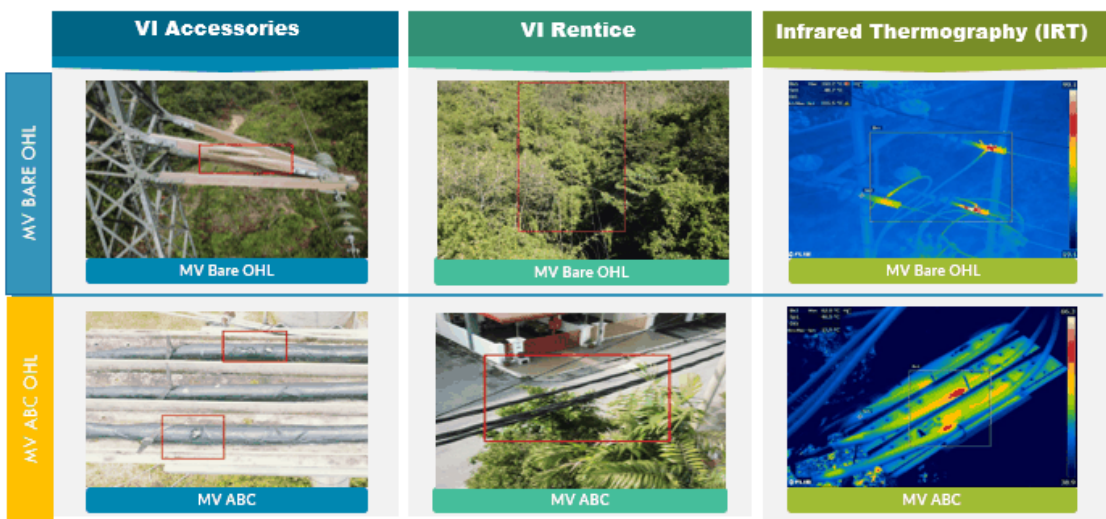


Figure 3.10: Capability and Effectiveness of UAS

The UAS architecture follows an integrated digital asset management approach. Data is captured through aerial platforms equipped with visual cameras, infrared sensors and advanced inspection technologies. The information is processed through analytics engines and stored in web-based platforms Vertikaliti.

The output includes defect identification, asset condition assessment, criticality ranking, inspection reports and maintenance recommendations. This establishes an end-to-end process from data acquisition, analytics and corrective action planning. This is illustrated in Figure 3.11.

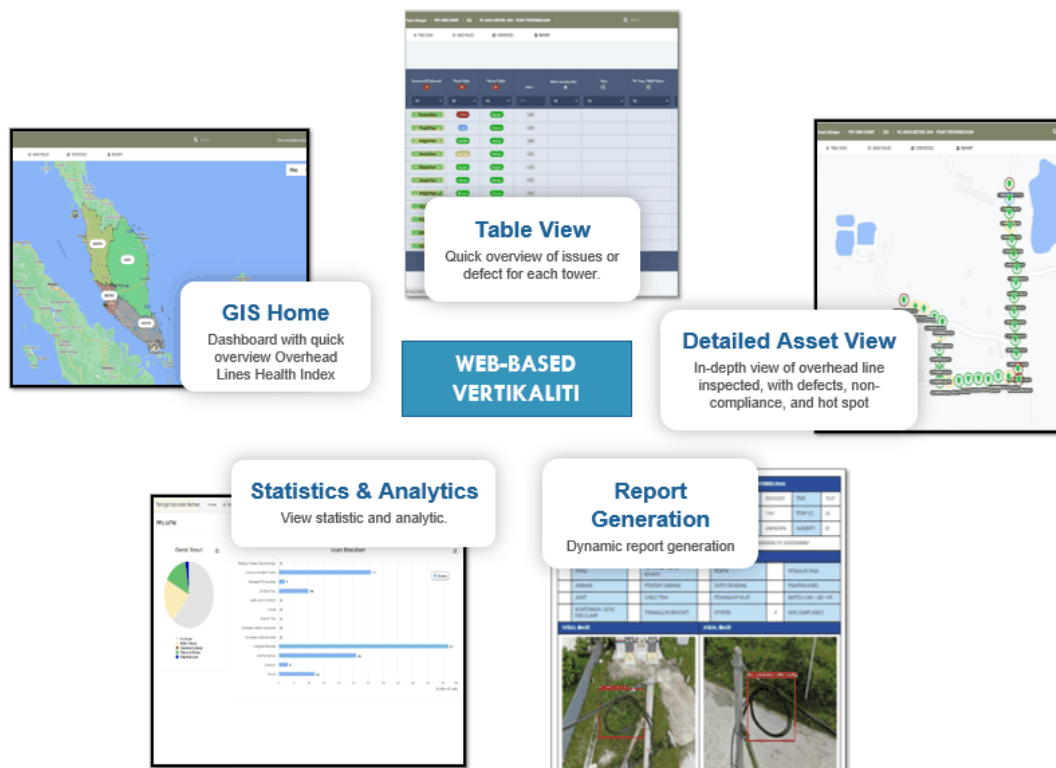


Figure 3.11: Data Management Platform Vertikaliti Web-based for UAS

UAS implementation started with pilot adoption in TNB in 2017 for visual inspection and infrared thermography. Full adoption was implemented in 2018 for MV Bare OHL and MV ABC maintenance activities.

The deployment has improved the MV OHL maintenance regime by strengthening condition-based maintenance, reducing manual inspection limitations and supporting Grid of the Future (GoTF) and grid modernization initiatives.

Future development of UAS technology focuses on wider digital capability including AI analytics, Single Point LiDAR ground clearance measurement, asset data collection, live breakdown inspection, disaster monitoring and vegetation assessment. This is illustrated in Figure 3.12.

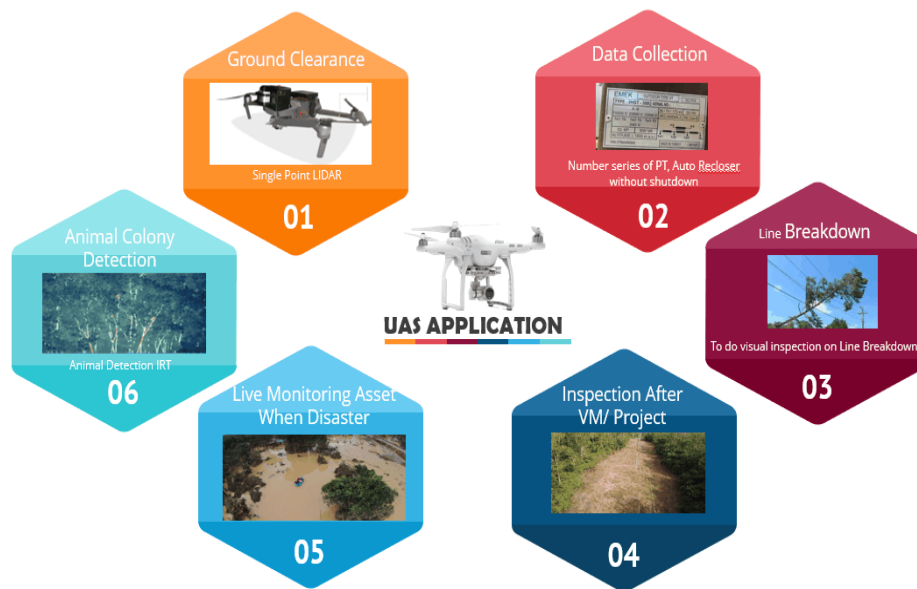
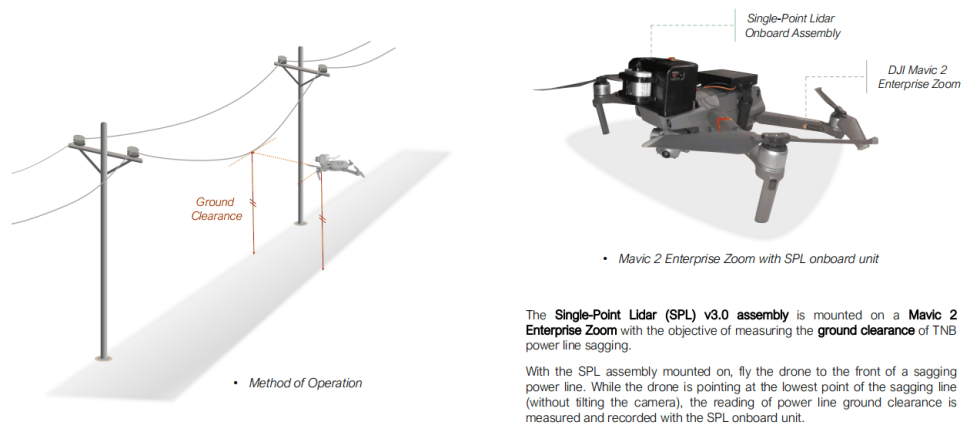


Figure 3.12: The Variety of UAS Capabilities

Introduction to Drone and Devices

Overview



The **Single-Point Lidar (SPL) v3.0 assembly** is mounted on a **Mavic 2 Enterprise Zoom** with the objective of measuring the **ground clearance** of TNB power line sagging.

With the SPL assembly mounted on, fly the drone to the front of a sagging power line. While the drone is pointing at the lowest point of the sagging line (without tilting the camera), the reading of power line ground clearance is measured and recorded with the SPL onboard unit.

4

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Figure 3.13: Ground clearance measurement by using UAS

The value of UAS implementation is demonstrated through improved safety, inspection efficiency, enhanced asset visibility, better defect detection and proactive maintenance planning.

UAS supports supply reliability and customer experience by enabling early identification of potential asset issues before they develop into failures.

Overall, UAS technology enables TNB to transform overhead line maintenance from conventional inspection towards smarter, safer and data-driven asset management.

3.2.3 Tree Hyperspectral Identification System (THySIS)

TNB is exploring the use of advanced remote-sensing and analytical technologies to support more environmentally informed vegetation management and transmission planning. The Tree Hyperspectral Identification System (THySIS) is one of the capabilities being developed to provide additional information on vegetation and tree species located within or near transmission corridors.

Vegetation management is important for maintaining the safety and reliability of transmission lines. At the same time, vegetation clearing may affect biodiversity, carbon sequestration and slope stability, particularly in environmentally sensitive or hilly areas. TNB therefore seeks to balance network reliability requirements with appropriate environmental considerations during planning and vegetation-management activities.

THySIS applies Light Detection and Ranging (LiDAR), hyperspectral imaging and Artificial Intelligence (AI) to support the identification and assessment of vegetation along transmission corridors. Aerial data collected using remote-sensing platforms provides information on forest structure, tree location and spectral characteristics. These datasets are subsequently analysed to support the identification of selected tree species and provide additional information for route planning, vegetation assessment and environmental review.

The high-level THySIS process is illustrated in Figure 3.14.

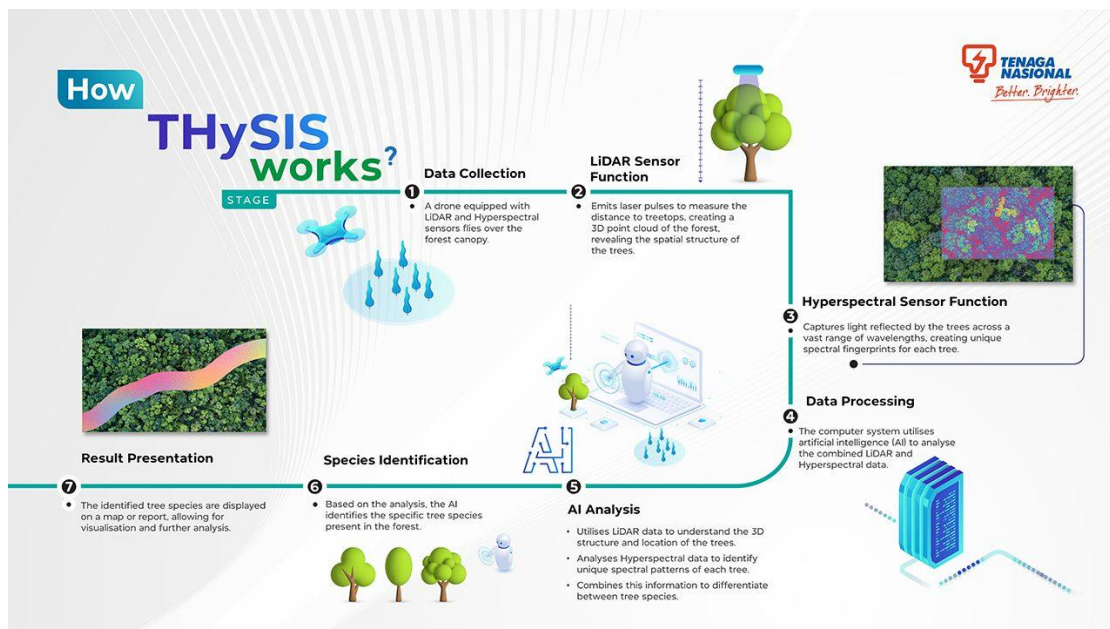


Figure 3.14: Tree Hyperspectral Identification System (THySIS)

The capability is intended to complement conventional field assessment and engineering review rather than replace them. Information generated through THySIS can provide an additional input

when evaluating vegetation conditions, identifying environmentally sensitive areas and considering potential mitigation measures during transmission planning and maintenance activities.

THySIS also supports TNB's broader efforts to strengthen environmental consideration during route planning. Information on vegetation and tree species may assist relevant teams in assessing areas that require further environmental review and in supporting engagement with the relevant authorities where required.

In parallel, TNB applies a risk-based vegetation-management approach to assess trees located near transmission lines. The assessment considers factors such as tree condition, slope stability and location relative to transmission assets. Based on the level of potential risk, trees may be prioritized for closer monitoring, mitigation or removal where necessary, while lower-risk vegetation may be retained subject to appropriate monitoring.

This approach supports more informed vegetation-management decisions by considering both network safety and environmental impact. Engineering assessment remains an important part of the decision-making process, particularly where vegetation may present a risk to transmission infrastructure.

As the capability develops, further enhancement may include improving the coverage and quality of remote-sensing data, expanding the reference database for tree-species identification, refining analytical accuracy and strengthening the use of THySIS information within planning and vegetation-management workflows.

Overall, THySIS demonstrates the potential of remote sensing and AI-assisted analytics to support more informed vegetation and biodiversity management around transmission infrastructure. Continued development can strengthen the use of environmental information in planning and maintenance while supporting the safe and reliable operation of the transmission network.

3.3 Predictive Asset Analytics

TNB strengthens predictive asset analytics by combining asset-condition information, connected sensing and analytical models to identify deteriorating conditions and support risk-based maintenance. The 11kV underground cable predictive model described in Section 3.1.1 also supports this component. The IoT sensor initiative below extends this capability through near real-time condition monitoring of critical assets.

3.3.1 IoT Sensor Deployment for Switchgear and Power Transformer Health Monitoring

The IoT condition information described in Section 1.1.4 provides an important input to TNB's predictive asset analytics capability. When combined with asset, maintenance and operational information within APMS, the data supports assessment of asset health, risk and emerging condition trends to inform maintenance decision-making.

By integrating IoT sensor data with the Asset Performance Monitoring System (APMS), the platform generates near real-time Asset Health and Asset Risk insights that support proactive maintenance planning and operational decision-making. The integration of previously isolated monitoring systems into a monitoring platform enables access to asset condition information, allowing engineers to obtain a consolidated view of asset performance, health trends, and potential risks. Early warning notifications alert maintenance teams when asset conditions begin to deteriorate, enabling timely intervention before faults result in equipment failures or customer interruptions.

The solution also supports early detection by identifying anomalies and emerging asset issues that may not be visible through routine inspections alone. This reduces the likelihood of unexpected failures, improves network reliability, and minimizes outage risks.

In addition, IoT-enabled condition monitoring supports asset life extension by enabling maintenance activities to be performed based on the actual condition of equipment rather than predetermined maintenance intervals. This allows assets to remain safely in service for longer while avoiding unnecessary maintenance activities and optimizing lifecycle costs.

IoT sensors deployed on critical assets, including power transformers and switchgear, collect condition data such as dissolved gas analysis (DGA), partial discharge (PD), thermal imaging, motor current, vibration, and other asset-specific measurements.

The primary outcome of the solution is a consolidated dashboard that provides a unified view of asset condition, alarms, and operational performance across multiple asset types. By bringing together data from IoT sensors, maintenance systems, and analytics platforms into a single interface, the dashboard enables maintenance teams and asset managers to monitor asset health in near real-time, identify emerging issues, and make faster, data-driven maintenance decisions.

The IoT Sensor Deployment initiative is currently being implemented in phases across the distribution network. To date, the deployment of IoT sensors for 12 power transformers has been completed, while IoT monitoring for switchgear has been implemented at five substations. These deployments provide near real-time asset condition monitoring and serve as the foundation for expanding IoT-enabled predictive maintenance capabilities across critical distribution assets

that will strengthen real-time asset visibility, enhance predictive maintenance capabilities, and further improve network reliability through data-driven asset management.

3.4 Multi-Objective Optimization

TNB is applying analytics, optimization and AI-assisted decision support to balance multiple considerations such as asset risk, performance, cost, investment priorities and operational efficiency. The initiatives in this section include APMS, AIPM and i-NET for asset and investment decision support, together with AI applications for generation optimization and workforce decision-making.

3.4.1 Asset Performance Management System (APMS)

The Asset Performance Management System (APMS) is an enterprise asset analytics platform that serves as the central intelligence engine for asset management within TNB. Designed to provide a comprehensive view of asset performance, condition, and risk, APMS enables informed decision-making on maintenance strategies, asset replacement planning, and overall asset performance optimization.

As one of the core initiatives identified under the initial TNB EAMS Implementation Roadmap and a key component of the TNB Smart Utility 2025 Master Plan, APMS was developed to systematically manage asset information throughout the entire asset life cycle. The platform integrates data from multiple enterprise systems to provide predictive and prescriptive analytics capabilities that support effective asset management and operational excellence.

Traditionally, asset performance assessments relied heavily on manual data gathering, spreadsheet-based analysis, and fragmented information sources. These processes were time-consuming, resource-intensive, and highly susceptible to human error. Furthermore, asset information was often distributed across multiple systems, resulting in limited visibility into asset condition, criticality, and risk, making it difficult to prioritize maintenance and investment decisions effectively.

To address these challenges, APMS provides an integrated enterprise solution that consolidates asset information and transforms it into actionable intelligence. The primary objective of the system is to develop and continuously monitor asset health, asset criticality, and asset risk indices, enabling a risk-based approach to maintenance optimization and asset management. Through advanced analytics and data-driven insights, APMS supports the optimization of risk, performance, and cost across the distribution network.

The initiative aims to provide a holistic view of asset information, improve maintenance strategies, optimize operating expenditures, and enhance overall power supply reliability. By enabling proactive asset management and informed decision-making, APMS supports the transition towards a smarter, more resilient, and more efficient electricity network. This is illustrated in Figure 3.16.

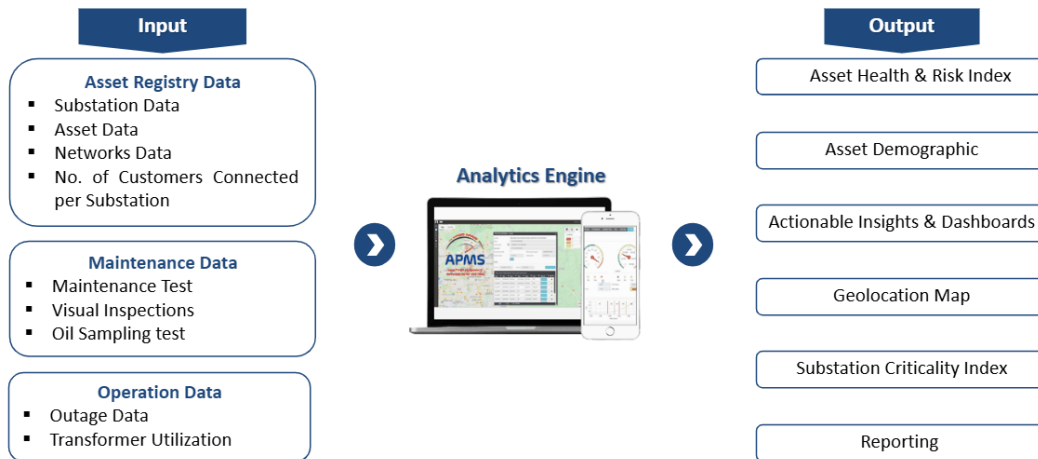


Figure 3.16: APMS Overview

APMS provides comprehensive asset intelligence capabilities by continuously assessing the condition, performance, and risk profile of network assets throughout their operational life cycle. The platform automatically generates Asset Health, Asset Criticality, and Asset Risk indices that support risk-based maintenance planning and prioritization, enabling maintenance resources to be directed towards assets with the highest operational impact and failure risk.

The system continuously monitors asset performance and provides actionable insights to support operational and strategic decision-making. When deteriorating asset conditions or elevated risk levels are detected, APMS can automatically trigger notifications and recommend appropriate intervention actions, allowing maintenance teams to respond proactively before failures occur.

At the core of APMS are advanced analytics algorithms developed in collaboration with technical subject matter experts and aligned with industry-recognized asset management methodologies, Condition Network Asset Indices Methodology (CNAIM). The Asset Health Index evaluates the overall condition of an asset by considering factors such as asset characteristics, condition assessments, operational performance, reliability history, maintainability, and safety considerations. This provides a consistent and objective view of asset health across different asset classes.

Complementing this assessment is the Substation Criticality Index, which measures the operational and business importance of substations within the network. The index considers

factors such as customer impact, network configuration, strategic importance, and service continuity requirements to determine the potential consequences of asset failure.

By combining both Asset Health and Substation Criticality assessments, APMS generates Asset Risk Indices that provide a comprehensive view of both the likelihood and consequence of failure. This enables TNB to optimize maintenance strategies, prioritize investments, improve resource allocation, and enhance overall network reliability through data-driven decision-making.

The solution integrates data from multiple enterprise systems, including asset registries, maintenance records, operational data, and IoT sensors installed on critical assets. All data sources are consolidated within the Asset Performance Monitoring System (APMS), where analytics and visualization are used to generate key outputs such as the Asset Health Index and Asset Risk Index.

The system begins with data collection, where maintenance and operational information is captured through field systems and IoT sensors that continuously monitor asset conditions. This data is then integrated from different systems into APMS to ensure a complete and consistent view of asset information.

Once integrated, APMS performs data analytics to assess asset condition and risk, which are then presented through dashboards for easy monitoring and decision-making. When poor asset conditions are detected, the system automatically generates alerts and recommends appropriate actions to the maintenance team.

Based on these insights, maintenance teams carry out necessary inspections, repairs, or replacements. The overall outcome of the system is a real-time dashboard that provides visibility of asset health and risk, enabling more informed and proactive maintenance decisions. This is illustrated in Figure 3.17.

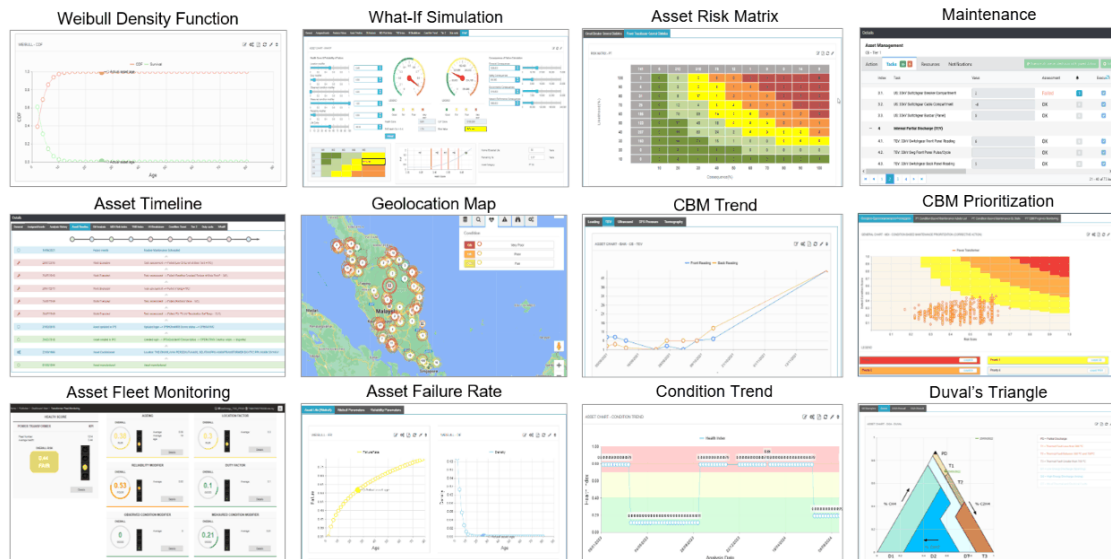


Figure 3.17: APMS Dashboards

The implementation of the Asset Performance Monitoring System (APMS) is being delivered in phases. APMS Phase 1 has been successfully completed, with asset analytics capabilities implemented for 33kV switchgear and power transformers. Building on this foundation, APMS Phase 2 is currently in progress, expanding the platform to include 11kV switchgear, 33kV underground cables, and 11kV underground cables. This phased approach extends APMS coverage across additional critical asset classes, enabling more comprehensive asset health, criticality, and risk monitoring throughout the distribution network.

The roadmap outlines key strategic initiatives designed to enhance asset intelligence, strengthen predictive capabilities, and enable end-to-end digital asset lifecycle management within the distribution network. This is illustrated in Figure 3.18.



Figure 3.18: APMS Roadmap

IoT Sensor Expansion focuses on the installation of IoT sensors in Criticality Class 1 substations and selected linear assets. This initiative enhances real-time visibility of critical network components, enabling improved condition monitoring, early fault detection, and data-driven maintenance decision-making.

IoT Field Equipment Deployment involves the bulk procurement and deployment of IoT-enabled test equipment for field crews. It refers to portable IoT-enabled devices used by field crews during inspections (e.g., thermal cameras, PD testers, vibration analysers). This enhances field operations by enabling faster data capture, improved diagnostic accuracy, and seamless integration of field measurements into central asset systems.

Advanced Asset Analytics Expansion extends the analytics engine to additional asset types, including underground cables, overhead lines, and protection devices. This enables a more comprehensive and unified view of asset performance, risk, and health across the entire distribution network.

Integrated Asset Lifecycle Management integrates end-to-end asset lifecycle analytics with the Asset Investment Planning Management (AIPM) solution. This ensures that asset performance insights are directly linked to investment planning, replacement strategies, and long-term capital optimization decisions.

Digital Twin Risk Simulation introduces simulation capabilities using a digital twin of the distribution network. This enables accurate modelling of interconnected assets, allowing scenario-based analysis, risk forecasting, and improved understanding of system-level asset behaviour.

Asset Health Centre establishes a common monitoring hub for near real-time tracking of distribution network asset performance and utilization. It enables predictive failure detection, improved operational visibility, and supports proactive asset management strategies across the network.

The initiative delivers significant measurable value across maintenance efficiency, asset performance, operational reliability, and workforce productivity, contributing directly to improved network performance and cost optimization.

The implementation of predictive and data-driven maintenance strategies reduces maintenance costs by minimizing unnecessary interventions and enabling maintenance activities to be prioritized based on actual asset condition and risk. This ensures that resources are utilized more efficiently while reducing avoidable operational expenditure.

The initiative also reduces unplanned downtime by enabling the early identification of potential asset failures and supporting proactive maintenance actions. This improves network reliability, minimizes service interruptions, and enhances overall system resilience.

In addition, the approach extends asset lifespan by shifting maintenance strategies from reactive practices to condition-based and predictive maintenance. This improves asset utilization, enhances long-term reliability, and delays the need for premature asset replacement.

Furthermore, the initiative increases workforce productivity by enabling maintenance teams to focus on high-priority and high-risk assets. By reducing unnecessary inspections and reactive fault handling, operational efficiency is improved, and maintenance resources are deployed more effectively.

3.4.2 Asset Investment Planning & Management (AIPM) for HV Assets

Asset Investment Planning and Management (AIPM) is a strategic asset management practice used by best-in-class organizations to realize the highest value from existing assets and select future opportunities that will provide the greatest return to the organization.

Key Features/Functions

The Asset Investment Planning Management (AIPM) project has a total of six (6) expected deliverables which include:

- Systematic & consistency in investment decision making
- Optimum, prudent & timely investment under IBR
- Transparent investment proposal to regulator
- Realization of values for every dollar spent on asset
- Manage dynamic & flexible IBR environment & other constraints
- Create long-term & efficient investment strategy while proactively managing risks. This is illustrated in Figure 3.19.

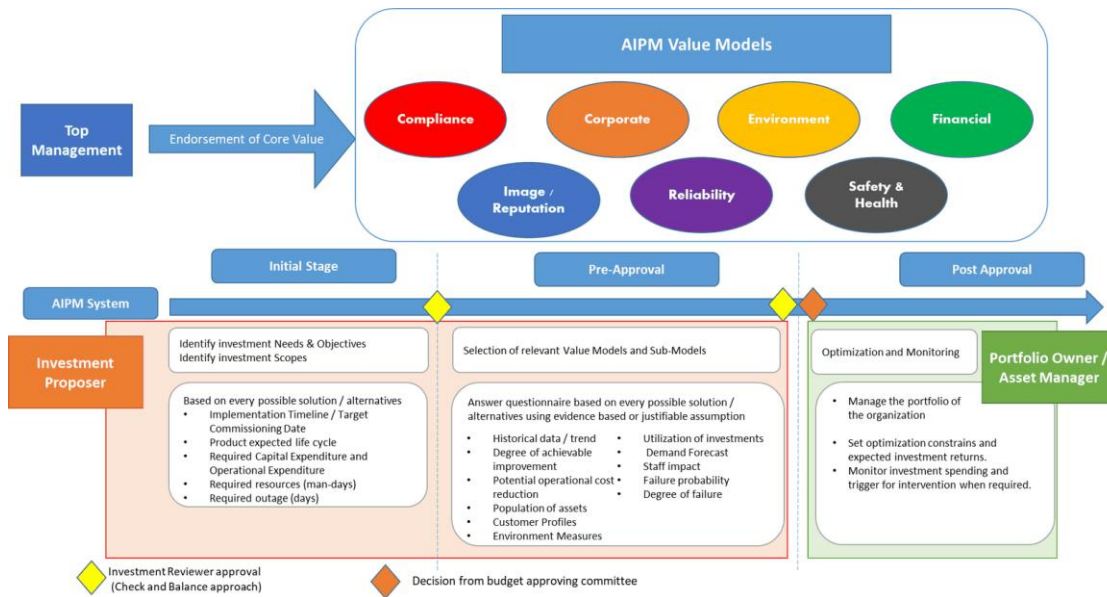


Figure 3.19: Simplified operating model of Asset Investment Planning Management (AIPM) System.

Among the critical path that is associated with the AIPM is value identification where all core values of the organizations need to be determined agreed by all departments. A total of seven (7) value models has been identified as the core values of the organization which covers compliance, corporate, environmental, financial, image / reputation, reliability and safety and health. In extension to that, the seven (7) value models are further divided into twenty-two (22) sub-models that represent the diverse risk or expected benefit that are commonly recognized through the purpose of investment in transmission utility. Ultimately, it reflects all the concerns, problem, risk and desired expectation in the organization, stakeholders and regulator in the framework of monetize value. Endorsement by the top management on the value models as it set the direction for decision making for the future in dealing with all investments.

AIPM also focuses on alignment of value models and calculation parameters. For tangible value models, different calculation formula will be formed to derive the risk value or benefit value, for example reliability - supply interruption / supply performance is calculated based on expected unserved energy and probability of failures. While non-tangible values are based on a set of consequence that are separated into five (5) degrees level from insignificant, minor, moderate, major and catastrophic which can be compared in monetized value. Alignment of processes that are associated with the decision making on investment is also considered in Asset Investment Planning Management (AIPM) System design. This is to provide standardized process for all investment proposal and having a clear line of sight for all the required approving processes and enable organization-wide portfolio monitoring and tracking.

In 2024, all the CAPEX investment initiatives and projects proposed for RP4 proposal to the regulators were evaluated by the AIPM. This is illustrated in Figure 3.20.

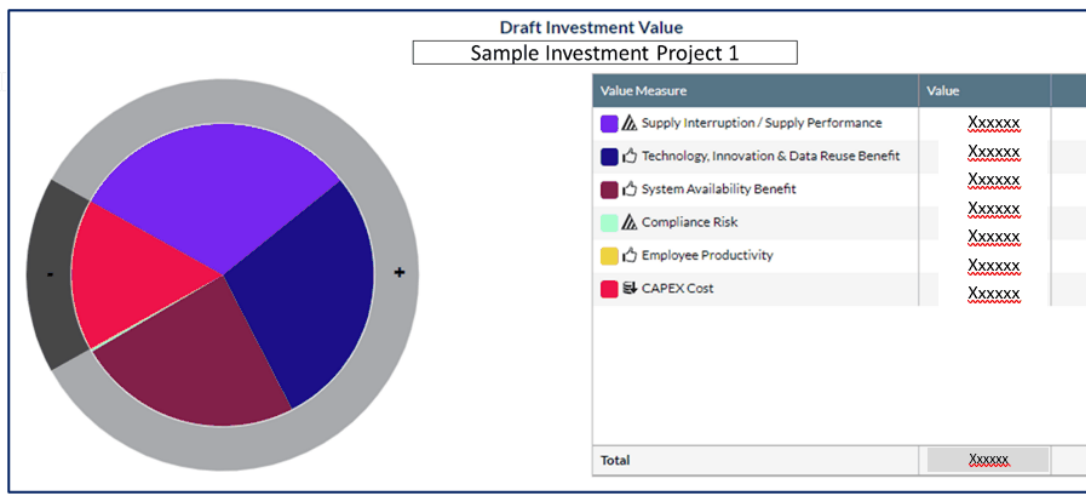


Figure 3.20: Draft Investment Value

3.4.3 i-NET (Integration Network Expansion Tool) and AIPM for MV Assets

i-NET is an analytical solution custom built for distribution network planners to facilitate Common Planning and Capacity Allocation Management. It was a digitalization initiative to enable effective realization of TNB grid modernization program which demands accurate network planning of dual power flow system, common governance of efficient planning, overall optimization of CAPEX planning and management as well as productivity improvement to cater for job enhancement of planning unit to take up additional tasks related to grid modernization. This is illustrated in Figure 3.21.

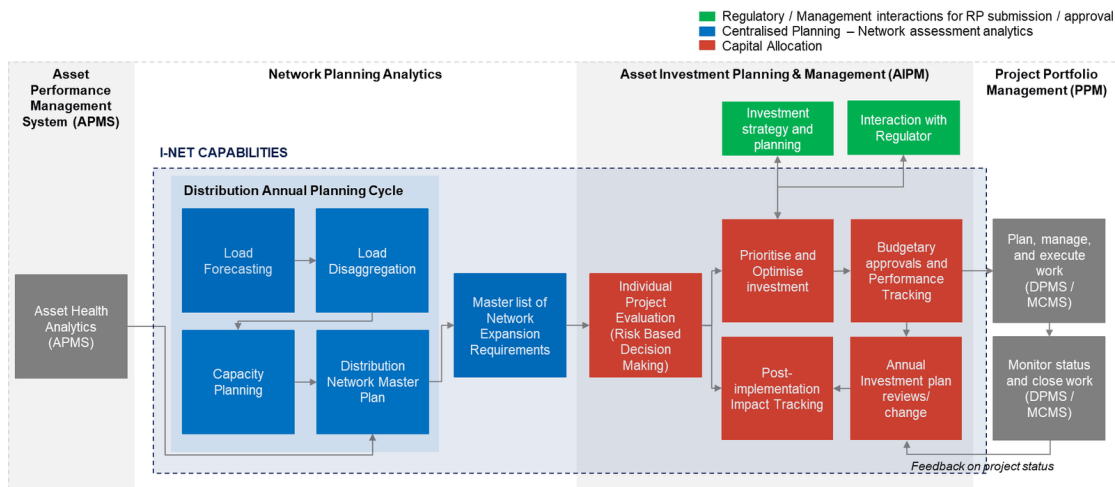


Figure 3.21: High level solution framework of i-NET Capabilities

While completing the traditional building blocks of EAMS, i-NET goes beyond the basic requirements of EAMS i.e. capabilities of Network Planning Analytics is coupled with AIPM as a total solution for planners sandwiched between APMS and PPM.

i-NET is embedded with the customised methodology of Distribution Annual Planning Cycle analysis which generates network expansion requirements and becomes an input to AIPM where

annual capital allocation is prioritized and optimized according to strategic objectives of the organization.

Hence, besides process automation, i-NET is a decision support system (DSS) and single source of truth for common planning and capital allocation with below features:

- A unified Platform for distribution annual planning cycle studies conducted by nationwide planners
- Common capex portfolio planning and management through risk-based evaluation and mathematical optimization
- Automated data collection and result generation based on admin specified logics and user-friendly Graphical User Interface (GUI)
- Ad-hoc result simulation for unique scenario planning
- Convenient interactive analytical tool with custom built Visual Analytics Reporting

As a total solution for distribution planners, the capabilities of i-NET can be segmented into 2 major parts i.e. Common Network Planning Analytics and Asset Investment Planning and Management.

1. Common Network Planning Analytics

The forecasting methodology adopted in i-NET allows advanced load forecasting capabilities. It is a progressive migration from simple time series forecast to a much-advanced multi-variant time series analysis which encapsulates time series as well as regression models. Time series analysis searches for recent trending as well as seasonal or recurrent relationship of demand with respect to time parameter. The multi-variant parameters used in this forecast model considers the influence of Peninsular Malaysia's economic factors such as population, Gross Domestic Product (GDP), weather and others.

With demand by main intake substation as the dependent variable and the respective econometric factors (Weather, GDP, Population, Nos. of Household, Electricity price & Commercial floor space) as the independent variables, i-NET automatically identifies the best statistical fit by comparing against unlimited models. Any irregularities are automatically detected which produces forecasting result that is free from human error. Besides, in i-NET there are functionalities to configure impact of recurring or non-recurring events such as festive season, natural disasters, high profile event and sudden spike of industrial step load.

As a result, i-NET generates high accuracy forecast which will basically determines the accuracies of consecutive studies of DAPC i.e. Load Disaggregation, Capacity Planning and Distribution Network Master Plan.

Upon finalisation of Load Forecasting, i-NET allows automated Load disaggregation, where forecasted demand is disaggregated to distribution primary and secondary substations to generate 20-year demand forecast by asset. All demand transfers between assets to optimise asset utilization are handled within i-NET properly recorded on a geospatial platform.

2. Asset Investment Planning and Management (AIPM) for MV Assets

The AIPM establishment in i-NET focuses in achieving end to end Core CAPEX lifecycle management with automated project evaluation, CAPEX portfolio optimization as well as post implementation impact tracking. It comprises of 5 main capabilities as deliberated below:

- Project Life Cycle Management and Tracking which provides single source of truth for CAPEX lifecycle management.
- Project Assessment & Risk Management which enables automated identification of “effective” CAPEX to avoid potential OPEX evaluated by unique needs of local area characteristics leveraging on concept of risk or value-based decision making.
- CAPEX Portfolio Planning & Optimization which can be broadly classified as mathematical optimization of CAPEX portfolios against constraints or targets i.e. short term / medium term strategic objectives of the organization, allowable CAPEX allowances specified by regulators, availability of resources and elements of related nature. This allows agile optimization of CAPEX portfolios for optimum value creation within Regulatory Period targets.
- Periodic Revision of Budgetary Requirements allows common CAPEX lifecycle management by distribution planners to ensure optimal utilization of CAPEX adjusted against constraint faced during implementation to avoid prolonged stagnation of CAPEX or project.
- Interactive Dashboards for Performance Monitoring provides easy performance tracking by middle management

In a nutshell, digitalization of abovementioned capabilities is expected to yield enhanced process efficiencies, enhanced risk management, enhanced investment evaluation, enhanced portfolio evaluation, improved system project outcomes and overall bullet proofing of TNB’s CAPEX proposal accompanied by risk monetization and proven value creation. These capabilities are illustrated in Figure 3.23.

3.4.4 Coal Fineness Optimization

Coal Fineness Optimization is an initiative to develop a Machine Learning (ML)-based simulation tool to optimise coal mill settings by considering coal quality, feeder speed, classifier speed and primary airflow. Coal mill settings need to balance coal properties and key mill parameters. Early

analysis shows that coal fineness has an impact on combustion efficiency, fuel cost, wear and tear and power consumption. Measuring coal fineness also requires lab analysis.

Currently, the coal mill relies on general guidelines, operator experience and lacking precise settings to account for varying coal properties and mill-specific requirements. This creates uncertainty in decision-making due to inconsistent variables, making it a good case for Machine Learning (ML). The solution is to develop an ML-based simulation tool that can prescribe the optimal mill settings for achieving the desired coal fineness, while balancing the many variables involved.

One of the main capabilities of this initiative is the ability to optimise mill settings by considering coal quality, feeder speed, classifier speed and primary airflow. This supports better decision-making in determining suitable coal mill parameters. The simulation models aim to improve combustion efficiency, reduce fuel and power consumption costs.

There are two (2) simulation models used in tandem. The first model predicts coal fineness percentage based on coal properties and controllable parameters. The second model predicts controllable parameters based on required fineness and coal properties. The simulation models provide operational benefits by acting as a reliable tool for predictions and decision-making, enabling quick and real-time changes with just a few clicks and allowing testing of scenarios when required.

The simulation models consider coal mill parameters that are controllable and non-controllable. The controllable parameters include classifier speed, feeder speed, and primary airflow. The non-controllable parameters include coal composition elements (e.g. TiO_2 and Na_2O). Byproducts of pulverization (e.g. motor current and gearbox vibration) are also identified as consequences from machinery operation.

The first simulation model is the Coal Fineness Percentage Prediction Model. The input is coal mill parameters, and the output is predicted fineness percentage. The second simulation model is the Controllable Parameters Prediction Model. The input is required fineness and coal properties. The output is the predicted controllable parameters (i.e. classifier speed, primary airflow and feeder speed). This is illustrated in Figure 3.22.

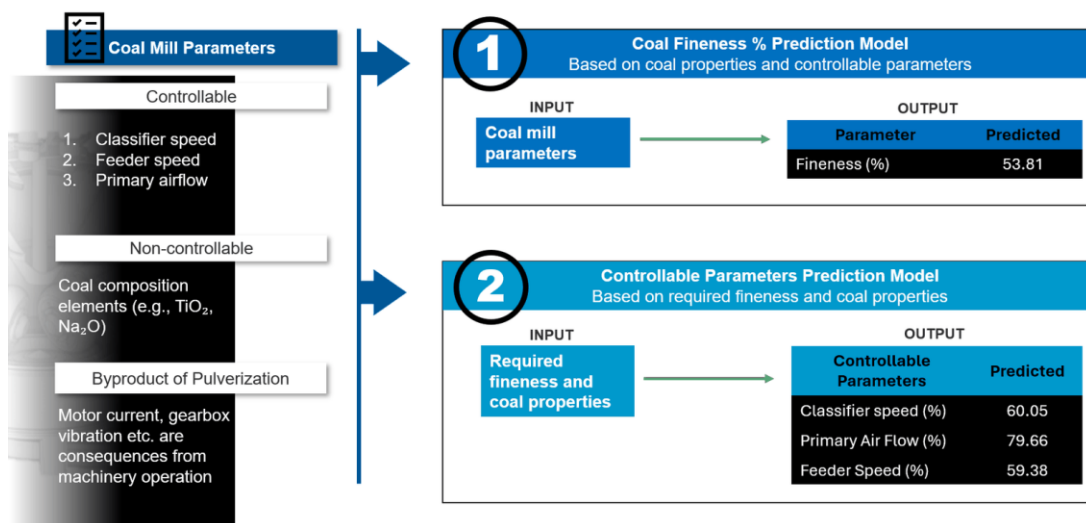


Figure 3.22: Simulation Models

Currently implemented at Manjung 4 and Manjung 5.

The value of Coal Fineness Optimization is seen through its ability to support more reliable predictions and decision-making for coal mill settings. It provides a faster way to make real-time changes with just a few clicks and allows scenario testing when required. The initiative helps improve combustion efficiency and reduce fuel and power consumption costs.

3.5 Governance & Regulatory Trust

TNB has established an AI governance framework to support responsible, secure and trustworthy adoption of AI across the organization. The framework provides a common approach for oversight, accountability, transparency and AI risk management as AI applications continue to expand across different business and operational use cases.

3.5.1 TNB Responsible AI Governance Framework

The TNB Responsible AI Governance Framework was established to enable responsible, secure, and trustworthy adoption of Artificial Intelligence (AI) across the organization. As AI capabilities continue to expand, the framework provides a structured approach to ensuring that AI solutions are developed, deployed, and operated in alignment with TNB's business objectives, governance requirements, and organizational values.

Building upon TNB's established cybersecurity, information security, and technology governance practices, the framework introduces AI-specific governance to address the unique risks and considerations associated with Artificial Intelligence. It complements existing governance by providing dedicated oversight for areas such as responsible AI, human oversight, transparency, accountability, and AI risk management.

The framework provides consistent governance throughout the AI lifecycle, from planning and development to deployment, monitoring, and continuous improvement. By embedding governance into AI implementation, TNB is able to accelerate innovation while maintaining appropriate oversight, accountability, and risk management.

The initiative serves as a common governance foundation for AI adoption across TNB, enabling business functions to implement AI solutions with greater confidence while supporting sustainable and responsible digital transformation.

The TNB AI Governance Framework provides a structured governance model that supports AI adoption across the organization through four key components: the TNB AI Policy, AI Code of Practice (AI CoP), AI Guidelines, and the AI Governance Structure. This is illustrated in Figure 3.23.

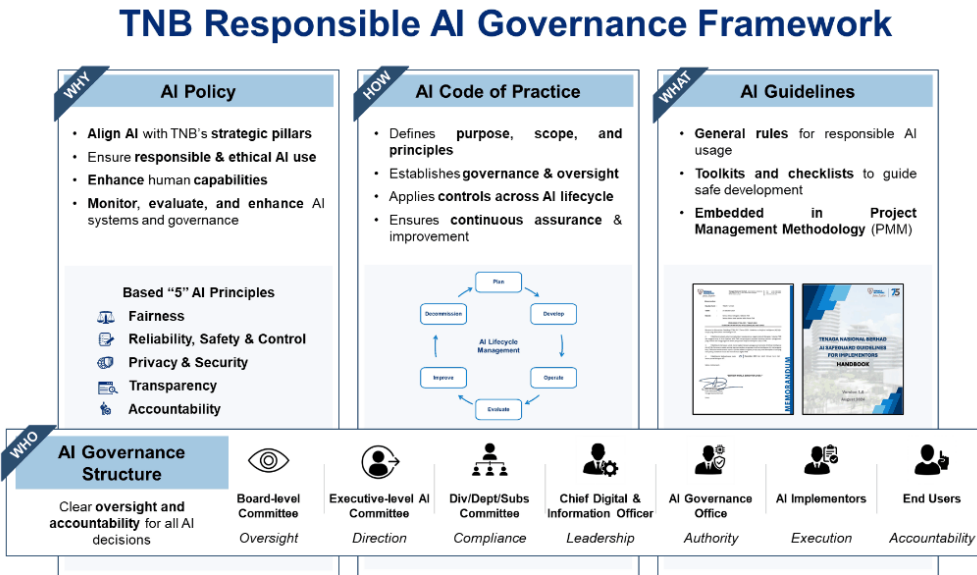


Figure 3.23: TNB Responsible AI Governance Framework

The AI Policy establishes TNB's commitment and guiding principles for responsible AI adoption. The AI Code of Practice defines governance requirements and expected practices throughout the AI lifecycle, while the AI Guidelines provide practical implementation guidance for project teams. The AI Governance Structure establishes oversight, accountability, and governance responsibilities to ensure AI initiatives are governed consistently across the organization.

Together, these components enable AI initiatives to be implemented using a common governance approach while promoting responsible AI practices, effective risk management, and continuous governance oversight.

- The TNB AI Governance Framework has been established and adopted as the enterprise governance framework for AI initiatives across the organization. It serves as the common governance foundation supporting the implementation of AI solutions, while continuing to

evolve through periodic reviews and updates to reflect emerging technologies, industry best practices, and organizational needs.

- The TNB AI Governance Framework enables AI to be adopted consistently and at scale by providing a common governance foundation for all AI initiatives across the organization. This accelerates AI implementation while ensuring appropriate governance, risk management, and oversight are embedded throughout the AI lifecycle.

The framework also strengthens regulatory readiness and organizational resilience by establishing clear policies, implementation standards, and governance responsibilities that promote safe, secure, and accountable AI adoption.

By providing a structured governance approach, the framework supports sustainable AI innovation and enables TNB to confidently realise the benefits of AI while maintaining stakeholder trust.

3.6 AI Copilots for Field Crews

TNB is also developing AI-powered assistants to improve access to organizational and technical knowledge and support employees in day-to-day and field activities. weKNOW provides the enterprise Generative AI foundation, while TEASERS extends AI-assisted knowledge discovery and technical decision support for engineering and operational users.

3.6.1 weKNOW Employee Assistant

weKNOW is TNB's enterprise Generative AI platform, developed to enable secure, scalable, and responsible adoption of AI across the organization. The platform provides employees with AI-powered assistance for accessing enterprise knowledge while serving as a common foundation for developing AI applications that support different business functions.

As organizations increasingly adopt Generative AI, balancing innovation with data security and governance has become increasingly important. weKNOW enables TNB to leverage the benefits of AI within a secure enterprise environment, allowing employees to interact with organizational knowledge while ensuring that enterprise information remains protected under TNB's governance framework.

The platform combines authorised internal enterprise knowledge with the broad knowledge capabilities of Generative AI. This enables users to receive responses that are contextualised to TNB's business, policies, procedures, and operations, while still benefiting from general knowledge to support a wider range of queries. By bringing these capabilities together, weKNOW

provides a trusted AI experience that is both relevant to TNB and valuable for everyday work. This is illustrated in Figure 3.24.



Figure 3.24: weKNOW Employee Assistant

weKNOW enables employees to access enterprise knowledge through natural language, making it easier to retrieve policies, procedures, technical references, and other organizational information. By delivering contextually relevant responses based on authorised enterprise knowledge, the platform improves information accessibility and supports faster, more informed decision-making. The platform also extends these capabilities to field personnel by providing convenient access to technical guidance and operational information, enabling them to perform their work more effectively while on site.

Beyond knowledge access, weKNOW provides a common enterprise AI platform for deploying business-specific AI applications. This enables different business functions to build AI solutions tailored to their operational requirements while leveraging a shared platform that promotes consistency, scalability, and responsible AI adoption across the organization.

The platform also supports AI-assisted ways of working through intelligent agents that help employees to complete tasks more efficiently. As these capabilities continue to expand, weKNOW lays the foundation for broader AI adoption and a more AI-enabled workforce across TNB.

A key capability of weKNOW is its secure enterprise environment, enabling employees to benefit from Generative AI while ensuring that organizational knowledge and data remain protected within TNB's governance and security framework.

weKNOW integrates authorised enterprise knowledge into a secure AI platform that enables employees to interact with organizational information through natural language.

When a user submits a query, the platform retrieves relevant information from authorised internal knowledge sources where applicable while leveraging the broad knowledge capabilities of Generative AI to provide contextual and meaningful responses. This combination enables users to obtain information that is tailored to TNB's business context while also supporting more general information needs through a single conversational interface.

weKNOW has been successfully deployed enterprise-wide across TNB and is actively used by employees as the organization's enterprise Generative AI platform.

To date, the platform has been adopted by approximately 13,000 unique users across TNB, reflecting broad organizational adoption and increasing utilization of AI to support day-to-day work. At the same time, the platform continues to expand through the introduction of additional business-specific AI applications and intelligent agents to address evolving operational requirements.

The roadmap for weKNOW focuses on expanding enterprise knowledge coverage, enhancing AI capabilities, and increasing the range of AI-powered applications available across the organization. Future developments will continue to expand the agents, improve user experience, and support wider adoption of Generative AI as part of TNB's enterprise AI ecosystem.

weKNOW delivers value by enhancing employee productivity through faster access to information and AI-powered assistance, enabling employees to complete day-to-day tasks more efficiently and make more informed decisions.

By providing a secure enterprise AI platform, weKNOW enables employees to leverage the capabilities of Generative AI while reducing the risk of organizational data leakage associated with the use of public AI tools. This allows TNB to accelerate AI adoption without compromising data governance and information security.

The platform also improves employee experience by providing a more intuitive and accessible way to interact with organizational knowledge and AI capabilities, reducing the effort required to search for information and supporting a more seamless digital workplace.

Beyond immediate productivity gains, weKNOW lays the foundation for an AI-empowered and agentic workforce, where AI-powered assistants and intelligent agents augment employees in their daily work and enable new ways of working across the organization. As TNB continues its digital transformation journey, weKNOW serves as a strategic platform for scaling enterprise AI capabilities responsibly and sustainably.

3.6.2 Technical Expert Advisor and Repository Centre (TEASERS)

The Technical Expert Advisor and Repository Centre (TEASERS) is an AI-assisted technical knowledge capability being developed by TNB to improve access to engineering and operational information. The initiative responds to the challenge of technical knowledge being distributed across multiple document repositories and available in different formats, which can make it difficult for employees to locate relevant information efficiently.

Technical references such as manuals, guidelines, circulars, engineering documents and historical records contain valuable organizational knowledge. However, conventional document-search methods may require users to manually navigate different repositories and rely on prior knowledge of document titles or locations. This can be particularly challenging for employees who are new to a role or require access to unfamiliar technical information.

TEASERS explores the use of Artificial Intelligence (AI), document-processing and multimodal-search capabilities to complement existing knowledge-management practices. The capability is intended to make selected technical information easier to discover through a conversational interface, while maintaining the relevant source documentation for user reference and verification.

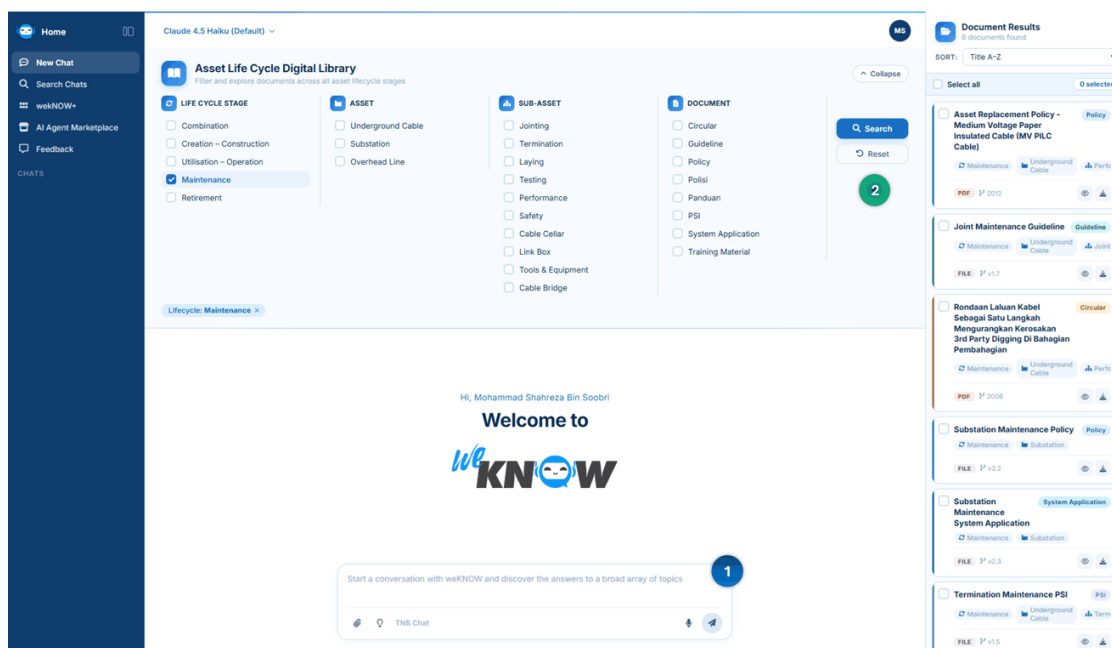


Figure 3.25: TEASERS User Interface

The current working model supports the processing and retrieval of information from technical documents, including textual content, scanned material and selected visual information such as images and diagrams. Users can submit natural-language queries, and the system searches the available knowledge sources to provide relevant information and references for further review.

Rather than replacing existing technical expertise or engineering judgment, TEASERS is intended to provide knowledge-access and decision-support assistance. Users remain responsible for reviewing the relevant approved technical references and applying appropriate engineering judgment before information is used for operational or technical decisions.

At its current stage, TEASERS provides a foundation for exploring capabilities such as multimodal technical search, retrieval of relevant document content and a chat-based user interface. The working model is being evaluated to better understand user requirements, information quality, usability and the suitability of AI-assisted knowledge retrieval for different technical functions.

The next phase of development will focus on improving the organization and filtering of technical information, including the ability to access content according to relevant asset categories and asset life-cycle stages. TNB is also progressing the alignment of TEASERS with its in-house AI environment, weKNOW, to support a more consistent approach to internal AI-enabled knowledge access.

Further testing and iterative improvement will be required before broader implementation. Areas for development include expanding the coverage and quality of technical information, improving search and retrieval performance, strengthening the handling of visual and legacy documents, enhancing user interfaces and refining governance arrangements for the use of approved technical references.

Over time, the capability may also support additional knowledge-assistance use cases such as guided access to technical procedures, onboarding support and selected technical calculation or visual-reference functions, subject to further development and validation.

Overall, TEASERS demonstrates the potential of AI-assisted knowledge management to improve the accessibility and use of technical information within TNB. Continued development can provide a stronger foundation for workforce knowledge support while ensuring that AI-generated information remains appropriately grounded in approved technical references and complemented by professional judgment.

DIMENSION 4: CUSTOMER EMPOWERMENT

4.1 Energy Insights & Transparency

4.1.1 AMI Customer Offering

Advanced Metering Infrastructure (AMI) is an integrated system of smart meters, communication networks and data management systems that enable the two-way communication of data between TNB and customers. Hence, AMI is paving the way for customers to enjoy more smart features and benefits as part of their daily living and energy consumption, in addition to enhancing operational efficiencies for TNB in the times to come as the customer offerings are being rolled out in phases.

Advanced Metering Infrastructure (AMI) pertains to a comprehensive system that combines smart meters, communication networks, and data management systems. This integrated system facilitates bidirectional data communication between TNB and its customers. As a result, AMI is ushering in a new era where customers can experience a range of intelligent features and advantages in their daily lives and energy usage. Simultaneously, it is set to enhance TNB's operational efficiencies as customer offerings are progressively introduced.

The customer offerings and benefits that have been rolled out from AMI implementation are as below:

- **Actual and Timely Electricity Bill** – Smart meter gives actual readings at 30-minute intervals; hence no site meter reading by meter reader is required. Timely electricity bill will be available in myTNB web portal and app.
- **Manage Electricity Consumption** using daily profile via myTNB Web Portal and Mobile App – Smart Meter customers can view detailed information on their energy consumption (down to 30 minutes' interval) and electricity bills through myTNB web portal and mobile application, which empowers customers to better manage their electricity usage and be more energy efficient.
- **Energy Budget** – Customers will receive alert notification via myTNB mobile application once they have reached the energy usage threshold limit set earlier. This feature empowers customers to manage their energy lifestyle better by allowing them to be more aware and purposeful in their energy usage from time to time, which will contribute to savings in their electricity bills.
- **Power Outage Notification - Notification of electricity supply interruption & restoration** – Customers will receive timely information on power outages and updates on when power will be restored via myTNB App instead of calling TNB Careline to obtain an update on the electricity supply situation. Hence, notification on supply disruption will reduce complaints and enquiries from customers.

- **Time of Use (ToU)** – This feature provides customers the choice to opt for ToU tariffs, which offer different pricing throughout various periods in a day e.g. peak, mid-peak and off-peak periods via Interval Billing Mechanism (IBM). As a result, customers could manage their energy usage according to the different tariffs offered in a day and enjoy reduction in monthly bills by shifting consumption to off-peak hours. Besides, with TOU implementation, the overall energy demand during peak-periods is reduced – resulting in lowered strain on grid infrastructure, increased energy efficiency and reduced customer impact.

The features of AMI in the current pipeline are as below:

- **Faster Power Reconnection (Move in Move Out) Remote Energisation and De-Energisation** – with this feature, customers could connect and disconnect power supply remotely while moving in or out of their houses and hence reducing the time for supply reconnection from up to 3 days by conventional method to within a day using smart meters – greatly enhancing existing customer experience. Customers can also choose the time and date at their convenience for connection and disconnection.
- **Smart Payment - Flexible Payment Scheme** – this feature helps customers to control their energy consumption by empowering them to manage their energy budget and spending. Flexible Payment Scheme also enables the premises owner to control energy usage at rented premises and reduce the risk of unpaid bill by the tenant. It allows customers to opt for flexible payment options such as post-paid or prepaid plans. Besides, customers could top-up credit online without visiting a pay-point.

CUSTOMER PORTAL - MYTNB APPLICATION AND PORTAL

MyTNB is an online platform or mobile app that allows customers to access a range of services related to their electricity accounts and consumption. Currently, 6.65 million customers are connected to myTNB. Here are some common features and services provided through myTNB:

- **Bill Payment:** Customers can pay their electricity bills conveniently through the platform. They can view their current and previous bills, make payments online, and receive electronic receipts.
- **Account Management:** MyTNB enables users to manage their TNB accounts, update their contact information, and monitor their electricity consumption history.
- **Consumption Analysis:** The platform often provides tools and features that allow customers to analyse their electricity consumption patterns, helping them make informed decisions to reduce energy usage and costs.
- **Notifications and Alerts:** Customers can receive notifications about billing, power outage updates, and other important information related to their electricity supply.
- **Meter Reading Submission:** In some cases, customers may be able to submit their own meter readings, which can be helpful for accurate billing.

- **Energy Efficiency Tips:** MyTNB may offer energy-saving tips and suggestions to help customers reduce their energy consumption and lower their electricity bills.
- **Customer Support:** Users can contact TNB customer support through the platform for inquiries, complaints, or assistance with any electricity-related issues.

MyTNB is designed to enhance the customer experience by providing convenient, self-service options for managing electricity accounts and understanding energy consumption. It helps customers stay informed and in control of their electricity usage and billing, promoting more efficient energy use and better customer service.



Figure 4.1: myTNB Portal

CUSTOMER DIGITAL APPOINTMENT (CDA)

The Customer Digital Appointment project is an integration and enhancement to the existing myTNB portal & apps, BCRM system and Mobility for Meter Management System (3MS) that will enable end-to-end customer digitalization initiatives related to individual OPC new meter installation:

- To empower customer experience by allowing them to make and reschedule appointments for new meter installation in myTNB app and portal. There is currently no proper functionality to handle customer appointments. Customer Service and customer have no visibility on the availability of TNB's metering field crew while making an appointment. This enhancement will be able to give visibility to the availability of the field crew enabling customers to make an appointment from myTNB App thus improving customer experience.
- The objective of the change is to ultimately increase customer satisfaction by keeping and improving TNB's Service Level Agreement compliance on MSL 3c. This project will provide customer empowerment to select appointment date and time for individual OPC new

meter installation. Besides that, effective schedule and service order planning also will optimize workforce and team productivity.

Features for Customer Digital Appointment:

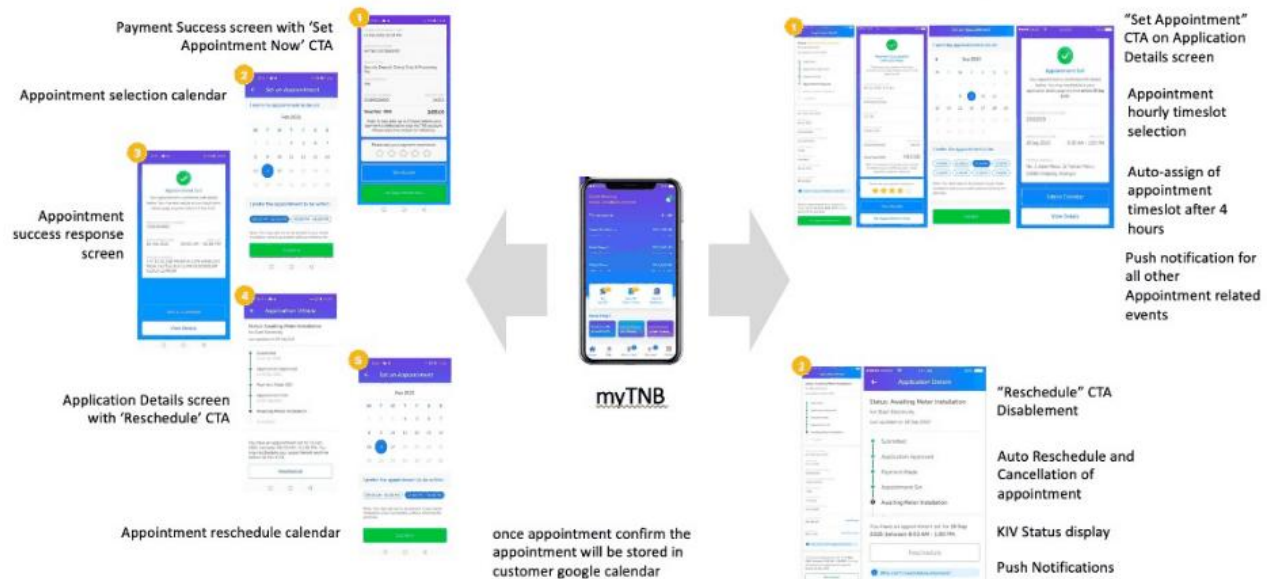


Figure 4.2: CDA to-be functions

DIGITAL BILLING AND CARBON FOOTPRINT AWARENESS

TNB's Digital Billing initiative enables customers to receive their electricity bills through multiple digital channels, including the myTNB app, email, and WhatsApp, providing a convenient, secure, and environmentally sustainable alternative to paper bills. By reducing paper consumption and the resources required for printing and distribution, Digital Billing contributes directly to lowering TNB's environmental footprint while supporting the company's digital transformation agenda.

As part of this initiative, TNB also promotes carbon footprint awareness by communicating the environmental benefits of digital bill adoption. This helps customers understand how choosing digital services contributes to resource conservation and carbon emission reduction, reinforcing sustainable behaviour and supporting TNB's Environmental, Social and Governance (ESG) commitments.

As of Q1 2026, more than 5.12 million customers have subscribed to Digital Billing. This level of adoption is estimated to have the following impact on the environment.

Environmental Impact (Q1 2026)

 5.12 million Digital Bill subscribers

 Approximately 128,000 trees conserved

 Approximately 256 acres of forest preserved

 Approximately 2,816 tonnes of CO₂ emissions reduced annually

These environmental benefits demonstrate how digital customer services can contribute to sustainability while enhancing customer experience.

myTNB Energy Consumption

The myTNB Energy Consumption feature empowers customers with greater visibility and control over their electricity usage through a user-friendly digital platform. By leveraging data from Advanced Metering Infrastructure (AMI), customers can access near real-time and historical energy consumption information, enabling them to better understand their consumption patterns and identify opportunities to improve energy efficiency.

The platform provides daily and monthly consumption trends, allowing customers to compare usage over different periods, monitor changes in consumption behaviour and make informed decisions to optimise electricity usage. This enhanced transparency encourages energy-conscious behaviour, supports cost savings and promotes sustainable energy consumption.

Beyond providing consumption data, myTNB serves as a key customer engagement platform that strengthens customer participation in the energy transition. Digital access to energy insights enhances customer experience, reduces dependency on manual bill tracking and lays the foundation for future smart grid services such as demand response, dynamic pricing and distributed energy resource integration.

The initiative improves customer empowerment, increasing digital adoption and enabling data-driven energy management, while supporting TNB's vision of a more intelligent, efficient and customer-centric electricity network.

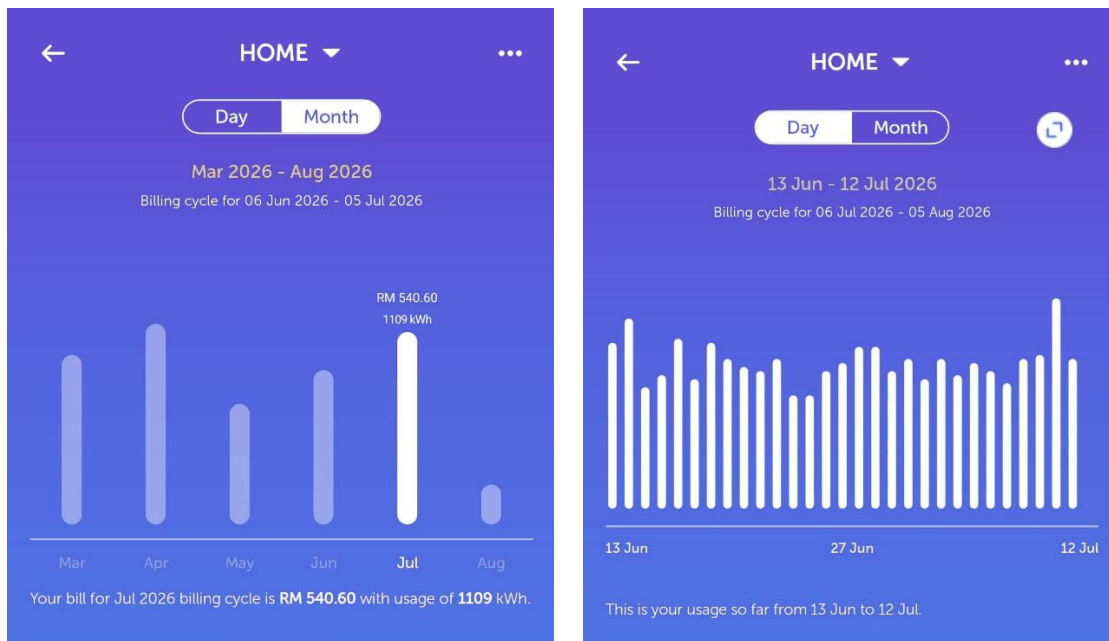


Figure 4.3: myTNB Energy Consumption feature

4.2 Participation in Flexibility

4.2.1 Demand Response with Customer Participation

Demand Response (DR) is envisioned to be an ancillary service for grid, aiding in frequency control and energy balancing. Moreover, it serves as a valuable mechanism to offset the inadequacies in generation ramping during the ongoing energy transition. By dynamically adjusting electricity consumption in response to grid conditions, DR effectively contributes to maintaining grid stability and reliability.

The Grid System Operator (GSO) has embarked on a pilot project for Demand Response with the goals of ascertaining the technical requirements that would be required for the deployment of a DR system and as a sandbox to gauge customers' experience. The technical development was done in collaboration with our research partners at TNBR to create a system that would be able to securely convey information and command signals between participant sites and the GSO control centre. The DR system was developed to be scalable as interested participants can install a DR-box at their sites and can leverage existing wireless networks for interfacing with GSO.

The diagram below provides an overview of the connection path between participants and the Grid System Operator (GSO).

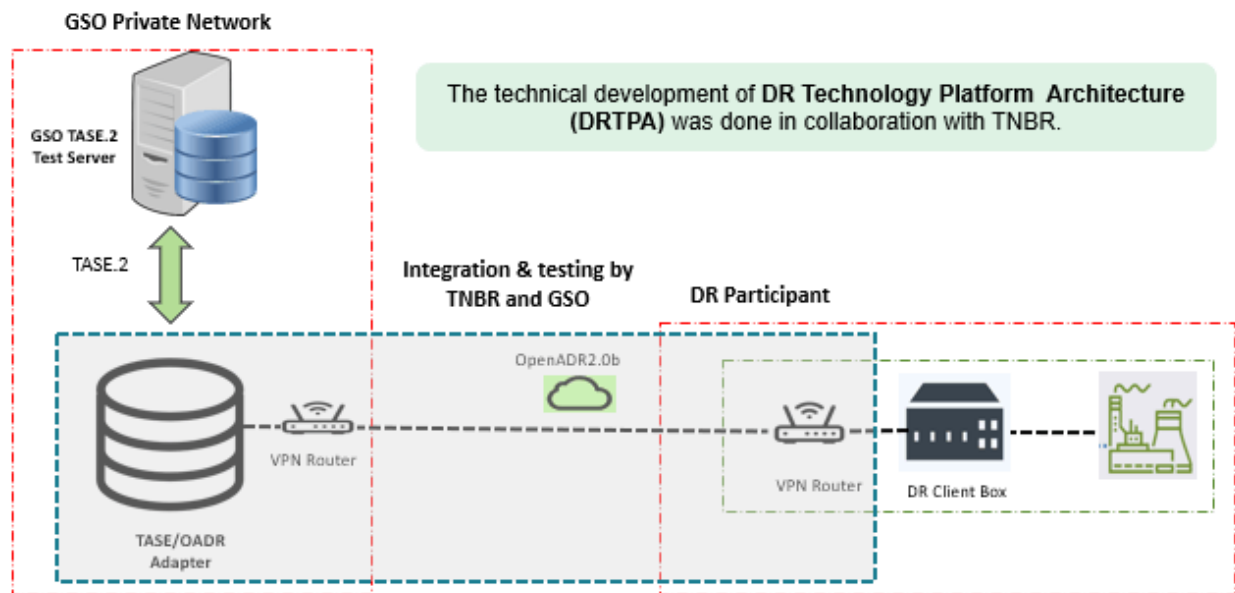


Figure 4.4: Architecture of DR Technology Platform

The Demand Response Management System (DRMS) user interface for the control centre allows for the operators to select different levels of power quantum and duration for each DR event execution for manual execution. Currently, an automated feature is being developed that would allow these DR resources to respond to frequency excursion events in the system.

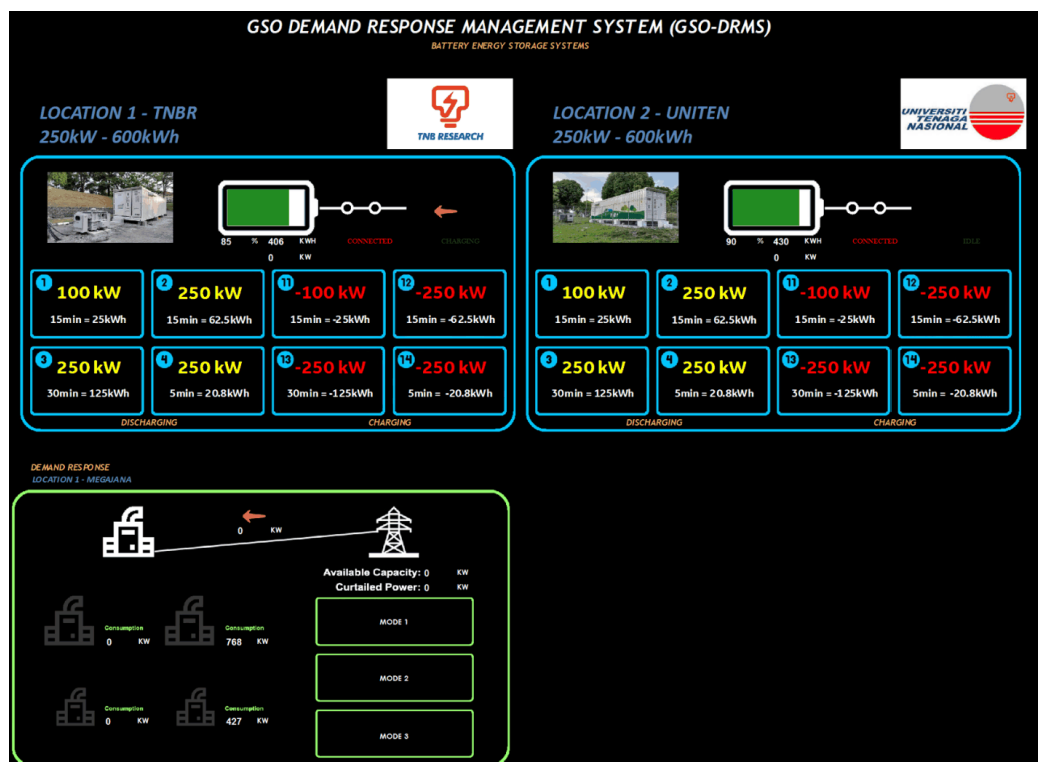


Figure 4.5: GSO Demand Response Management System (DRMS)

The following are the targeted customer segments involved in the DR pilot project:

- Industrial or Large Power Consumers: Customers would have the capability of nominating equipment within their installation that would be available for DR events activation.
- District Cooling System: The consumer would allow GSO to turn off their pumps which they would nominate based on their cooling water reserves and their customer consumption.
- Battery energy storage systems (BESS): BESS systems can be discharged and recharged according to system requirements.
- EV charging stations: Development in-progress. The increasing number of EVs and charging stations could present a challenge to the system however if it can be leveraged as a DR resource it can be an opportunity to secure the grid. Currently, GSO and TNBR are in the process of developing the conversion adapter between OADR (DR system protocol) and OCPP (charging station protocol) to enable remote control of EV charging stations.

4.2.2 Time-of-Use (ToU) Scheme

Time-of-Use (ToU) Scheme is a demand-side management initiative that supports the development of a smarter, more flexible electricity grid. It contributes primarily to Customer Empowerment and Satisfaction, Data Analytics, and Grid Flexibility dimensions by enabling customers to better manage their electricity consumption through time-based tariff signals.

The Time of Use (ToU) Scheme is an electricity tariff mechanism in which electricity charges are based on energy consumption according to different time zones throughout the day. The tariff rates vary depending on the time of use, namely Peak Hours and Off-Peak Hours, where electricity rates are higher during Peak Hours and lower during Off-Peak Hours. This structure provides customers with greater flexibility to plan their electricity usage and encourages the shifting of selected energy-intensive activities to periods with lower demand, supporting more efficient energy consumption and cost management.

ToU enhances customer empowerment by improving customers' awareness and control over their electricity usage and associated costs. Through access to smart metering information and digital platforms, customers can better understand their consumption patterns, identify periods of higher energy usage, and make informed decisions to optimise their electricity consumption. This promotes greater customer engagement and encourages active participation in demand-side energy management.

The implementation of the Time of Use (ToU) Scheme is enabled by Advanced Metering Infrastructure (AMI) and digital grid technologies, which require the installation of a Current Transformer (CT) meter, a Remote Meter Reading (RMR) meter, or an enabled Smart Meter to support billing under the Interval Billing Mechanism (IBM). These technologies enable accurate interval-based measurement of electricity consumption during Peak and Off-Peak Hours, while

facilitating secure data collection and two-way communication between utilities and customers. The consumption data generated through smart metering provides valuable insights into customer usage patterns, supporting improved demand analysis, load management, and the development of demand response capabilities.

ToU also contributes to enhanced grid flexibility by encouraging more efficient utilization of electricity resources and supporting better management of demand patterns. By providing customers with incentives to adjust their consumption behaviour according to system conditions, ToU helps improve demand-side management capabilities and supports more efficient operation of the electricity network.

Overall, the ToU Scheme is an important component of smart grid development, integrating time-based pricing, advanced metering technologies, and digital platforms to strengthen customer participation, enhance data-driven decision-making, and improve grid operational flexibility. Its contribution to customer engagement, energy efficiency, and demand management supports improved performance towards a more intelligent and resilient electricity network. For more information on the Time-of-Use (ToU) Scheme, including tariff details and how to switch to ToU, please visit <https://www.mytnb.com.my/tariff>.

4.2.3 Renewable Energy & Prosumer Participation: Net Energy Metering (NEM) and Solar Accelerated Transition Action Programme (ATAP), CREAM and CRESS

Prosumer participation is a key indicator of a modern smart grid, reflecting the transition from passive electricity consumers to active participants who both consume and generate electricity. Prosumer participation contributes primarily to the Integration of Distributed Energy Resources (DER) and Customer Empowerment and Satisfaction dimensions. High levels of prosumer engagement improve grid flexibility, increase renewable energy penetration, and enhance overall grid resilience.

TNB supports different forms of renewable energy participation through mechanisms that enable participation by individual prosumers, communities and corporate consumers. These include the Net Energy Metering (NEM) programme, Solar Accelerated Transition Action Programme (Solar ATAP), Community Renewable Energy Aggregation Mechanism (CREAM), and Corporate Renewable Energy Supply Scheme (CRESS).

Net Energy Metering (NEM) and Solar Accelerated Transition Action Programme (Solar ATAP)

Net Energy Metering (NEM) has enabled prosumers to offset their electricity consumption with electricity generated from rooftop solar photovoltaic (PV) systems and exported to the grid. Excess electricity generated during the day is credited against electricity consumed at other times in accordance with the applicable programme arrangements, thereby reducing overall electricity

bills. NEM encourages self-consumption of renewable energy, improves energy efficiency, and promotes customer participation.

Effective 1 January 2026, the Government of Malaysia introduced the Solar Accelerated Transition Action Programme (Solar ATAP) to replace the Net Energy Metering (NEM) programme. By removing capacity quotas, Solar ATAP provides fairer and more equitable access for consumers to adopt rooftop solar photovoltaic (PV) systems. The programme is designed to accelerate rooftop solar deployment by maximizing the utilization of available rooftop space across residential, commercial, industrial, and public sector buildings.

As a consumer-centric initiative, Solar ATAP offers a transparent and cost-neutral mechanism that enables consumers to generate electricity for their own use while exporting excess energy to the electricity grid. The programme supports Malaysia's renewable energy targets and reinforces the nation's commitment to building a sustainable, resilient, and low-carbon energy future.

TNB is committed to supporting the successful implementation of Solar ATAP by providing a seamless digital platform that enables customers to apply for rooftop solar PV grid connections through a simple, efficient, and transparent process. In addition, TNB conducts comprehensive power system studies to assess the technical feasibility of each application, ensuring that solar PV installations comply with grid connection requirements while maintaining the safety, reliability, and stability of the electricity distribution network.

As the number of prosumers increases, utilities may also need to address technical challenges such as bidirectional power flows, voltage regulation, and equitable cost recovery for grid infrastructure. NEM and Solar ATAP therefore complement wider smart grid capabilities such as smart meters, Advanced Metering Infrastructure (AMI), Distributed Energy Resource Management Systems (DERMS), and digital energy platforms that facilitate monitoring and management of distributed energy resources.

Through these initiatives, TNB facilitates the wider adoption of rooftop solar and supports Malaysia's transition towards a cleaner, more sustainable, and resilient energy system.

For more information, please visit: <https://www.mytnb.com.my/renewable-energy/solar-accelerated-transition-action-programme>

CORPORATE RENEWABLE ENERGY SUPPLY SCHEME (CRESS)

The Corporate Renewable Energy Supply Scheme (CRESS), introduced by the Ministry of Energy Transition and Water Transformation (PETRA), is designed to enhance the adoption of green energy by allowing participants to supply or purchase green electricity through open access to the grid network with a pre-determined System Access Charge. CRESS enables Green Consumers to contract directly with Renewable Energy Developers (REDs) for green electricity and associated

Renewable Energy Certificates (RECs). By participating in CRESS, Green Consumers can meet their sustainability objectives by offsetting their carbon emissions.

As Malaysia's national utility and the owner of the grid network, TNB plays a significant role in ensuring the success of this initiative. TNB is committed to ensuring that the national grid remains reliable, resilient, and capable of accommodating the growing volume of applications under CRESS, as more solar players participate in this initiative.

CREAM

Malaysia's Community Renewable Energy Aggregation Mechanism (CREAM) was announced in February 2025. This government initiative is designed to maximise residential rooftop solar potential, enabling homeowners to lease or rent out their rooftops to third parties for solar power generation. The CREAM program aims to encourage local community participation in the energy transition by homeowners leasing rooftops for solar PV installations to increase the share of RE to 40% by 2035 and eventually reaching 70% by 2050. As the electricity network operator, TNB supports the implementation of CREAM by facilitating the safe, reliable, and efficient integration of community renewable energy into the distribution network. Through close collaboration with the Government, regulators, and industry stakeholders, TNB remains committed to enabling a secure, resilient, and sustainable electricity grid while supporting the nation's renewable energy targets and net-zero aspirations. For more info about CREAM please visit <https://www.singlebuyer.com.my/market/market-operations/programs/cream>.

4.3 Digital Service Tools

4.3.1 myTNB Portal and myTNB App

The myTNB Portal and myTNB App are key digital customer platforms that support customer empowerment and digital engagement, contributing to the Customer Empowerment and Satisfaction. These platforms enable customers to conveniently access electricity services, monitor their energy usage, and manage their accounts through secure, self-service digital channels.

The myTNB Portal provides customers with access to account information, electricity bills, payment history, energy consumption data, and service requests through a web-based interface. Customers can also submit applications for new electricity supply, track application status, update account information, and receive notifications on service-related matters. By digitizing these services, the portal improves operational efficiency, reduces reliance on physical customer service centres, and enhances customer convenience.

Complementing the web portal, the myTNB App offers similar functionalities through a mobile platform, enabling customers to manage their electricity accounts anytime and anywhere. The app allows users to view and pay bills, monitor electricity consumption trends, report supply issues, and access energy-saving tips. Integration with digital payment platforms further streamlines the customer experience while promoting cashless transactions.

myTNB Portal and myTNB App strengthen customer empowerment by providing customers with greater visibility of their electricity consumption and enabling informed energy management decisions. The availability of near real-time consumption information, digital self-service capabilities, and personalized notifications encourages customers to actively participate in energy efficiency initiatives and demand-side management programmes.

These digital platforms also support utility digitalization by reducing manual processes, improving service responsiveness, and facilitating two-way communication between the utility and customers. Customer interactions and usage analytics generated through these platforms enable continuous service improvements and support data-driven decision-making.

Overall, the myTNB Portal and myTNB App demonstrate TNB's commitment to digital transformation and customer-centric service delivery. By enhancing accessibility, transparency, and customer engagement, these platforms contribute to the areas of customer empowerment, digital services, operational efficiency, and smart utility management.

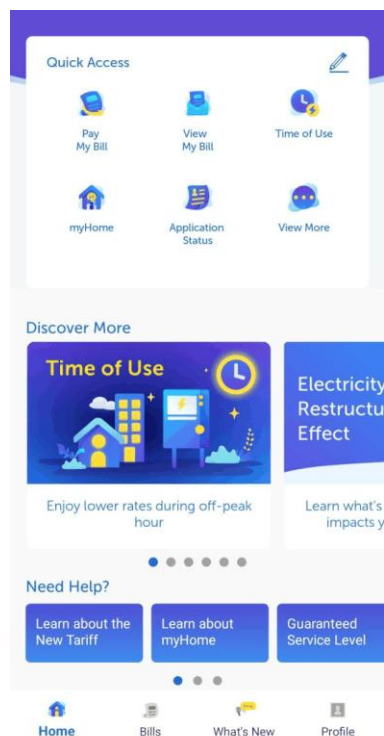


Figure 4.6: myTNB app – anytime, anywhere

4.3.2 SARA Chatbot

SARA (Smart Artificial Intelligent Retail Agent) chatbot is a digital customer engagement initiative that supports the transformation towards a smarter, more customer-centric electricity grid. SARA contributes primarily to the Customer Empowerment and Satisfaction dimension by enhancing customer accessibility, improving service responsiveness, and enabling efficient digital communication between the utility and customers.

SARA provides customers with a convenient self-service channel to obtain information and support for electricity-related enquiries. Through automated conversational assistance, customers can access services such as account-related information, application guidance, service requests, and general electricity information without the need for direct interaction with customer service personnel.

SARA enhances customer empowerment by providing customers with faster access to information and enabling them to resolve common enquiries independently. The chatbot operates through digital platforms, allowing customers to interact with the utility anytime and improving overall customer experience through quicker response times and greater service availability.

SARA also supports operational efficiency and digitalization by reducing dependency on manual customer service processes and enabling customer interactions to be handled more effectively. The chatbot can manage repetitive enquiries, allowing customer service teams to focus on more complex cases requiring personalized assistance. Data collected from customer interactions can also provide insights into common issues and customer needs, supporting continuous service improvement.

The implementation of SARA aligns with smart grid objectives by strengthening two-way communication between the utility and customers. By integrating digital technologies such as artificial intelligence (AI), automation, and data analytics, SARA enables a more responsive and intelligent customer service ecosystem.

Overall, SARA chatbot improves customer engagement, enhancing digital service delivery, supporting data-driven improvements, and promoting a more interactive relationship between the utility and its customers. It represents an important step towards achieving a smarter, more efficient, and customer-focused energy ecosystem.

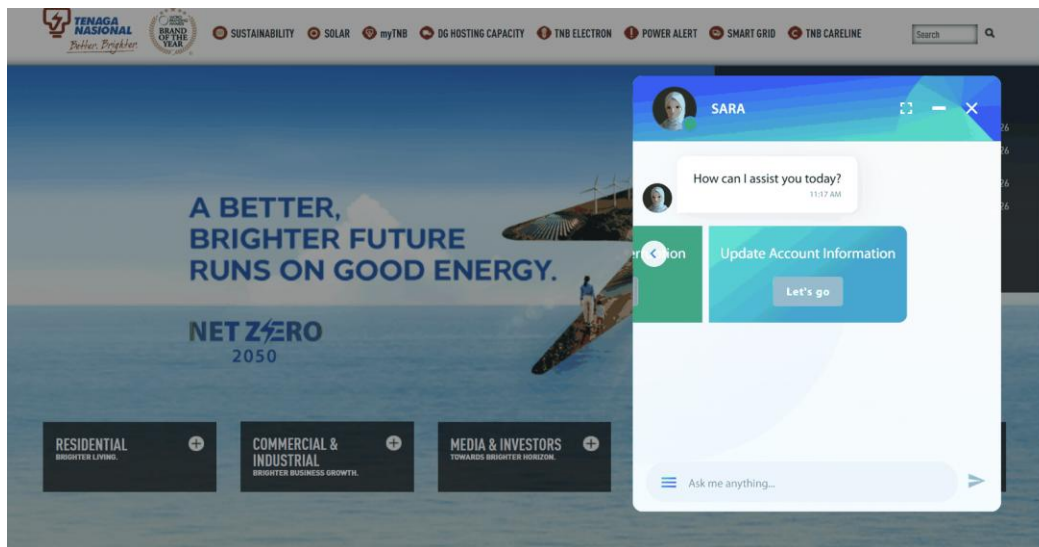


Figure 4.7: SARA Chatbot on www.tnb.com.my

4.4 Proactive Communication

4.4.1 Mobile Field Force Automation 2.0 (MFFA 2.0)

MFFA 2.0 provides the digital operational capability that enables TNB to deliver timely and accurate outage and restoration information by supplying near real-time field data to the Distribution Command Tower (DCT). The platform digitalizes the end-to-end operational workflow, from work order dispatch and field crew assignment to work progress monitoring, estimated time of arrival (ETA), restoration progress, and work completion. Through continuous synchronization of field information from mobile devices, operational updates are made available to the Distribution Command Tower (DCT) and customer service channels, enabling timely and accurate communication with customers regarding outage status, restoration progress, and service requests. This supports improved service transparency, faster responses to customer enquiries, and enhances customer experience through efficient, data-driven, and digitally enabled outage management.

The restoration workflow supported by MFFA 2.0 is described further in Section 6.3, Restoration & Recovery.

4.4.2 Power Alert

TNB's Power Alert service enables customers to check whether their area is experiencing or expected to be affected by electricity outages by searching according to state, area and date. The service helps customers stay informed of planned supply interruptions associated with TNB's preventive maintenance activities.

SUSTAINABILITY

SOLAR

myTNB

D6 HOSTING CAPACITY

TNB ELECTRON

POWER ALERT

SMART GRID

TNB CARELINE

HOME » RESIDENTIAL » POWER ALERT

POWER ALERT

In this section you can use the search function to see if your located areas will be affected by outages, helping you stay informed.

Customers in Selangor, Melaka, Kedah, Perlis, Johor and Kelantan can now view outages in a map. We will expand our reach to other states in stages. [Try it here.](#)

Power Alert

Please select a state :

Selangor

Please select an area :

Subang Jaya

Please select date :

From : 2/9/2026 To : 2/9/2026

Submit

In order to ensure uninterrupted supply to our customer, TNB carries out structured preventive maintenance program of systematic inspection, detection, correction and prevention of incipient failures before they become actual or major faults throughout the year.

No.	Sub-Area	Date & Time	Duration hr(s)	Title	Area(s) affected	Attachment	Person In-Charge
1	Subang Jaya	02/09/2026 10:00 AM	4 hr(s)	NOTIS GANGGUAN BEKALAN ELEKTRIK BANDAR KINRARA PARK NO 1	KWSN SEKITAR JALAN BK 1/1, BK 1/9, BK 1/9A, BK 1/9B, BK 1/8, BK 1/7, BK 1/6, BK 1/5, BK 1/4, BK 1/3, BK 1/2 BANDAR KINRARA (PE BDR KINRARA PARK NO 1)	Bahasa English	Careline No: 15454
2	Subang Jaya	02/09/2026 10:00 AM	4 hr(s)	NOTIS GANGGUAN BEKALAN ELEKTRIK JLN BK 4/2 BANDAR KINRARA	JALAN BK 4/6 BANDAR KINRARA, PUCHONG, 47180 (RMH NO 143)	Bahasa English	Careline No: 15454
3	Subang Jaya	02/09/2026 02:00 PM	4 hr(s)	NOTIS GANGGUAN BEKALAN ELEKTRIK SUBANG JAYA NO 13	JALAN PJS 11/12 SUBANG INDAH BANDAR SUNWAY, SUBANG JAYA, 46150 (RMH NO 5)	Bahasa English	Careline No: 15454
4	Subang Jaya	02/09/2026 11:30 PM	4 hr(s)	NOTIS GANGGUAN BEKALAN ELEKTRIK USJ SENTRAL NO 1	PREMIS YANG BERHAMPIRAN DENGAN PENCAWANG TNB USJ CENTRAL NO 1	Bahasa English	Careline No: 15454

Figure 4.8: TNB Power Alert service

4.5 Satisfaction & Sentiment

4.5.1 Customer Satisfaction Index (CSI)

Customer Satisfaction Index (CSI) is a key measure of customer experience and service quality, reflecting how effectively a utility meets customer expectations. A strong CSI score demonstrates the utility’s ability to provide reliable services, responsive support and positive customer interactions. CSI supports the Customer Empowerment and Satisfaction dimension.

TNB achieved a CSI score of 9.0 in 2025, indicating a high level of customer confidence and satisfaction with its services. This performance reflects the impact of customer-centric initiatives, including enhanced digital platforms, improved communication channels, more efficient service delivery and continued efforts to strengthen the overall customer experience.

Source: [*TNB Integrated Annual Report 2025, page 29.*](#)

The CSI result shows that customers are benefiting from greater accessibility, transparency and responsiveness. Digital platforms, self-service channels, automated support and timely service updates enable customers to access information, manage their accounts and interact with TNB more conveniently.

CSI also serves as an important tool for continuous improvement. Customer feedback helps TNB identify evolving expectations, service gaps and opportunities to enhance operational processes, service reliability and customer solutions.

A high level of customer satisfaction is also important to the wider development of the smart grid. Customer trust and engagement will support the adoption of future initiatives such as demand-side management, renewable energy integration and digital energy services.

Overall, TNB's CSI score of 9.0 demonstrates strong performance in customer experience and reinforces its contribution to the customer empowerment and satisfaction. It reflects TNB's commitment to delivering reliable, accessible and customer-focused services while advancing towards a smarter and more sustainable electricity ecosystem.

4.5.2 Reputation and Relationship Strength Index (RRSI) and Corporate Reputation Index (CRI)

Reputation and Relationship Strength Index (RRSI) of 96%, indicating sustained stakeholder trust. Customer and brand metrics also strengthened during the year. TNB was ranked the second strongest utility brand globally by Brand Finance, while the Customer Reputation Index (CRI) increased to 88% from 82% in 2024. Source: [*TNB Integrated Annual Report 2025, page 29.*](#)

4.6 Service Quality & Resolution

4.6.1 TNB Call Centre Performance

TNB CareLine has continued to strengthen its customer service delivery through improvements in both operational efficiency and resolution effectiveness, achieving an Average Handling Time (AHT) efficiency rate of 8.1 minute and a First Contact Resolution (FCR) rate of 77.6%. The AHT improvement was driven by the deployment of integrated customer engagement platforms, real-time system prompts, automated interaction summaries, and simplified documentation processes, enabling agents to access customer information and service records more efficiently

while reducing navigation and after-call work. Continuous competency development through targeted training on active listening, problem identification, and effective communication further enhanced agents' ability to accurately understand customer concerns and provide timely assistance without compromising service quality. These initiatives have enabled TNB CareLine to manage customer interactions more efficiently while maintaining a customer-centric approach and ensuring that enquiries and complaints are addressed within the expected service standards.

Simultaneously, the achievement of a 77.6% FCR rate demonstrates TNB CareLine's capability to resolve the majority of customer issues during the first point of contact, minimizing the need for repeat calls, follow-up enquiries, and escalations. Frontline agents were empowered with broader access to operational systems, knowledge repositories, and guided troubleshooting tools, allowing them to independently handle a wider range of customer issues, including billing enquiries, payment-related matters, account management requests, supply interruptions, and service-related complaints. The implementation of structured root-cause diagnostic guides and resolution frameworks also strengthened agents' ability to identify and resolve issues accurately during the initial engagement, thereby reducing customer effort and improving overall customer experience.

These achievements are further supported by the distinct yet complementary roles of TNB's customer engagement channels. The Care Management Centre (CMC) via 15454 serves as the dedicated channel for electricity supply-related matters, including power outage reports, restoration status enquiries, streetlight complaints, electrical infrastructure issues, and public safety concerns. Given the urgency associated with supply disruptions and public lighting complaints, CMC focuses on rapid incident logging, immediate escalation to Distribution Network operational teams, and continuous coordination to facilitate timely restoration and resolution. Meanwhile, the One Stop Engagement Centre (OSEC) via 1300 88 5454 functions as the primary customer touchpoint for commercial and customer service-related matters, including billing enquiries, high bill complaints, payment and collection issues, tariff-related information, metering enquiries, account management requests, and other general customer services. Through the integration of comprehensive customer information and service management capabilities, OSEC enables customers to obtain end-to-end support through a single contact channel, improving accessibility, reducing customer effort, and enhancing service consistency.

Collectively, the strong performance in AHT and FCR, coupled with the effective operation of both CMC and OSEC, reflects TNB CareLine's ongoing commitment to delivering efficient, responsive, and customer-focused services. These initiatives continue to support TNB's objective of improving customer experience, enhancing complaint resolution capabilities, reducing repeat contacts, and meeting the service expectations of customers as well as regulatory stakeholders.

DIMENSION 5: SECURITY

TNB has taken a proactive stance to enhance the cyber resilience of its Information Technology (IT) and Operational Technology (OT) systems, achieving ISO/IEC 27001:2022 Information Security Management System (ISMS) certification across various domains encompassing power generation, transmission, distribution, physical security and digital systems. These domains include critical operational platforms such as Distributed Control Systems (DCS), SCADA systems in the Control Centre, ICT data centres, and smart grid infrastructure. To ensure continuous compliance with regulatory and industry requirements, TNB undertakes regular certification renewals, security audits, and assessments.

Furthermore, TNB remains committed to strengthening cybersecurity through adherence to internationally recognized standards and best practices, including ISO/IEC 27001, Payment Card Industry Data Security Standard (PCI DSS), NIST Cybersecurity Framework, NERC-CIP, IEC 62351, ISA/IEC 62443, IEEE Standard Cybersecurity for Substation Automation, Protection and Controls Systems, and Device Language Message Specification/Companion Specification for Energy Metering (DLMS/COSEM) security specifications for Advanced Metering Infrastructure (AMI). TNB applies industry best practices for system hardening across IT and OT environments and secures smart meters and AMI systems through robust authentication and cryptographic controls.

Standards and Governance, provides the overall structure that connects all the other areas. Cybersecurity cannot depend solely on technology because organizations also need policies, procedures, responsibilities, risk management, and accountability. Cybersecurity governance is integrated into enterprise risk management processes to provide effective oversight, accountability, continuous risk assessment, and proactive management of cyber risks across the organization. In line with TNB's Digital Trust and Cybersecurity commitment, cybersecurity awareness programmes, employee training initiatives, and security campaigns are regularly conducted to foster a strong cyber-aware culture while strengthening the protection of customer, operational, and enterprise information assets.

One of the important cybersecurity areas is Unified Security Architecture, which provides the foundation for cybersecurity. A unified architecture means that security is considered across the entire IT and OT environment rather than being applied separately to individual systems. Closely connected to the architecture is Identity and Access Management, or IAM. IAM determines who or what is allowed to access systems and what they are permitted to do. This is extremely important because even a well-designed network can be compromised if unauthorized users obtain excessive privileges. To strengthen the security posture of both IT and OT environments, TNB adopts a defence-in-depth incorporating network segmentation, secure configuration baselines, Multi-Factor Authentication (MFA), Privileged Access Management (PAM), and periodic access governance reviews. These controls minimize attack surfaces, restrict unauthorized

access, prevent lateral movement across interconnected environments, and ensure that only authorized personnel are granted access to critical systems and operational assets.

However, preventing every cyberattack is difficult, so organizations also need Real-Time Threat Detection. This is the part of cybersecurity that watches the environment for suspicious activity and potential attacks. TNB maintains continuous cybersecurity monitoring and threat detection capabilities through a Security Operations Centre (SOC) supported by Security Information and Event Management (SIEM) platforms. These capabilities provide real-time visibility of cybersecurity events across IT and OT environments, enabling proactive threat detection, event correlation, incident analysis, security monitoring, and coordinated response to cyber threats. Through continuous monitoring and security analytics, TNB enhances its ability to rapidly identify, assess, and respond to evolving cyber threats while reducing cybersecurity risks across critical operational systems.

This leads to the next cybersecurity area, Resilience and Incident Recovery. Cybersecurity is not simply about preventing an attack; organizations must also be prepared for situations in which an attack succeeds, or a system fails. Resilience means that an organization can continue operating, or restore its operations quickly, despite disruption. Incident recovery involves having response plans, conducting cyber drills, and maintaining system redundancy. To ensure reliable and resilient operations, TNB maintains established cyber incident response and recovery procedures supported by business continuity planning, disaster recovery capabilities, cybersecurity exercises, tabletop simulations, cyber drills, and system redundancy measures. These capabilities enable TNB to respond effectively to cybersecurity incidents, minimize operational disruption, and restore critical services in a timely manner. Regular testing and validation activities are performed to maintain the effectiveness and readiness of response and recovery processes, ensuring the continuity of critical electricity services under various operational scenarios.

Finally, Supply Chain and Device Integrity are important because an organization's security does not end at its own network. Modern organizations depend on suppliers, contractors, hardware manufacturers, software developers, IoT devices, firmware, and other third parties. This creates additional risks because a weakness in a supplier's product or service could potentially become a weakness in the organization's own environment. Device, software, and firmware integrity controls are implemented throughout the asset lifecycle to safeguard OT assets, smart grid technologies, smart meters, and connected systems from cybersecurity risks arising from external dependencies and interconnected technologies. This measure supports the development of a secure and resilient supply chain ecosystem while maintaining the integrity, availability, and security of critical operational technologies.

Our commitment to cybersecurity has not gone unnoticed, earning us accolades and recognition:

- "Cyber Security Project of the Year 2019" at the Malaysia Cyber Security Awards 2019 presented by Cybersecurity Malaysia.
- Inclusion in the "Share Guide Association Malaysia (SGAM) IT Users Group" at the SGAM ICT Conference & Awards 2019 by SGAM.

These accolades stand as testament to our unwavering commitment to upholding the highest cybersecurity standards across our operations against the cyber threats benefitting TNB, Rakyat and Negara.

DIMENSION 6: SUPPLY RELIABILITY & RESILIENCE

6.1 Core Reliability KPIs

6.1.1 Transmission System Minutes & Equivalent Availability Factor

TNB recorded Transmission System Minutes of 0.15 minutes and performance across the generation fleet also improved, with the Equivalent Availability Factor (EAF) rising to 87.84% from 81.2% in 2024. This reduced capacity payment losses during the year and reflects ongoing efforts to optimize asset performance and operational efficiency.

Source: [TNB Integrated Annual Report 2025, page 29.](#)

6.1.2 SAIDI, SAIFI & CAIDI Performance

TNB has set an annual SAIDI target of 47–49 min/customer/year for 2026 and will continue to monitor SAIDI performance for 15 selected cities as shown below. The SAIDI cities target for 2026 is 35-40 min/customer/year.

List of cities monitored under SAIDI Cities performance:



Figure 6.1: Cities monitored under SAIDI Cities performance

TNB achieved SAIDI of 46.93 minutes/customer/year in 2025, maintaining performance below the targeted range of 47–49 minutes/customer/year. Sustaining a SAIDI level below 47 minutes

reflects TNB’s strong commitment to delivering a highly reliable electricity supply to its customers.

Achieving even a 1-minute reduction in SAIDI requires substantial investment in network infrastructure, automation, maintenance, and operational improvements. Despite these challenges, TNB successfully recorded outstanding reliability performance in several key areas. In 2025, Putrajaya achieved a SAIDI of only 5.24 minutes/customer/year, while Kuala Lumpur recorded 26.04 minutes/customer/year, demonstrating world-class supply reliability in these urban locations. These achievements are the result of TNB’s segmented, location-based reliability strategy, where improvement initiatives are prioritized according to the operational characteristics, network conditions, and reliability requirements of each area. This targeted approach enables resources and investments to be deployed more effectively, delivering the best possible reliability performance while continuously improving the overall SAIDI across the network.

SAIFI for 2025 improved to 0.95 compared to 2024, reflecting a reduction in the average number of power interruptions experienced by each customer. Meanwhile, CAIDI also improved by 1.04% in 2025 to 49.61 minutes.

As of 2025, SAIDI cities improved to 37.62 minutes/customer/year, compared to 45.10 minutes/customer/year in 2024, representing 16.6% reduction in the average duration of supply interruptions. Notably, Majlis Bandaraya Petaling Jaya recorded SAIDI of 17.47 minutes/customer/year, demonstrating an exceptional level of electricity supply reliability and reinforcing TNB’s commitment to delivering reliable power to customers in key urban centres.

The chart below illustrates the trends in SAIDI, demonstrating TNB’s continuous improvement in power system reliability over the years. The long-term SAIDI reduction trend demonstrates TNB’s continuous commitment and sustained investment in delivering a more reliable electricity supply, achieving a best-ever performance of 46.93 minutes/customer/year in 2025.

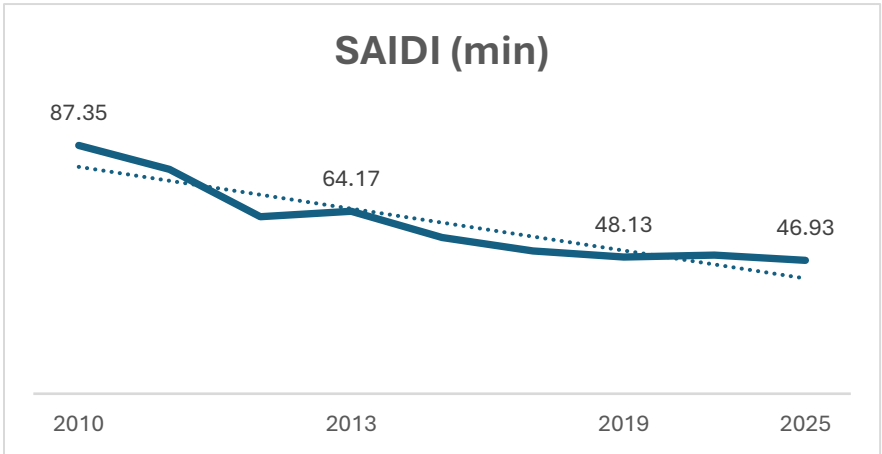


Figure 6.2: SAIDI performance trend

6.1.3 SAIDI Improvement Initiatives

To sustain SAIDI below 47 minutes, five (5) core strategies have been established, as follows:



Figure 6.3: Five core strategies for sustaining SAIDI performance

Each strategy is supported by SAIDI Initiatives as shown in Table 6.1 with respective targets for 2026.

Table 6.1: Activities for Sustaining SAIDI Performance

No.	Main Strategies	Major Initiatives
1	Potential Failure Detection	Online PD Scanning & PIDAR For MVUG Cable PD Mapping for MV Cable (OWTS) CBM For Switchgear (PMU/PPU/SSU 33kV)
2	Major Failure Prevention	Commissioning of ARC Protection
3	Asset Replacement Program	Replace MV Critical Cable Section 11kV Project Injections
4	Enhance Automation Enabler	Distribution Automation Project
5	GSL Management	Reduce Worst Performing Feeders *

*Note: Rule for determining Worst Performing Feeder: -

- For KL & Putrajaya: 2 times or more within 12 months
- For other states: 3 times or more within 12 months
- Graduate from WPF: no tripping within 6 months after last tripping date

Under Potential Failure Detection initiative, TNB is strengthening system reliability through an enhanced Condition Based Maintenance (CBM) approach. For underground cable assets, CBM leverages Partial Discharge (PD) Mapping and Online PD Detection technologies to identify early-stage insulation degradation, enabling timely intervention before failures occur. To further enhance these potential detection activities, TNB has developed a machine learning model - Advanced Asset Analytics (AAA) to predict 11kV Underground Cable breakdowns, enabling early detection of potential cable defects before failure occurs. This predictive capability supports potential detection activities by identifying high-risk cable sections for targeted inspection, testing, and corrective maintenance, thereby preventing unplanned breakdowns and improving network reliability. Detailed information on this can be found in Section 3.1.1.

In parallel, CBM activities on 33kV switchgear are being intensified to minimize defect-related flashover risks. To further prevent catastrophic equipment failures, TNB is installing arc flash protection schemes at PMUs and PPUUs. This technology enables early detection of arc initiation in AIS switchgear and provides rapid isolation of faulty sections, significantly reducing the severity and impact of flashover events. In addition, reliability improvement efforts at the 11kV level continue through targeted project injections. As part of the Asset Replacement Program, TNB is focusing on replacing ageing and high-risk installations that contribute to frequent breakdowns and large customer impacts. Priority assets include medium-voltage critical cable sections, particularly high-risk PILC and XLPE cables, as well as armoured, oil-filled, and other legacy cable types. TNB will prioritize the replacement of critical Medium Voltage (MV) section to enhance system reliability and reduce SAIDI, resulting in an overall increase in numbers of activities.

To enhance SAIDI and CAIDI performance, TNB is placing greater emphasis on reducing restoration times. This is supported through network automation initiatives enabled by SCADA/Distribution Automation (DA) systems. These systems strengthen the Network Controller's capability to execute faster fault isolation and service restoration during outage events. The deployment of Distribution Automation (DA) has significantly contributed to the improvement of CAIDI by enabling faster restoration of supply, thereby reducing the average outage duration experienced by customers.

In 2026, TNB will continue to implement targeted strategies to improve both SAIDI and CAIDI performance in selected focus areas, which have been identified as reliability hotspot zones. These strategies include the implementation of CAPEX-funded system enhancement projects, expansion of SCADA and Distribution Automation (DA) facilities at strategic locations, intensified critical maintenance activities, and strengthened cleansing initiatives under the Worst Performing Feeder (WPF) programme. Collectively, these initiatives are aimed at reducing both the frequency and duration of power supply interruptions, improving asset performance, and enhancing the long-term reliability and resilience of the electricity distribution network.

6.2 Automated FDIR & FLISR

6.2.1 Fault Location, Isolation & Service Restoration (FLISR)

Fault Location, Isolation, and Service Restoration (FLISR), a critical functionality within ADMS is designed to automatically detect, pinpoint the location of faults or disruptions in the distribution network, isolate the affected areas, and quickly restore service to minimize outage durations.

It is represented by a set of applications used for locating and isolating faults, as well as restoring power supply to de-energized customers. The applications are as below:

1. Fault Location (FL) - this application is used to quickly pinpoint a group of feeder sections where an electrical fault may have occurred. The number of sections identified as potentially containing the fault depends on the extent of fault measurement equipment installed in the network. If there are many, it can pinpoint the issue to a specific section; otherwise, it gives a broader section of where the fault might be.
2. Fault Localization (FLL) – this application provides location and isolation functionality for feeders with fewer fault location equipment installed. The FLL application feeds the Switching Sequence (SS) module with a proposed switching procedure, enabling remotely and/or manually controlled switching operations to pinpoint and isolate the faulted section.
3. Fault Isolation (FI) – the FI application provides the SS module with the faulted element or set of elements resulting from the FL/FLL analysis and isolation.
4. Supply Restoration (SR) – The SR application furnishes an optimal operational plan to reinstate service to the unaffected section of the feeder following the isolation of the faulty element. The outcome of the SR application is a series of switching sequences, prioritized based on the user's selected criteria.
5. Restore to Normal State (RN) – The RN application generates the switching sequence, detailing the operations necessary to restore the network to its normal or pre-fault state—the state it was in before the fault occurred.

Detailed information on ADMS can be found in Section 2.1.1.

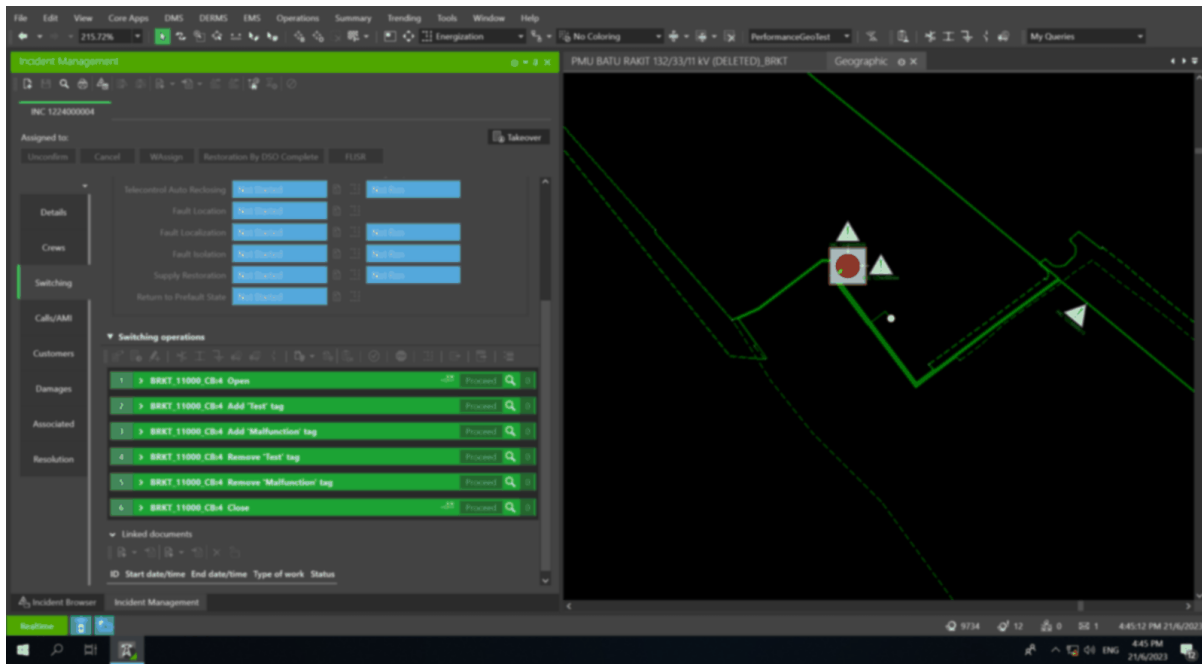


Figure 6.4: FLISR Status in ADMS

6.2.2 SCADA in DMS Functionalities

ADMS power applications like Fault Calculation, Relay Protection, and Volt Var Optimization rely on estimated current derived from the State Estimation (SE) function. The SE is used to assess (estimate) the distribution network state considering:

1. Remotely monitored data (SCADA) such as breaker status, current & voltage measurements, tap changer positions, etc.
2. Initial load data which is derived from the load curves given in the model or from the previous estimated state

The model incorporates various measurements, including voltage magnitudes of MV busbars, current, and real and reactive power measurements from distribution transformers. These measurements also encompass results from EMS State Estimation (from TNB) for boundary nodes between EMS and DMS networks, such as estimated voltage magnitude and phase angle, as well as injected real and reactive power. These estimation procedures rely heavily on real-time telemetry redundancy and the availability of switchgear statuses provided by SCADA systems.

6.2.3 SCADA in Outage Management System (OMS) Functionalities

Through SCADA signals, the Outage Management System (OMS) receives reports on forced outages, leveraging SCADA information such as breaker status to pinpoint faulted sections of the network. Additionally, the OMS provides estimated power loss based on Distribution Management System (DMS) analytics, offering comprehensive reports detailing affected transformers, customers, load loss, and other pertinent information.

This integrated service shares information with TNB's work management system i.e. MVORR, empowering crews with incident details. Crews can then provide updates on the incidents as they work on restoration efforts. Furthermore, the OMS generates restoration switching sequences for Fault Location, Isolation, and Service Restoration (FLISR) and force outages. This collaborative ecosystem enhances the restoration process significantly.

6.2.4 Special Protection Scheme (SPS) for Automated System Integrity Protection

TNB has implemented Special Protection Schemes to protect the transmission system against severe but credible contingencies that cannot be adequately managed through conventional protection, normal network redundancy or operator intervention alone. SPS provides a coordinated, high-speed system-integrity defence capability that detects defined network conditions and automatically executes predetermined remedial actions before the disturbance escalates into instability, cascading tripping or widespread supply interruption.

Unlike conventional protection, which primarily isolates individual faulty equipment, SPS assesses conditions across a wider area of the power system. It combines electrical measurements, equipment status and predefined system logic to determine whether a major contingency has occurred or whether the network is approaching an unacceptable operating condition. Depending on the scheme design, SPS may initiate corrective actions such as selective generation tripping or de-loading, load reduction, transmission-line tripping, transfer switching or network reconfiguration.

TNB has progressively developed multiple SPS applications since 2010 to manage system-specific risks across different parts of the transmission network. As the grid expanded, the schemes evolved from relatively independent applications into a more interconnected network of detection, communication and mitigation functions. Changes to generation dispatch, transmission topology, renewable-energy connections and other grid facilities may therefore affect how an existing SPS performs.

Because SPS is required to remain available for system security, complete end-to-end testing on the live network is difficult and may not be operationally acceptable. Testing only the modified portion of a scheme may also leave hidden logic, communication or system-interaction issues undetected. To strengthen SPS testing and assurance, TNB developed an integrated SPS Digital Twin and real-time simulation capability in 2022. The platform reproduces the electrical network, SPS devices, control logic and communication behaviour in a controlled environment so that existing schemes, modifications and new system conditions can be tested without exposing the operational grid to unnecessary risk.

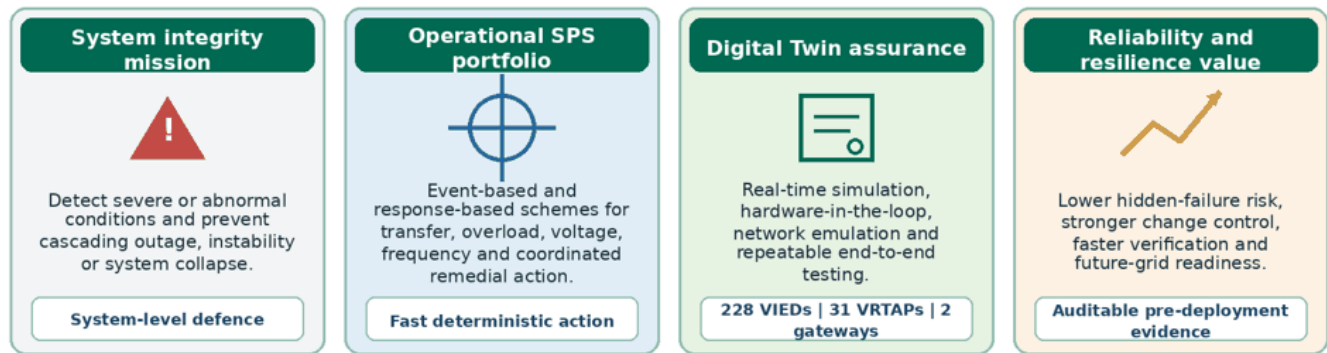


Figure 6.5: Overview of SPS capability and Digital Twin assurance

The principal capability of SPS is its ability to respond automatically to a major system event within a timeframe that cannot be achieved through manual control-room intervention. Measurements and equipment-status information are collected from selected locations across the network and processed through coordinated SPS logic. When the predefined operating criteria are satisfied, remedial commands are issued to the appropriate field equipment.

This provides a system-level self-healing capability. Rather than waiting for the disturbance to propagate or for an operator to manually assess and respond, SPS takes immediate and coordinated action to arrest the event and maintain the remaining power system within a stable operating condition.

SPS also integrates protection and control functions across transmission lines, substations, generation facilities and other critical network interfaces. This allows a single scheme to consider the combined condition of several geographically separated assets rather than relying only on local measurements.

The coordinated approach is particularly important for contingencies involving multiple outages, excessive power transfer, generation loss, voltage instability or other events where the consequence extends beyond a single item of equipment. SPS therefore strengthens the grid's ability to withstand abnormal system conditions and prevents local disturbances from developing into larger system events.

The SPS Digital Twin provides a controlled environment for testing the complete operating chain—from the initial network contingency, through SPS detection and communication, to the final corrective action. The acceptance programme verified the operation of 228 virtual protection and control devices, 31 virtual SPS processing platforms and two virtual acquisition and control gateways. It also compared the responses of physical and virtual devices and verified several operational SPS representations under simulated system conditions. This capability allows engineers to repeat tests under controlled conditions, vary system parameters, introduce

communication delays and reproduce complex contingencies that would be difficult or unsafe to create on the live network.

The simulation environment can also represent emerging power-system technologies and changing network characteristics. Models developed for the platform include renewable generation, battery energy storage, HVDC systems, flexible AC transmission devices, load variation and other future-grid elements. This enables TNB to assess how new generation sources, inverter-based resources and changing power-flow patterns may interact with existing SPS functions before actual implementation. The capability therefore supports renewable-energy and BESS readiness while maintaining appropriate system-integrity protection.

The operational SPS acquires real-time electrical measurements and equipment-status signals from selected substations, transmission lines and generation interfaces. These inputs are processed through coordinated SPS logic to detect predefined high-impact contingencies. When the required conditions are confirmed, the scheme automatically issues remedial commands such as generator or load reduction, circuit-breaker operation or network reconfiguration to prevent instability, cascading tripping or widespread supply interruption.

The SPS Digital Twin reproduces the same end-to-end operating chain in a controlled real-time simulation environment. Validated network models generate realistic disturbances, while virtual or physical SPS devices, processing platforms, gateways and communication models respond as they would in the live system. The resulting corrective actions are returned to the simulated network so that their timing, effectiveness and overall system impact can be assessed.

Beyond monitoring and post-event analysis, the Digital Twin supports new scheme development, modification testing, hardware-in-the-loop verification, troubleshooting, regression testing and assessment of future-grid conditions. It enables TNB to evaluate renewable generation, BESS, changing power flows, communication delays and equipment unavailability before implementation, thereby reducing hidden failure risk and strengthening confidence in SPS performance.

Multiple SPS applications are operational at selected strategic transmission areas to manage defined high-impact contingencies and prevent instability, cascading tripping or major supply interruption. The schemes are supported by established protection, control, communication and monitoring infrastructure across the relevant substations, transmission corridors and generation interfaces.

The SPS Digital Twin and real-time simulation platform were completed and formally accepted in 2022. The platform has since been used for pre-installation simulation, testing of new and modified schemes, hardware-in-the-loop verification, troubleshooting and assessment of changing network conditions.

Overall, SPS is an established operational grid-protection capability, while the Digital Twin provides the supporting engineering environment for scheme development, validation and performance assurance. Together, they strengthen TNB's ability to maintain reliable SPS operation as the transmission network evolves.

SPS improves supply reliability and resilience by detecting severe system contingencies and executing coordinated corrective actions faster than manual intervention. This reduces the risk of instability, cascading tripping and widespread supply interruption, while helping the remaining network continue operating securely.

The Digital Twin strengthens SPS performance by enabling end-to-end testing under realistic and repeatable conditions without exposing the live grid to unnecessary risk. It supports earlier detection of logic errors, communication issues and unintended system interactions, reduces dependence on partial field testing and provides clearer evidence for design acceptance, commissioning and troubleshooting.

The combined capability also improves readiness for renewable generation, BESS and other future-grid technologies by allowing their impact on existing SPS to be assessed before implementation.

6.2.5 Automatic Fault Analysis (AFA)

When a fault occurs on the transmission system, prompt fault detection and diagnosis are critical to minimizing downtime and reducing the costs associated with repairs and maintenance of transmission-line assets. Prior to AFA, the fault-analysis process could be time-consuming and rely heavily on human expertise. To make fault detection and analysis more efficient, TNB successfully developed an Automatic Fault Analysis (AFA) software tool that can automatically identify fault locations and support performance-data analysis. AFA functions include automated collection of disturbance-related data, synchronization of time-domain data, determination of fault location and automated fault analysis. Most importantly, AFA captures data during a disturbance and sends a notification to the system operator almost immediately after the fault.

AFA has proven to provide the following benefits:

1. Reduced outage times with accurate fault location.
2. Lower line patrol costs.
3. Increased productivity by automating data compilation tasks, which expedite detailed event analysis.
4. Increased system resilience, by performing structured verification of protection systems.

6.3 Restoration & Recovery

Where field intervention is required, TNB uses MVORR and MFFA 2.0 to support restoration and recovery activities, complementing the automated restoration capabilities described in Section 6.2. In addition, TNB maintains black start capability through designated gas and hydro generating plants, as well as the Santong Battery Energy Storage System (BESS), to support wider system recovery following major disturbances.

6.3.1 MVORR and MFFA 2.0

MVORR (Medium Voltage Operation Recovery & Repair System) and MFFA (Mobile Field Force Automation) 2.0 are digital operational platforms developed to support restoration and recovery activities across TNB's medium and low-voltage distribution networks. The solutions digitalize field operation processes, improve coordination between Distribution Command Tower (DCT) and field crews, and provide real-time operational visibility throughout restoration activities. By supporting efficient work execution and resource coordination, the platforms contribute to faster service restoration and improved network resilience during planned and unplanned outage events.

MVORR manages the end-to-end operational workflow for medium-voltage restoration activities, including isolation, fault location, repair, joint work, and network normalization. Through digital work order management and continuous work status monitoring, Operation Commanders can effectively coordinate restoration activities and optimize resource deployment. This aligns with MVORR's role in supporting DCT operations for centralized management of planned and unplanned medium-voltage work.

MFFA 2.0 complements these capabilities by supporting low-voltage field operations through digital work order dispatch, field crew management, real-time progress monitoring, and operational information updates. Continuous synchronization of field information improves situational awareness and enables more effective coordination during restoration activities.

Together, MVORR and MFFA 2.0 establish an integrated digital workflow that improves operational coordination, optimizes resource utilization, supports faster restoration of electricity supply, and enhances the resilience and reliability of TNB's distribution network.

MFFA 2.0 integrates Distribution Command Tower (DCT) operations with field workforce through a digital work management platform. Customer complaints and operational requests are converted into digital work orders, which are dispatched to field crews through mobile devices. Field personnel continuously update work progress, estimated time of arrival (ETA), restoration progress, work completion, and operational findings from site. The information is synchronized

with DCT in near real-time, providing operational visibility and supporting customer service communication. This establishes a connected digital workflow from work assignment to service restoration while improving operational efficiency and customer experience.

MVORR digitalizes medium-voltage restoration processes by integrating work planning, resource management, field execution, and work monitoring into a single operational platform. Operation Commanders create and assign digital work orders covering isolation, fault location, repair, joint work, and network normalization. Field crews update work progress continuously through mobile devices, enabling real-time monitoring of restoration activities, operational coordination, and resource deployment. This creates a structured digital workflow that supports faster restoration and improved operational decision-making.

MFFA 2.0 and MVORR have been deployed to support Distribution Command Tower (DCT) operations across low- and medium-voltage networks. MFFA 2.0 is operating nationwide as a Business-as-Usual (BAU) platform for low-voltage field operations, while MVORR supports medium-voltage operation and restoration activities. Together, the platforms enable digital work management, field workforce and resource coordination, planned and unplanned work execution, customer complaint restoration, and broader operational restoration processes.

MFFA 2.0 and MVORR deliver value by digitalizing field workforce and restoration management across low- and medium-voltage operations. MFFA 2.0 enhances customer complaint restoration through faster work dispatch, improved coordination between DCT and field crews, timely operational information, and better customer communication, while MVORR strengthens medium-voltage restoration through real-time work monitoring, resource optimization, and structured restoration processes. Together, the platforms improve operational efficiency, accelerate restoration of electricity supply, enhance service transparency and customer experience, optimize resource utilization, and support a more resilient, reliable, and digitally enabled distribution network.

6.3.2 Gas and Hydro Plant Black Start Capability

TNB has established and maintains Black Start capability across its designated hydroelectric and gas-fired power plants as part of its commitment to ensuring the secure and reliable operation of the Peninsular Malaysia Electricity Supply System (PMES). The Black Start capability enables selected generating units to start independently without relying on external electrical supply. This provides the initial generation source required to restore the transmission network following a total or partial system blackout. These generating units form an integral part of the System Restoration Plan coordinated by the Grid System Operator (GSO).

One of the main capabilities of the Black Start generating unit is System Restoration Capability. This includes starting without external grid supply, energizing transmission lines and substations, providing auxiliary supply to other generating stations, supporting sequential restoration of additional generating units. The capability also supports the establishment of voltage and frequency reference during system restoration, as well as progressive restoration of customer loads under the direction of the GSO. This coordinated restoration process enables secure recovery of the interconnected power system following a major system disturbance.

Hydroelectric generating stations provide rapid initial generation due to their short start-up time, while gas-fired generating stations provide additional generation capacity to accelerate restoration of the interconnected transmission network.

Selected generating units are equipped with dedicated Black Start systems, including emergency diesel generators for auxiliary power supply, DC battery systems for protection, control and instrumentation, independent station service arrangements, generator excitation systems, protection and control systems, communication systems for coordination with GSO and operational procedures supporting autonomous plant start-up and synchronization.

The implementation extends across the Peninsular Malaysia Electricity Supply System (PMES) and supports the restoration strategy developed by the GSO. The distributed geographical locations of hydro and gas generating stations provide strategic advantages in restoring multiple grid or network islands, improving restoration flexibility, reducing restoration time and enhancing overall system resilience following widespread disturbances.

Black Start capability is equipped at designated hydroelectric and gas-fired power plants within the TNB fleet. The available station list includes JOR, WOH, Ulu Jelai, Kenyir, Hulu Terengganu, Temenggor and Pergau.

The facilities are maintained in accordance with plant maintenance programmes and operational procedures to ensure continuous readiness. Annual Black Start assessments and performance

verification exercises are conducted to evaluate the availability, reliability and operational readiness of generating units, auxiliary systems and supporting equipment.

The assessment includes verification of start-up sequence, auxiliary supply readiness, synchronization capability, communication systems, operational procedures and compliance with the restoration strategy established by the GSO.

The implementation of Black Start capability delivers operational value to the Peninsular Malaysia Electricity Supply System in terms of reliability, flexibility, security and resilience.

For reliability, Black Start capability enables rapid restoration of generating units following widespread outages, reducing restoration time and improving continuity of electricity supply. In terms of flexibility, the distributed locations of hydroelectric and gas-fired Black Start units allow multiple restoration paths to be initiated simultaneously. Hydroelectric plants provide fast-response initial generation, while gas-fired stations contribute additional generation capacity and system support.

For resilience, Black Start capability enables autonomous restoration without dependence on external supply, progressive re-establishment of transmission infrastructure, safe synchronization of generating units, controlled restoration of customer loads and faster recovery of critical infrastructure. Overall, it supports a secure, resilient and future-ready electricity network for Malaysia's energy transition.

6.3.3 BESS Black Start (Santong)

The Santong BESS is a 100 MW / 400 MWh grid-connected installation developed by TNB as a strategic asset to strengthen system reliability, support renewable integration, and validate advanced grid-forming and black start capabilities in real operation. Built on a compact site in Terengganu, it employs modular liquid-cooled battery units and power conversion systems designed for high round-trip efficiency and robust grid support functions.

The project marks Malaysia's Grid-Forming Connected BESS. With commissioning completed, the Santong BESS has transitioned from construction and testing into operational service, and TNB is now focusing on post-commissioning activities such as structured lessons-learned and specification updates to ensure that future BESS projects can benefit from this experience while acknowledging that new BESS deployments are subject to ST's regulatory processes.

Santong BESS is engineered as a grid-forming BESS, meaning its inverters can act as voltage sources that establish and regulate frequency and voltage on an otherwise de-energized bus, rather than merely following an existing grid waveform. This enables autonomous black start capability: the plant can start from a dead-grid condition, energize its transformers and local bus,

and prepare to pick up designated loads or support restoration of a wider network segment under controlled conditions.

Beyond black start, the BESS provides a suite of operational capabilities:

1. Fast frequency response and inertia-like support, stabilizing frequency during large disturbances and high renewable penetration periods.
2. Voltage regulation and reactive power support, improving local voltage profiles and contributing to system stability at the point of interconnection.
3. Peak shaving, congestion management and renewable smoothing, using its 400 MWh energy capacity to shift energy and mitigate variability from solar and other resources.

Collectively, these capabilities position Santong BESS not only as an energy storage asset but as an active grid support resource, capable of operating both grid-connected and in islanded/grid-forming modes as required by system conditions.

During black start operation, the data flow becomes critical: the black-start controller in coordination with the Facility Energy Management System (FEMS) controller, executes predefined sequences, uses feedback from voltage and frequency measurements to adjust its grid-forming output, and exchanges signals with protection and grid operator systems to manage energization steps and synchronization back to the main grid when ready. This architecture underpins both safe operation and the detailed performance logging now used in the post-commissioning review.

Santong BESS has completed its development, construction, testing and commissioning phases and is in active operation. The project has successfully demonstrated plant-level grid-forming operation and black start capability under controlled test conditions, including energization of transformers, establishment of a stable islanded microgrid, and transitions between grid-connected and islanded modes.

Santong's value can be viewed across technical, operational and strategic dimensions.

1. Technical and operational value

- It demonstrates in practice how a grid-forming BESS can provide black start capability, fast frequency response, voltage regulation and other essential grid services, offering a new tool for system restoration and resilience.
- It provides real data on dynamic performance, control interactions and protection behaviour that can be fed back into models, standards and planning assumptions, improving the accuracy of future studies and designs.

2. Strategic and governance value

- Santong BESS serves as a proof that advanced storage technologies can be integrated into a regulated grid under ST's oversight, supporting national energy transition goals while maintaining system security.

- The structured post-commissioning review and specification updates position TNB as technically prepared to handle future BESS projects, ensuring that when such projects arise through regulatory or market mechanisms, TNB has a mature reference and clear expectations for performance, safety and operability.

3. Future impact

- Through lessons learnt from Santong BESS' black start and grid-forming operation, TNB builds institutional knowledge that will be critical as more inverter-based resources and storage systems connect to the grid under ST's evolving frameworks.
- This approach helps ensure that future BESS deployments, wherever they originate, are evaluated and integrated against a tested, experience-based standard, rather than treated as isolated experiments.



Figure 6.8: BESS Santong 100MW/400MWh

6.4 Network Redundancy

6.4.1 Network Redundancy and N-1/N-2 Security Criterion for HV Grid

TNB applies the Grid Code of Peninsular Malaysia (GCPM) and Transmission System Reliability Standards (TSRS) as key technical frameworks for maintaining the security and reliability of the transmission system. These frameworks establish the planning, operational and performance requirements used to ensure that the network is developed with sufficient robustness to meet electricity demand under both normal operating conditions and credible contingency events.

As part of transmission planning, network performance is assessed against defined reliability criteria, including N-1 contingency requirements, to determine whether the system can continue operating securely following the loss of a single transmission element such as a circuit, transformer or other critical network component. The assessment supports the identification of potential constraints and the need for network reinforcement, alternative supply paths or other mitigation measures where required.

Through the application of these standards, TNB can plan transmission expansion and connection requirements using consistent engineering criteria, strengthening network redundancy and reducing the risk of widespread supply interruption following individual asset outages. The approach also provides a structured basis for accommodating new generation and emerging technologies while maintaining the reliability and resilience of the Grid System.

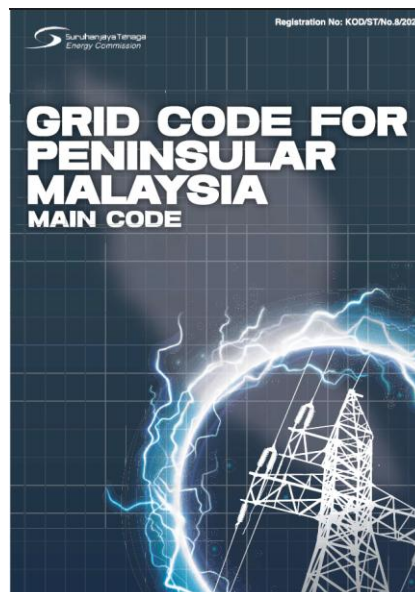


Figure 6.9: Grid Code for Peninsular Malaysia by Energy Commission

Grid Code for Peninsular Malaysia by Energy Commission. Full document can be found [here](#)

6.4.2 Network Redundancy and N-1/N-2 Security Criterion for MV Network

In addition to monitoring supply reliability through SAIDI and SAIFI, TNB also places significant emphasis on network redundancy to enhance the resilience and security of the distribution network. One of the key planning principles adopted is the N-1 security criterion, whereby the network is designed to continue supplying electricity to customers even in the event of the failure or outage of a single critical network component such as a transformer, feeder or transmission line without resulting in widespread supply interruption.

The implementation of the N-1 criterion enables TNB to minimize the impact of planned maintenance activities and unplanned equipment failures by allowing supply to be restored through alternative network configurations or backup supply sources. This planning philosophy not only improves supply continuity and operational flexibility but also enhances the overall resilience of the electricity network against equipment failures, extreme weather events and other unforeseen contingencies.

This planning approach is aligned with the requirements of the Distribution Code, which requires the distribution system to be planned and developed to achieve an acceptable level of security, reliability and continuity of supply while taking into consideration technical, operational and economic factors.

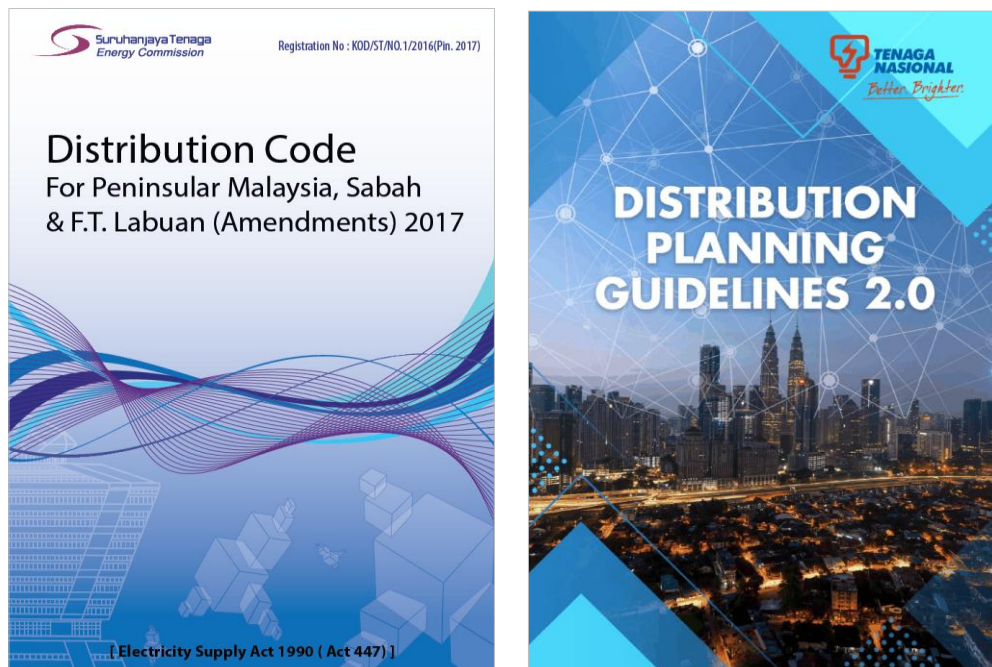


Figure 6.10: Distribution Code for Peninsular Malaysia, Sabah & FT Labuan (Amendments) 2027 by Energy Commission & Distribution Planning Guidelines Version 2.0 by Tenaga Nasional Berhad

To ensure consistent implementation of the Distribution Code requirements, TNB has established the Distribution Planning Guidelines, which provide standardized planning criteria for the development and reinforcement of the distribution network. The guidelines require the 33kV distribution backbone network to be planned based on a 2-1-2 system configuration- to provide N-2 security criterion and enhancing network redundancy. Similarly, the 11kV distribution network is planned to meet the N-1 security criterion ensuring that the loss of a single network component does not result in prolonged interruption to customer supply, wherever technically and economically practicable.

These planning criteria establish the foundation for a resilient and secure distribution network enabling Distribution Automation (DA) and Advanced Distribution Management System (ADMS) to perform effective fault isolation, network reconfiguration and service restoration. Consequently, the integration of network redundancy with smart grid technologies contributes to improved supply reliability, operational flexibility and enhanced customer service.

6.5 Climate & Physical Hardening

6.5.1 Climate Analysis and Risk Assessment (CLARA)

As climate change continues to increase the frequency and severity of extreme weather events, TNB is strengthening the resilience of its electricity distribution network through the Climate Analysis and Risk Assessment (CLARA) initiative. Developed as part of TNB's climate resilience programme, CLARA provides a systematic approach to identifying distribution assets that are exposed to climate-related hazards and assessing their vulnerability to future climate scenarios. The initiative supports TNB's sustainability agenda and aligns with the National Energy Transition Roadmap (NETR) by enhancing the resilience of critical electricity infrastructure against climate risks. CLARA integrates climate hazard modelling with geospatial asset information to evaluate the potential impact of hazards such as riverine flooding, coastal inundation, extreme wind, extreme heat and soil movement on Distribution Network assets. The outcome enables proactive planning, prioritization of mitigation measures and more informed investment decisions to safeguard network reliability under changing climate conditions.

The initiative adopts internationally recognized climate risk assessment principles aligned with ISO 14091, incorporating both current and future climate scenarios to identify high-risk assets and establish appropriate adaptation strategies. By leveraging GIS technology, climate science and engineering data, CLARA supports TNB's transition from reactive asset management towards a predictive and risk-informed climate resilience framework.

Flood Analysis and Risk Assessment (FARA 2.0)

As the first phase of TNB's climate resilience implementation, Flood Analysis and Risk Assessment (FARA 2.0) is currently being developed as an initiative to focus on strengthening the Distribution Network's resilience against flood-related risks, which remain the most frequent and impactful climate hazard affecting electricity infrastructure in Malaysia. By establishing a GIS-based flood risk assessment and early warning platform, FARA 2.0 provides the foundation for integrating climate risk into asset management and operational decision-making. The geospatial capabilities and analytical framework developed through FARA 2.0 also serve as key building blocks for the broader CLARA initiative, which expands the assessment to multiple climate hazards under both current and future climate scenarios.

FARA 2.0 is the enhancement of FARA 1.0, and this new system will replace the current FARA 1.0 system by merging and integrating all relevant TNB data assets within the TNB GIS platform with data from multiple sources, ensuring compliance with TNB ICT standards. FARA 2.0 consists of four modules:

1. Module 1 (Flood Analysis) - Analyse flood risks associated with substations, leveraging up-to-date GIS data and historical records. It helps identify substations at high risk of flooding, assess flood-prone areas for new substations, and ensure infrastructure safety and preventive planning.
2. Module 2 (Flood Forecasting) - Use weather data to analyse the potential flood risks for substations.
3. Module 3 (Flood Alert) - Provides notifications based on water levels and rainfall data from National Flood Forecasting and Warning System to TNB Flood Forecasting and Warning (Pusat Ramalan dan Amaran Banjir, DN (PRABDN)), ensuring that immediate action can be taken for substations in flood prone areas.
4. Module 4 (Flood Reporting) - Provides reporting of the flood situation and substation status. It includes an interactive dashboard that displays flood related data by area.

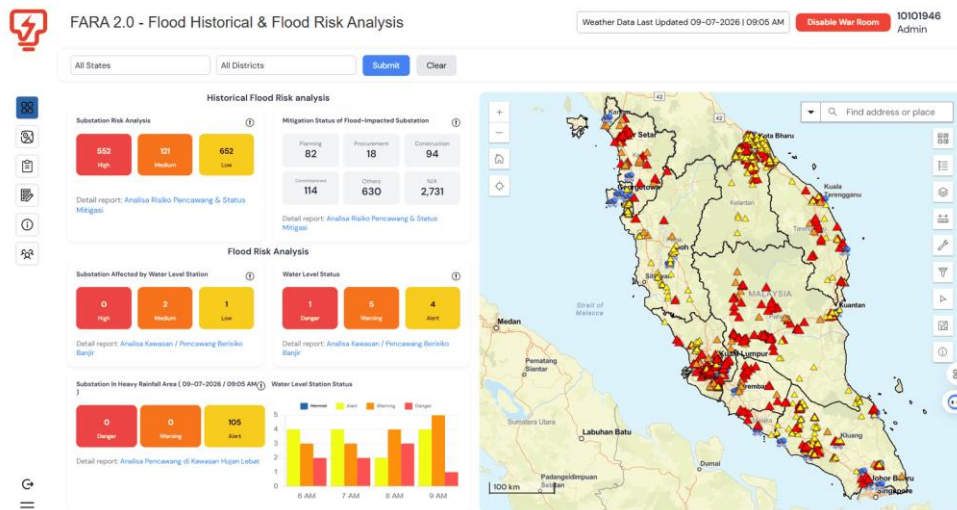


Figure 6.11: FARA 2.0 Home Page Dashboard

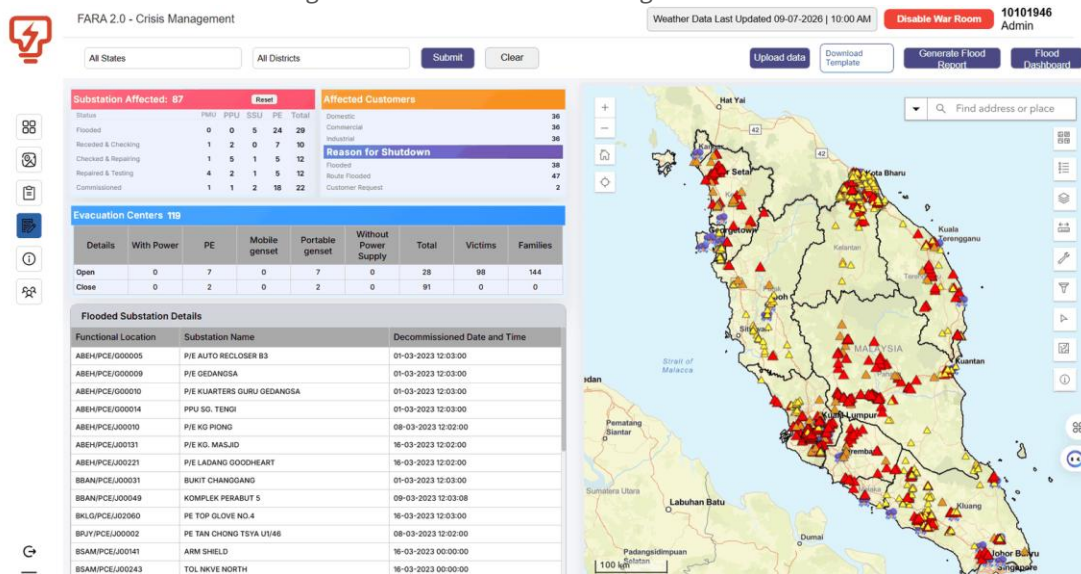


Figure 6.12: FARA 2.0 Crisis Management Dashboard

One of the main capabilities of FARA 2.0 is risk identification where it can systematically analyse and identify substations that are vulnerable to flood, ensuring infrastructure safety and allows early preventive planning. Besides that, it adapts real-time forecasting and alert by providing timely flood forecasts and warnings that enables field crews to take immediate action and as a result, could minimize potential damage.

Another important capability is the part where the system produces efficient reporting. It streamlines and facilitates efficient communication from the flood operation room and management, ensuring coordinated responses and information dissemination during flood events. Those who have been given access, can view and download the reports they are interested directly from the system.

FARA 2.0 is also supported with informative dashboards. These dashboards provide visibility of current flood event that is happening where users could monitor substation and temporary

evacuation centre statuses. After a flood event, operation team can update substation mitigation statuses in order to support continuous progress monitoring for future improvements. Together, these tools create a more connected workflow from active flood events to action plans.

The system architecture depicted is designed for the FARA 2.0 platform, a comprehensive flood analysis and forecasting system. It integrates ArcGIS Enterprise with various data sources, including subscription information, flood analysis data, and weather forecasts. The architecture leverages a geodatabase and FARA 2.0 application to process and analyse data, producing outputs like flood analysis, forecasting, and reports. Data inputs range from historical flood data and river basin information to real-time weather updates. This system aims to provide actionable insights for flood management and warning systems.

Implementation of FARA 2.0 is progressing as a nationwide roll-out for substations flood analysis, forecasting, alert, and reporting. The project includes the deployment and analysis of high-risks and potential risks of substations, early warnings on flood alerts, and effective reporting on flood events in order to support operational updates.

The implementation has also introduced a more structured way to manage past flood events by making enhancements wherever possible. Potential risk substations can be identified earlier, monitoring can be prioritized more effectively, and improvement activities can be guided by forecasting insights. This helps to improve coordination, reduce dependency on manual assessment, and strengthen the overall decision-making process.

The value of FARA 2.0 lies in its ability to strengthen the climate resilience of TNB's distribution network through improved flood risk management and data-driven decision-making. By identifying substations that are vulnerable to flooding at an early stage, FARA 2.0 enables better control of flood-related incidents, supports proactive asset enhancement initiatives, and improves the prioritization of maintenance and infrastructure improvement works. This allows operational resources to be focused on higher-risk areas, increasing operational efficiency while enhancing the resilience of critical electricity infrastructure against the growing impacts of climate change.

In addition, FARA 2.0 contributes to improved power supply reliability and customer experience by enabling preventive measures before flood events occur. Early identification of flood-prone substations helps to reduce the likelihood of prolonged power interruptions caused by sudden equipment shutdowns, flashovers, or asset failures during extreme weather conditions. This proactive approach strengthens network resilience by minimizing service disruptions and enabling more effective responses to flood events.

Overall, FARA 2.0 provides TNB with a smarter and more forward-looking approach to managing flood risks and building a more resilient electricity distribution network. By integrating predictive analytics and operational workflows into a single platform, it enhances situational awareness,

supports informed decision-making and drives the continuous improvement of asset resilience, operational readiness, and network performance in an increasingly climate-challenged environment.

6.5.2 THyCAS Hydro Dam Slope Monitoring

TNB Hydro Catchment Area Surveillance (THyCAS) Hydro Dam Slope Monitoring was developed for hydro power stations to digitally monitor vast catchment areas. THyCAS was established and utilized by TNB in collaboration with the Malaysian Space Agency (MYSA). The initiative uses space-based technology, remote sensing, a Geospatial Information System (GIS) and ICT to support monitoring of TNB hydro dam catchment areas. It has been used in Perak, Kelantan, Pahang and Terengganu.

One of the main capabilities of THyCAS is digital monitoring of hydro catchment areas using geospatial data, high-resolution satellite images and Unmanned Aircraft System (UAS) datasets. The geospatial database is updated monthly with current high-resolution satellite images and data collected using UAS technology. The system can support critical slope monitoring, including rapid landslide crisis assessment and critical slope assessment using the Critical Slope Monitoring module.

THyCAS functions can also be used for area measurement, slope profiling, land clearing detection, deforestation detection and encroachment detection using the latest images. The initiative also supports baseline mapping using UAS, with MYSA guiding the TNB team.

THyCAS uses remote sensing-based applications and a spatial database to monitor overall hydro catchment areas. MYSA provides and manages infrastructure, satellite images, hardware, software, researchers and space technologies for TNB utilization.

Satellite images are obtained through the Satellite Data Receiving Station, while high-resolution satellite images are obtained from overseas data suppliers. These images are processed and enhanced at MYSA Headquarters according to user specifications.

For slope monitoring, the initiative identifies areas of interest for baseline mapping using UAS and supports a 3D web application. The expected outcome is improved catchment area surveillance, enhanced slope monitoring capability and better support for hydro dam-related crisis assessment.

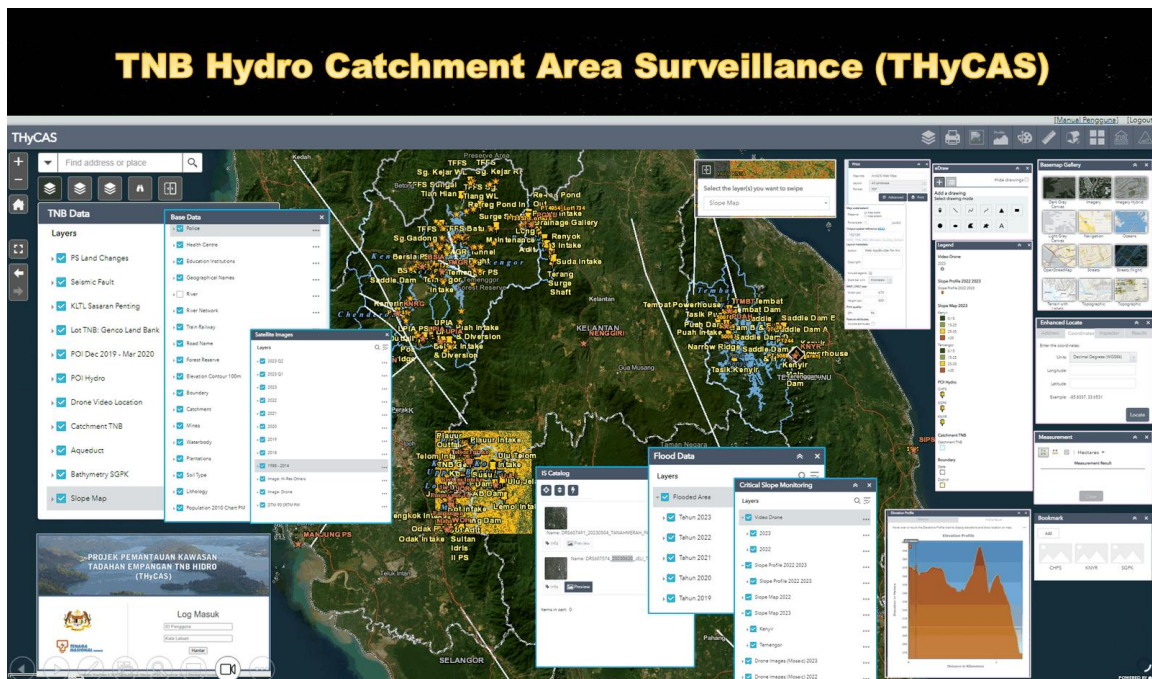


Figure 6.14: THyCAS Online Application

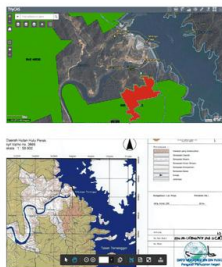
THyCAS started at Sungai Perak (SGPK) in 2018 and was subsequently extended to Kenyir (KNYR) and Cameron Highland (CHPS). The THyCAS module was developed in 2018 and has grown according to TNB requirements.

For Critical Slope Monitoring, hydro stations implement slope monitoring using space-based technology. Under the current status, the Critical Slope Map is listed as Business as Usual (BAU).

THyCAS outcomes since establishment until now



Approved Logging Permit at TMGR (2019)



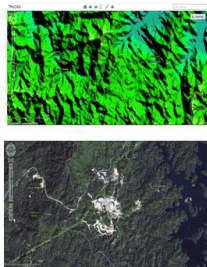
Approved Logging Permit near to TMGR Main Dam.

Dam integrity may jeopardize. Road repairs costly.



Logger to change the logging area & concession permit.

PGAU Lake Water Quality (2020)



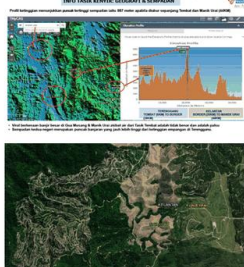
District Officer Jeli claimed dirty water came from Tasik Temengor.

Banjaran Titiwangsa separates between Jeli & Gerik.



PGAU updates D.O. Jeli this was resulted from SKS Plantation activities.

Manik Urai Flood (2021)



Viral news flood caused by Tembat Lake overflows.

Banjaran Titiwangsa separates between Kelantan & Terengganu.



Engagement with MB Kelantan & MB Terengganu. Resolved 2014 pending issues.

Encroachment Development (2022)



Permanent Structure at KNYR Saddle Dam A.

Saddle Dam integrity at stake. Risk to public. Argument of implied consent.



Further discussion with Terengganu state government.

KNYR Landslide Drone Mapping (2022)



KNYR Landslide aerial images and area surveillance.

MYSA delivered images & analysis within 3 days.



Data shared with ES-Hydro for crisis management.

Figure 6.15: THyCAS Critical Slope Monitoring

The value of THyCAS Hydro Dam Slope Monitoring is seen through improved hydro catchment area surveillance, slope monitoring capability and crisis response support. During the landslide incident at Sultan Mahmud Kenyir Power Station, THyCAS was used to generate findings and crisis assessment in less than three days, enabling recovery action and early risk assessment by TNB management and relevant national-level stakeholders.

6.5.3 Centralized Online Monitoring of TNB Power Plants

Centralized Online Monitoring is TNB's enterprise-wide digital asset monitoring capability established to enhance fleet reliability, improve operational performance, and strengthen asset reliability through centralized engineering surveillance.

The platform consolidates operational data, predictive analytics, engineering expertise and asset health intelligence into a single monitoring ecosystem. This enables proactive identification of equipment degradation before failures occur.

By shifting from reactive maintenance to predictive intervention, the platform supports reduction of forced outages, optimization of maintenance planning and maximization of generation availability across TNB's power generation fleet.

The centralized monitoring centre serves as the technical surveillance arm of Asset Health Management (AHM) and continuously evaluates the operational health of critical generating assets. It provides engineering recommendations to stations and supports informed decision-making through data-driven insights. It also supports emergency and crisis management by enabling faster response and informed decision-making during critical situations.

One of the main capabilities of the platform is performance intelligence. The system monitors plant efficiency using thermodynamic modelling to detect performance degradation, quantify heat rate impact and assess pre- and post-outage performance.

The platform also provides predictive anomaly detection using Intelligent Predictive Diagnostic and Monitoring (IPDM) to identify subtle deviations before conventional alarms occur, thereby enabling early intervention. For machinery condition monitoring, the initiative monitors rotating equipment using advanced vibration diagnostics.

The system also supports plant chemistry and emissions monitoring, boiler and combustion surveillance, dam integrity performance monitoring, hydro machine health monitoring and Asset Health Index assessment.

The monitoring framework integrates multiple operational and engineering information sources into a unified asset health assessment model. These include real-time operational data from PI

System and PI Vision, Intelligent Predictive Diagnostic & Monitoring (IPDM), machinery vibration monitoring, thermodynamic performance monitoring through Digital Twin models, plant chemistry and emissions monitoring, boiler combustion monitoring, hydro performance and catchment monitoring, dam performance monitoring through instrumentation data and Asset Health Index.

The centralized monitoring operating model starts with continuous fleet monitoring using real-time operational data. This is followed by technical assessment and engineering validation by domain specialists, communication of findings and recommendations to generating stations, site verification and implementation of corrective actions and tracking of corrective actions until closure.

The outcome is a centralized monitoring ecosystem that combines real-time monitoring, predictive analytics, engineering intelligence and standardized asset health assessment to enhance operational resilience and asset reliability.

The value of Centralized Online Monitoring is seen through improved plant reliability and availability, reduced forced outages and secondary equipment damage, enhanced plant efficiency and reduced heat rate losses. The initiative also supports condition-based maintenance, optimized maintenance planning, fleet-wide asset health visibility, data-driven engineering decisions, improved operational resilience and asset lifecycle management.

Overall, the initiative acts as a key enabler of TNB's digital asset management transformation and establishes a strong foundation for predictive asset management, operational excellence and long-term generation reliability.

6.5.4 Flood Mitigation at Flood-Prone Substations

Increasingly frequent and intense flood events have become a significant threat to the reliability and resilience of TNB's assets. Substations located in flood-prone areas are particularly vulnerable to floodwater intrusion and mudflow, which can damage critical electrical equipment, compromise operational safety, and result in prolonged power supply interruptions. Beyond the immediate physical damage, flood events often require extensive cleaning, inspection, testing, and recommissioning activities before substations can be safely returned to service, leading to higher operational expenditure (OPEX), extended restoration times, and reduced network performance.

The flood mitigation at flood-prone substations project has been developed as a strategic asset resilience initiative to strengthen the protection of critical substation infrastructure against flood-related hazards. The project targets substations identified through flood risk assessments as having a high likelihood of recurring flooding, with the objective of minimizing asset vulnerability,

improving operational continuity, and enhancing network reliability during extreme weather events.

To address these challenges, the project implements an integrated flood protection system that combines structural flood barriers with engineered drainage solutions to prevent floodwater ingress and improve water management within substation compounds. The integrated flood protection system comprises:

- Reinforced Concrete (RC) Perimeter Flood Walls and Elevated Entrance Ramps to act as physical barriers against floodwater, sediment, and debris entering the substation compound.
- Flood-Resistant Doors to protect control buildings and safeguard critical electrical, protection, communication, and control equipment from water intrusion.
- Integrated Sump Pits with Automatic Pumping Systems to efficiently collect and discharge accumulated water, ensuring effective drainage during heavy rainfall and flood events.

The implementation of this integrated flood protection system will significantly reduce the impact of flooding on critical substation infrastructure by minimizing equipment damage, shortening recovery and restoration times, and reducing maintenance and operational costs associated with flood events. Ultimately, the project will enhance the resilience and reliability of TNB's assets, strengthen climate adaptation capabilities, support sustainable asset management, and ensure the continued delivery of a secure, reliable, and uninterrupted electricity supply to customers.

One of the key capabilities of the flood mitigation at flood-prone substations project is enhanced substation flood resilience. Through the implementation of an integrated flood protection system, the project minimizes floodwater intrusion into critical operational areas, reducing equipment damage and improving the ability of substations to remain operational during extreme weather events.

The project also strengthens critical asset protection by safeguarding electrical equipment, control buildings, and protection systems against floodwater, mud, and debris. This improves asset reliability, reduces maintenance requirements, and extends the service life of critical infrastructure.

Another important capability is to improve operational continuity and recover by minimizing flood impacts and enhancing site drainage, the project reduces restoration time, shortens power supply interruptions, and enables faster recommissioning of affected substations.

Finally, the project supports climate-resilient asset management by providing a standardized approach to flood mitigation across vulnerable substations. This improves long-term infrastructure resilience, optimizes maintenance resources, and strengthens TNB's ability to manage increasing flood risks while ensuring a secure and reliable electricity supply.

Since 2014, flood mitigation measures have been successfully implemented at 12 flood-prone substations across the TNB's substations. The completed projects have strengthened the protection of critical substation infrastructure by reducing floodwater ingress and minimizing damage to electrical equipment during flood events.

The mitigation measures have also improved post-flood recovery by reducing the time required for cleaning, inspection, testing, and recommissioning before substations can be safely returned to service. These improvements have contributed to shorter outage durations, enhanced network reliability, lower operational expenditure (OPEX), and a more resilient Grid network.

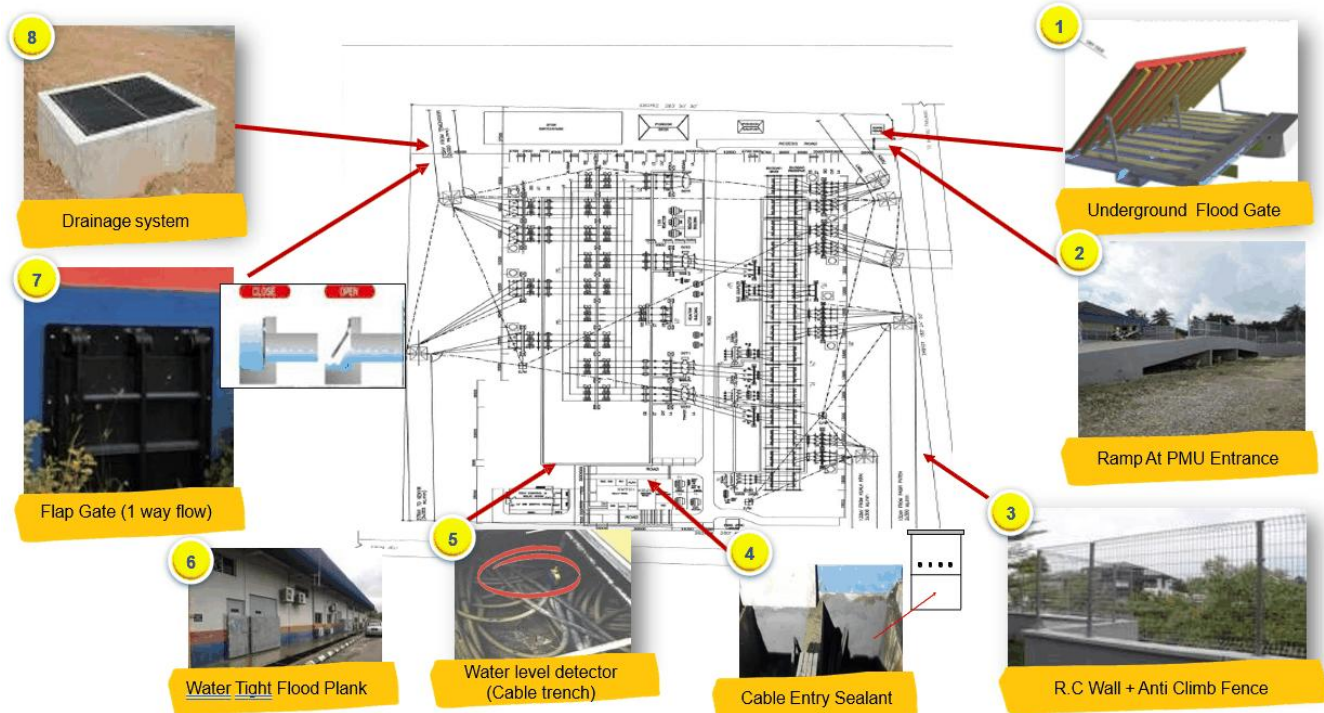


Figure 6.16: Typical Flood Mitigation Measures

The flood mitigation at flood-prone substations project is being progressively expanded to substations identified as having a high risk of recurring flooding. The programme adopts a risk-based implementation approach, prioritizing projects according to flood exposure, asset criticality, and operational impact to maximize investment effectiveness.

The current implementation has established a standardized flood mitigation framework across TNB, providing consistent engineering solutions and design practices for flood-prone substations. This standardization improves project delivery, facilitates future maintenance, and provides a scalable foundation for the next phase of flood resilience initiatives.

The value of the flood mitigation at flood-prone substations project is realized through enhanced resilience of critical substation infrastructure against flooding, improved protection of high-value electrical assets, and greater operational continuity during extreme weather events. By

minimizing floodwater ingress and improving site drainage, the project reduces the likelihood of equipment damage, shortens restoration time, and lowers operational expenditure (OPEX) associated with post-flood recovery.

The project also strengthens network reliability and customer service by reducing the risk of prolonged outages caused by flooding at critical substations. Faster recovery and restoration enable TNB to maintain a more reliable electricity supply while improving overall system performance and business continuity during severe weather conditions.

Overall, the project enables TNB to manage flood risks in a more resilient and proactive manner. By integrating engineered flood protection measures with a long-term roadmap towards smart flood management, the initiative supports sustainable asset management, optimizes maintenance resources, enhances climate resilience, and reinforces TNB's commitment to delivering a secure, reliable, and uninterrupted electricity supply.

6.5.5 Tower Foundation Stabilizer (TFS)

Climate change has become one of the major challenges affecting the reliability and sustainability of power transmission infrastructure in Malaysia. The increasing frequency and intensity of extreme weather events, particularly prolonged and heavy rainfall, have significantly increased the occurrence of geotechnical hazards such as soil erosion, landslides, slope failures, and ground settlement. These hazards pose substantial risks to transmission towers, especially those located in hilly terrain, steep slopes, and environmentally sensitive areas.

Transmission towers rely on stable ground conditions to maintain their structural integrity and operational performance. When slope failures occur, the supporting soil surrounding the tower foundation may weaken or be displaced, resulting in foundation exposure, structural deformation, or even tower collapse. Such incidents can lead to transmission line tripping, disruption of electricity supply, costly emergency restoration works, and adverse impacts on grid stability and reliability.

Recognizing the increasing vulnerability of transmission assets to climate-induced geotechnical hazards, the Tower Foundation Stabilizer (TFS) initiative was developed as a proactive engineering solution to strengthen tower foundations and improve slope stability. The TFS system integrates various slope protection and drainage measures to safeguard transmission towers against erosion, landslides, and ground settlement. By mitigating these risks, TFS enhances the resilience of transmission assets, extends asset lifespan, and ensures the continuous delivery of reliable electricity to consumers.

The implementation of TFS involves the application of suitable stabilization techniques based on site-specific geotechnical conditions. These methods include soil nailing, guniting (shotcrete),

steel grid netting with hydroseeding, reinforced concrete tie-back walls, sheet piles, rockfill protection, rubble walls, terramesh walls, reinforced earth structures, gabion walls, surface drainage systems, and horizontal drains. The selection of the appropriate method depends on factors such as slope geometry, soil properties, groundwater conditions, accessibility, and the severity of the identified geotechnical risks.



Figure 6.17: Transmission tower foundation before and after the implementation of soil nailing with gunite.



Figure 6.18: Transmission Tower Foundation Before and After the Implementation of Soil Nailing with Steel Grid Netting

Through a combination of engineering innovation and proactive asset management, the TFS initiative serves as a strategic measure to protect transmission infrastructure from the growing impacts of climate change while supporting long-term grid reliability and operational sustainability.

The Tower Foundation Stabilizer system possesses a wide range of technical capabilities that enable it to address various geotechnical challenges affecting transmission towers. One of its primary capabilities is slope stabilization, whereby the system strengthens unstable slopes and prevents soil movement that could compromise tower foundations. By utilizing appropriate stabilization measures such as soil nailing, gabion structures, reinforced earth systems, and retaining walls, TFS effectively improves the stability factor of safety of the slope and reduces the likelihood of landslides.

In addition to slope protection, TFS provides comprehensive drainage management capabilities. Surface runoff generated during heavy rainfall is efficiently collected and diverted through engineered drainage systems, thereby preventing uncontrolled water flow that can speed up

erosion and weaken soil structures. Horizontal drains and subsurface drainage systems further reduce groundwater pressure within the slope, improving overall slope stability.

Furthermore, the TFS system contributes to climate resilience by enabling transmission assets to withstand increasingly severe weather conditions. Through its comprehensive approach to geotechnical risk management, the system reduces asset vulnerability, improves reliability, and supports sustainable infrastructure management. The incorporation of environmentally friendly solutions such as hydroseeding and vegetative stabilization techniques also promotes ecological sustainability while providing long-term erosion control.

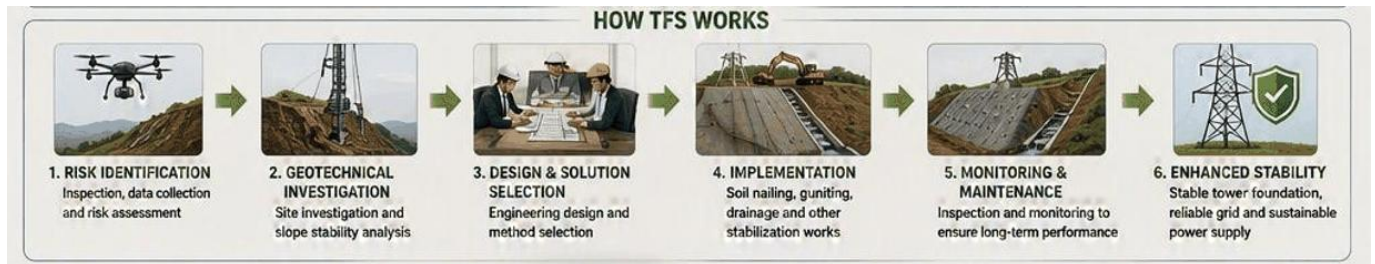


Figure 6.19: Overview of the TFS process for slope stabilization and transmission tower safety.

The implementation of the TFS program follows a systematic and data-driven process designed to identify, assess, mitigate, and monitor geotechnical risks affecting transmission towers. The process begins with the collection of data relating to climate conditions, rainfall intensity, slope performance, tower inspections, and historical geotechnical incidents. This information is gathered through routine inspections, geotechnical investigations, drone surveys, topographical assessments, and asset condition monitoring programs.

Once the relevant data is collected, engineering and geotechnical specialists conduct detailed risk assessments to evaluate the likelihood and consequences of slope failure, soil erosion, landslides, or foundation settlement. The findings are then analysed to determine the most suitable stabilization and protection measures required for each location.

Based on the assessment results, engineering designs are developed to address the identified risks. Appropriate TFS solutions are selected according to site-specific conditions, ensuring that the proposed measures effectively mitigate the existing geotechnical hazards. Following design approval, the selected stabilization works are implemented on site and subjected to quality control and compliance verification.

Upon completion of installation, continuous monitoring and inspection activities are carried out to evaluate the effectiveness of the implemented measures. Monitoring data is used to assess performance, identify emerging risks, and support future maintenance planning. This continuous improvement cycle ensures that the TFS system remains effective in protecting transmission towers against evolving environmental and geotechnical challenges.

The implementation of the Tower Foundation Stabilizer programme has produced significant improvements in geotechnical stability, operational reliability, and asset resilience. Stabilized slopes have demonstrated greater resistance to landslides, erosion, and settlement, while drainage improvements have effectively managed water infiltration and runoff. These improvements strengthen tower foundations and reduce the likelihood of structural failures during extreme weather events.

From an operational perspective, the programme has contributed to improved Grid's system reliability by reducing outage risks associated with geotechnical hazards. Emergency restoration requirements have been minimized, enabling maintenance resources to be allocated more efficiently. The enhanced stability of tower foundations also supports longer asset service life and reduces long-term maintenance expenditure.

More importantly, TFS strengthens the preparedness for climate change by ensuring that critical transmission infrastructure remains resilient under increasingly challenging environmental conditions. The successful implementation of TFS demonstrates the value of proactive geotechnical risk management in supporting a stable and reliable Grid system.

The implementation of the Tower Foundation Stabilizer system has resulted in significant improvements in both the technical performance and operational reliability of Grid's infrastructure. From a geotechnical perspective, TFS has substantially reduced the occurrence of slope instability, soil erosion, and foundation settlement at high-risk tower locations. Stabilized slopes exhibit improved safety margins, while enhanced drainage systems effectively manage runoff and subsurface water infiltration.

Operationally, the improved stability of tower foundations reduces the likelihood of unplanned outages caused by geotechnical failures. This contributes directly to increased system reliability and minimizes disruption to electricity supply. Maintenance activities can also be planned more effectively, reducing the need for costly and resource-intensive emergency repair works.

The implementation of TFS further strengthens asset resilience by enabling transmission towers to withstand extreme weather events and climate-related hazards. By extending the service life of foundation structures and reducing deterioration rates, the system supports long-term asset sustainability and improves overall network performance.

The successful application of TFS demonstrates the effectiveness of proactive risk management strategies in protecting critical infrastructure and ensuring continuous service delivery under increasingly challenging environmental conditions.

TFS initiative delivers significant value to the organization through enhanced asset protection, improved network reliability, optimized maintenance expenditure, and strengthened climate

resilience. By preventing failure mechanisms associated with landslides, soil erosion, and foundation settlement, TFS protects critical transmission infrastructure and reduces the risk of costly asset damage.

The system contributes directly to improved electricity supply reliability by minimizing transmission outages caused by geotechnical failures. Reduced emergency restoration requirements result in lower operational costs and allow maintenance resources to be utilized more efficiently. The extension of asset lifespan further improves return on investment and supports sustainable asset management objectives.

From a safety perspective, TFS reduces risks to maintenance personnel, contractors, and surrounding communities by stabilizing potentially hazardous slopes and preventing catastrophic failures. The incorporation of environmentally responsible stabilization practices also contributes to broader sustainability goals and climate adaptation initiatives.

Overall, TFS has proven to be an effective and strategic solution for managing geotechnical risks affecting transmission towers. By combining engineering innovation, proactive maintenance, and climate resilience principles, the initiative significantly enhances the stability, reliability, availability, and longevity of transmission assets, ensuring a stronger and more resilient power grid for the future.

6.6 System Flexibility

TNB is strengthening system flexibility through the coordination of distributed energy resources and other stabilizing resources to support voltage and frequency stability under changing system conditions. This includes the application of EIP-supported capabilities involving VRDT and CESS under the Elmina SCI concept, together with ADMS DERMS to support more flexible management of distributed energy resources and network conditions.

In addition, cross-border energy arrangements such as CBES provide an additional source of system flexibility during contingency conditions, allowing power exchange between interconnected countries to support supply adequacy and system recovery when required. Collectively, these capabilities enhance TNB's ability to respond to system variability, manage changing network conditions and maintain overall grid stability.

6.6.1 Elmina Smart Community Infrastructure and DERMS

As Malaysia progresses towards a sustainable energy future outlined in the National Energy Transition Roadmap (NETR), it is undertaking a transformative journey through the 10 Catalyst Flagship Projects. These projects support key national aspirations, including higher renewable-energy penetration, Net Zero emissions by 2050, development of the region as an RE hub and

reduced solar curtailment. Aligned with the NETR, Malaysia continues to transition towards cleaner and more sustainable energy sources, with solar power playing an important role in this shift.

A critical aspect of Malaysia's energy transition involves the readiness of TNB supply systems to accommodate a higher level of renewable energy. Traditionally, TNB's distribution system operated with one-way supply from the grid to consumers. However, the rise of distributed energy resources (DERs) signals a shift. The future grid envisions bidirectional flow, allowing energy generated from sources like rooftop solar panels to integrate, store, and distribute locally. This evolution fosters microgrids, ensuring communities access resilient, sustainable energy, reducing reliance on centralized grids. Storing surplus solar energy enhances resilience against fluctuating demands and grid disruptions, bolstering energy security, particularly during peak times or emergencies. Moreover, local energy storage maximizes renewable energy potential, cutting reliance on fossil fuels, reducing carbon emissions, and minimizing transmission losses, enhancing distribution efficiency, and driving cost savings for consumers and utilities. Overall, integrating solar rooftops and storage enhances sustainability, empowering communities with energy autonomy, resilience, and cost-effectiveness.

Despite the promise of numerous benefits from integrating renewable energy, technical challenges hinder its greater adoption at the community level. Technical and economic issues such as voltage limit violations, increased fault levels, heightened network losses, and line loading, along with energy curtailment due to reverse power flows, pose significant obstacles. Voltage limit breaches can lead to equipment malfunctions and safety hazards. Similarly, integrating renewable energy can escalate fault currents, risking damage and extended outages. Moreover, higher integration can amplify network losses and line loading, impacting grid efficiency. Energy curtailment, caused by surplus energy unable to be absorbed due to distribution capacity limits, undermines economic viability and savings for prosumers.

The expansion of residential rooftop solar is an important part of Malaysia's renewable energy strategy, creating a growing need to optimize the distribution network to accommodate the increasing penetration of DERs.

To address challenges and unlock the full potential of renewable energy integration in Malaysia, innovative solutions and investments in robust grid-modernization infrastructure are essential. A pioneering initiative by TNB developed Malaysia's first interconnected smart community infrastructure to encourage the adoption of DERs and enhance local energy generation and consumption. Leading this effort is Elmina Ilham Residence in Shah Alam, which demonstrates the integration of technology, sustainability and green energy. With 513 houses equipped with 2 kW solar capacity under Net Energy Metering (NEM), alongside an additional 6 kW for 223 houses through rooftop leasing and export of excess energy to the grid, the residence demonstrates strong renewable-energy adoption. This holistic approach is supported by end-to-end smart

community infrastructure comprising Community Energy Storage Solutions (CESS), Voltage Regulated Distribution Transformers (VRDT), Online Feeder Pillars (OFP), Distribution Intelligent Switches (DIS), SCADA-Distribution Automation (DA) and Smart Meters, supported through the Energy Integration Platform (EIP).

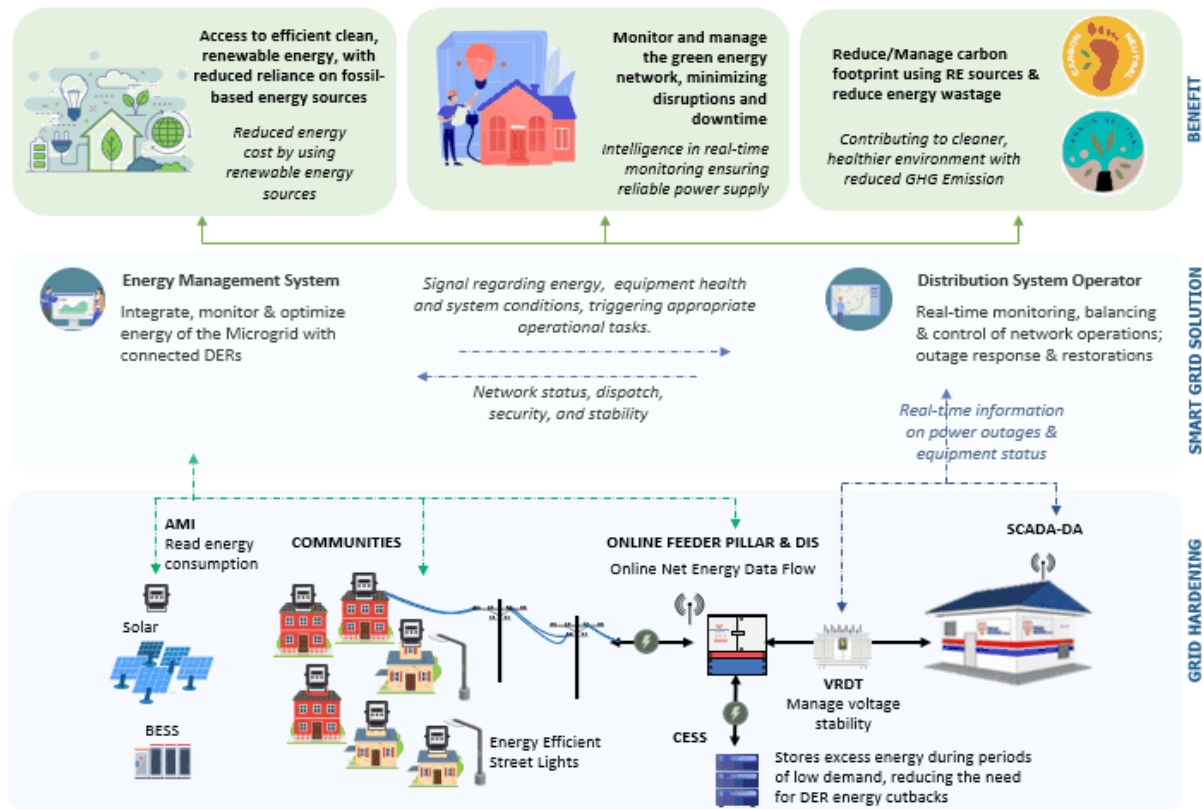


Figure 6.20: Offerings & Benefits of TNB's Smart Community Infrastructure (Microgrids)

In this smart community energy system, electricity is supplied from the grid to users through transformers, online feeder pillars, LV cables and AMI meters. During peak solar hours, surplus energy generated from rooftop solar flows to nearby users, while excess energy is stored in the CESS to support efficient utilization. When generation exceeds local demand, voltage may rise, allowing the VRDT to regulate voltage within allowable limits. During periods of low sunlight, stored energy from the CESS is redistributed to users to supplement grid supply when demand rises. At night, when RE supply is unavailable, the system switches to full grid supply while the VRDT continues to regulate voltage. These functions operate automatically and interoperate through DIS and IoT technology, with monitoring supported through EIP.



Figure 6.21: Online Feeder Pillar, Voltage Regulated Distribution Transformer & DIS

TNB's Smart Community Infrastructure, or microgrids, offers a promising solution to challenges posed by increased renewable energy integration, particularly within local communities. Implementing smart community infrastructure offers various benefits, including access to clean energy, reduced reliance on fossil fuels, enhanced efficiency, lower emissions, and increased savings. Tenaga Nasional Berhad (TNB) is spearheading this effort by embracing smart technologies, laying the foundation for a sustainable and resilient energy future in Malaysia. With the motto "PRODUCE LOCALLY, USE LOCALLY" and a commitment to fostering an energy-sharing community, TNB aims to lead Malaysia towards a brighter and sustainable future for generations to come.



Figure 6.22: The commissioning of TNB's Microgrid in Elmina

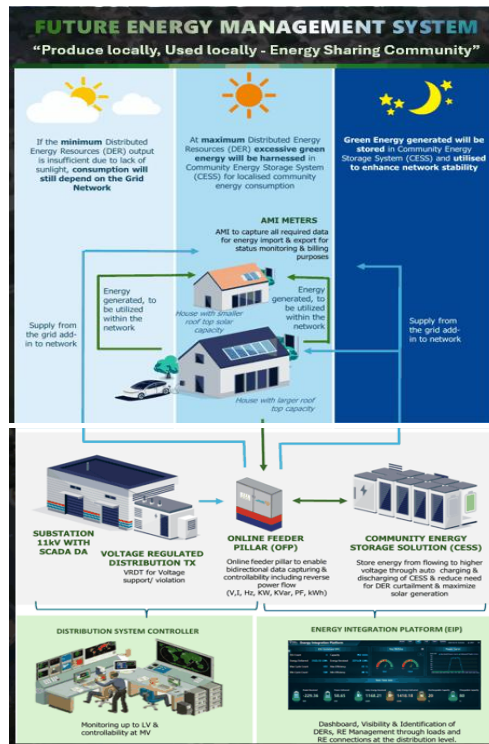


Figure 6.23: TNB's Smart Community Infrastructure (Microgrids) Scenario & Ecosystem

6.6.2 Cross-Border Energy Scheme (CBES)

TNB continues to strengthen regional energy cooperation and system flexibility through cross-border electricity trading under the Cross-border Electricity Sales for Renewable Energy (CBES RE) Scheme.

As part of this initiative, TNB and Singapore's licensed electricity importer, Sembcorp Power Pte Ltd, signed a Renewable Energy Supply Agreement (RESA) to facilitate the export of renewable electricity from Malaysia to Singapore through Energy Exchange Malaysia (ENEGEM). ENEGEM, operated by Single Buyer, conducted its inaugural auction in June 2024, where Sembcorp secured an allocation of 50 MW of green electricity with Renewable Energy Certificates (RECs) sourced from Malaysia's solar and hydro generation.

The electricity is transmitted through the existing Malaysia–Singapore interconnection, demonstrating the role of existing cross-border infrastructure in enabling renewable energy exchange between neighbouring countries. The Malaysia–Singapore interconnection currently has a capacity of 1,000 MW, of which 300 MW has been allocated for the CBES RE Scheme and 200 MW for Phase 2 of the Lao PDR–Thailand–Malaysia–Singapore Power Integration Project (LTMS-PIP). The Cross-border Power Trade Interconnection Agreement between TNB and SP PowerAssets Limited further supports the enabling framework for cross-border electricity transactions.

Beyond facilitating renewable energy trading, cross-border interconnections provide an additional source of system flexibility by enabling electricity to be exchanged between interconnected countries when required. This can support supply adequacy and provide additional options during system contingencies, while strengthening regional energy security and resilience.

The first 50 MW contribution under the CBES RE pilot demonstrates Malaysia's potential to participate more actively in regional green electricity trading. Through ENEGEM, CBES RE and wider ASEAN Power Grid initiatives, TNB is supporting greater regional energy integration while advancing renewable energy utilization, energy security and decarbonization across the region.

6.6.3 Santong BESS

Santong BESS also contributes to system flexibility through grid-forming operation, frequency and voltage support, peak management and other stabilizing services. Its capability is described in Section 6.3.3.

DIMENSION 7: SUSTAINABILITY

Sustainability reflects how TNB supports decarbonization, renewable energy integration, efficiency, emissions reduction and responsible asset management. This Dimension 7 summary should be read together with [TNB Sustainability Report 2025](#), which provides a comprehensive reference for TNB's sustainability strategy, initiatives, performance and disclosures.

7.1 Renewable Energy Integration

TNB is increasing renewable energy integration through a combination of renewable generation expansion, customer and community participation, grid and connection enablement, and emerging clean-energy technologies. These efforts are supported by improvements in transmission and distribution planning, energy storage, digital platforms and smart-grid capabilities so that increasing levels of renewable energy can be accommodated while maintaining system reliability, stability and affordability.

Renewable energy integration is guided by TNB's Energy Transition Plan and Renewable Energy Expansion Plan. The initiatives in this section are organized across TNB's renewable energy performance and portfolio, distributed and customer renewable energy adoption, renewable energy connection and market enablement, smart renewable energy communities and microgrids, and emerging strategic renewable energy development.

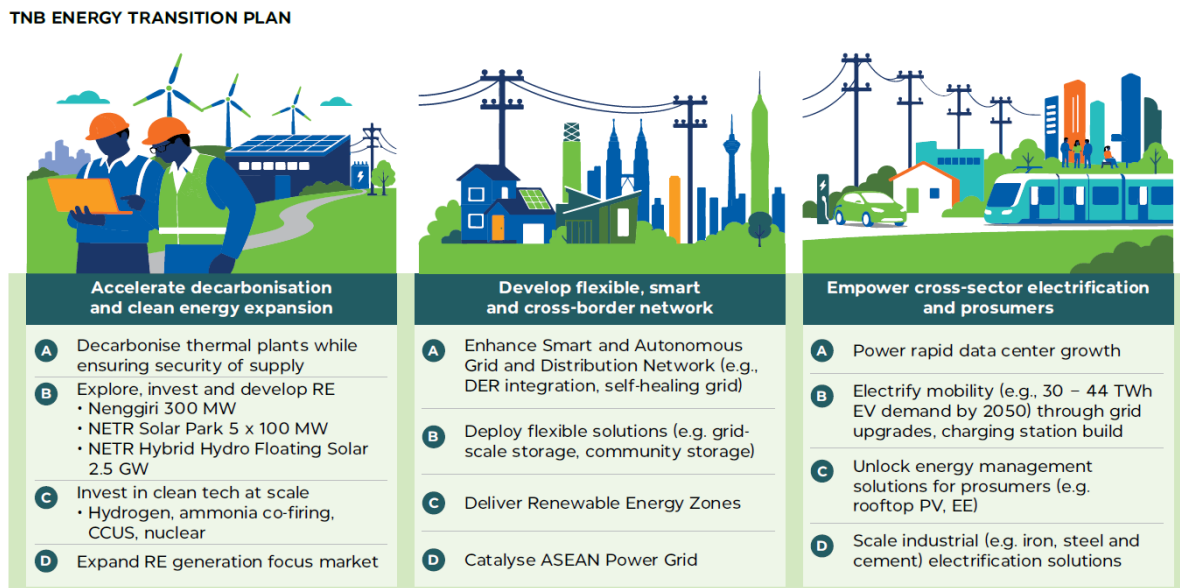


Figure 7.1: TNB Energy Transition Plan

Further reference: [TNB Sustainability Report 2025, pp. 45–48 and 58–65.](#)

7.1.1 Renewable Energy Performance and TNB RE Portfolio

For FY2025, TNB recorded a total installed renewable energy capacity of 4,681 MW, representing approximately 24% of its generation capacity mix, comprising 14% hydro and 10% other renewable energy sources, including solar, wind, mini hydro and biomass/biogas. Renewable energy also contributed approximately 11.8% of total net electricity generation, comprising 9.8% hydro and 2.0% other renewable energy sources. The daily and monthly system generation profile can also be viewed through the [GSO portal](#).

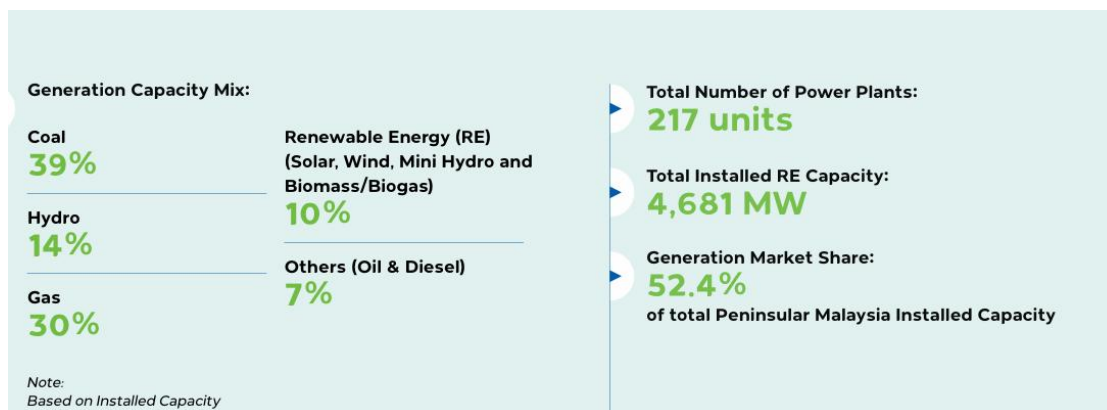


Figure 7.2: TNB renewable energy installed-capacity mix for FY2025
(TNB Integrated Annual Report 2025, p. 12.)

ISSB/Bursa/GRI	Indicator	Units	FY2023	FY2024	FY2025
Net energy output broken down by primary energy source					
IF-EU-000.D	Total Net Energy Output	GWh	79,535.45	73,185.02	75,373.46
	Gas	GWh	26,065.97	22,238.84	19,769.21
G4-EU2	Coal	GWh	44,826.58	40,678.64	46,158.96
	Hydro	GWh	6,452.92	7,148.16	7,380.92
	Diesel	GWh	365.68	532.65	412.82
	Solar	GWh	572.01	1,274.96	1,023.61
	Biomass	GWh	13.16	31.37	15.61
	Biogas	GWh	13.80	-	9.90
	Wind	GWh	544.43	852.24	447.17
	Oil	GWh	660.52	395.21	107.68
	Solar hybrid	GWh	20.38	32.95	47.58

Figure 7.3: TNB renewable energy contribution to total net generation for FY2025
(TNB Sustainability Report 2025, p. 70.)

TNB's domestic solar portfolio includes TNB Sepang Solar 50 MWac (LSS1), TNB Bukit Selambau Solar, Kedah 30 MWac (LSS2), TNB Bukit Selambau 2 Solar, Kedah 50 MWac (LSS4), and TNB Bukit Sidim Kulim Solar, Kedah 29.99 MWac under the Corporate Green Power Programme (CGPP). TNB Kuala Muda Solar, Kedah 500 MWac (LSS5) is under construction, with scheduled commercial operation in December 2027. These developments support the continued growth of TNB's renewable generation portfolio.

TNB also continues to strengthen its hydro portfolio. The Hydro Life Extension Programme covers selected hydro stations, beginning with the Sungai Perak scheme and continuing with Kenyir and Cameron Highlands, to extend the useful life of existing low-carbon generation assets. The development of the 300 MW Nenggiri Hydroelectric Project further supports the expansion of TNB's low-carbon portfolio. Internationally, TNB continues to expand its renewable energy presence through solar, wind and battery-storage investments in markets including the United Kingdom, Europe and Australia.

7.1.2 Distributed and Customer Renewable Energy Adoption

TNB also supports renewable energy growth by enabling customers and communities to participate more actively in distributed generation and rooftop solar. In FY2025, an additional 47 MWp of rooftop solar capacity was commissioned, bringing cumulative installed rooftop solar capacity to 216 MWp. Customer participation is further supported through government-led mechanisms that provide additional pathways for consumers to generate, use and export renewable electricity.

Supporting this growth also requires network readiness and informed connection planning at both transmission and distribution levels. TNB's Renewable Energy Hosting Capacity Assessment evaluates the transmission network's ability to accommodate additional renewable generation, while the DG Hosting Capacity Map provides initial visibility of connection opportunities within the medium-voltage network. These complementary capabilities support renewable energy integration through the identification of available network capacity, technical constraints and reinforcement needs, as described in Sections 2.2.2 and 2.2.3, respectively.

Solar Accelerated Transition Action Programme (Solar ATAP)

Effective 1 January 2026, the Government of Malaysia introduced the Solar Accelerated Transition Action Programme (Solar ATAP) to replace the Net Energy Metering (NEM) programme. Solar ATAP is designed to accelerate rooftop solar deployment across residential, commercial, industrial and public-sector buildings by enabling consumers to generate electricity for their own use while exporting excess energy to the electricity grid. TNB supports the implementation of Solar ATAP through a digital application process and power system studies to assess technical feasibility and ensure that solar PV connections comply with applicable grid requirements while maintaining network safety, reliability and stability.

Community Renewable Energy Aggregation Mechanism (CREAM)

The Community Renewable Energy Aggregation Mechanism (CREAM), announced in February 2025, is designed to maximize residential rooftop solar potential by enabling homeowners to lease or rent their rooftops to third parties for solar power generation. TNB supports the implementation of CREAM by facilitating the safe, reliable and efficient integration of community

renewable energy into the distribution network in collaboration with the Government, regulators and industry stakeholders.



Figure 7.4: TNB facilitation of government-initiated green energy solutions (TNB Integrated Annual Report FY2025, p. 124.)

7.1.3 Renewable Energy Connection and Market Enablement

Beyond customer and community adoption, TNB supports larger renewable energy developments through market mechanisms, digital connection management and technical planning capabilities that facilitate the orderly connection of new generation while maintaining grid reliability.

Corporate Renewable Energy Supply Scheme (CRESS)

The Corporate Renewable Energy Supply Scheme (CRESS), introduced by the Ministry of Energy Transition and Water Transformation, is designed to enhance the adoption of green energy by allowing participants to supply or purchase green electricity through open access to the grid network with a pre-determined System Access Charge. CRESS enables Green Consumers to contract directly with Renewable Energy Developers for green electricity and associated Renewable Energy Certificates. TNB supports the implementation of CRESS by maintaining a reliable and resilient grid capable of accommodating increasing renewable energy applications.

Generator Connection Management System (GCMS)

The Generator Connection Management System (GCMS) supports the growing volume and complexity of generation connection applications through a common digital platform. GCMS streamlines the end-to-end process for connecting new generation facilities, including renewable energy projects, conventional power plants, BESS and emerging energy technologies. The platform provides structured workflows covering project registration, technical assessment, power system studies, document management, approvals and project monitoring, improving transparency, coordination and traceability throughout the connection lifecycle.

Renewable Energy Hosting Capacity and Transmission Planning

Renewable Energy Hosting Capacity Assessment supports proactive planning by evaluating the capability of the transmission network to accommodate additional renewable generation without compromising system reliability, voltage performance, thermal loading or operational security. Using detailed network models and power system studies, planners assess available capacity, identify technical constraints and determine reinforcement requirements before new generation projects are connected. This approach supports more transparent and technically justified connection decisions while improving utilization of existing network infrastructure. The detailed transmission-planning capability is described in Section 2.2.2.

The Grid Code of Peninsular Malaysia and Transmission System Reliability Standards provide the technical and operational foundation for these connection and planning activities. The frameworks establish common requirements for renewable generation, voltage and frequency performance, fault ride-through, dynamic behaviour and other grid-support functions, allowing increasing renewable penetration to be accommodated while maintaining system security and reliability.

7.1.4 Smart Renewable Energy Communities and Microgrids

TNB is also demonstrating how renewable energy, energy storage and smart-grid technologies can be coordinated at community and island level. These use cases provide practical references for managing localized renewable generation, improving visibility of distributed energy flows and maintaining reliable electricity supply under changing operating conditions.

Elmina Residential Solar Community

The Elmina Residential Solar Community demonstrates the coordinated management of distributed energy resources within a low-voltage network with high rooftop solar penetration. Through the Energy Integration Platform (EIP), information from Smart Meters, Voltage Regulating Distribution Transformers (VRDTs), Online Feeder Pillars (OFPs) and Community Energy Storage Systems (CESS) is brought together to support near real-time monitoring of reverse power flow, battery state of charge and feeder voltage profiles. The complete EIP and Elmina microgrid story

is described in Section 2.1.2, with the related Smart Community Infrastructure described in Section 2.5.1.

Pulau Tenaga Hijau (PTH)

Pulau Tenaga Hijau (PTH) is a flagship initiative by TNB to modernize electricity supply across selected resort islands through the implementation of Smart Green Island solutions. The project covers Pulau Tioman, Pulau Perhentian and Pulau Redang, supporting Malaysia's National Energy Transition Roadmap (NETR) while strengthening electricity reliability, improving operational efficiency and accelerating the transition towards a lower-carbon energy system.

Historically, electricity supply on these islands has relied on isolated diesel generation, resulting in challenges related to fuel logistics, high operating costs, carbon emissions and limited system flexibility. As electricity demand continues to grow alongside tourism activities and local community development, there is a need for a more resilient, efficient and sustainable electricity infrastructure.

The PTH Project addresses these challenges through a smart-grid approach combining 33 kV submarine cable interconnection, Solar Photovoltaic (PV) generation, Community Energy Storage Systems (CESS) and supporting energy-management capabilities. These technologies provide enhanced network visibility, improved operational flexibility and better utilization of renewable energy while maintaining a secure and reliable electricity supply.

In 2025, five (5) CESS units rated at 150 kW/430 kWh were installed across Pulau Perhentian, Pulau Redang and Pulau Tioman at identified locations. Solar PV has also been progressively deployed across the islands, including building-integrated and rooftop installations at community facilities and TNB premises. A selected solar installation at Masjid Pulau Perhentian is shown in Figure 7.5.



Figure 7.5: Solar BIPV system at Masjid Pulau Perhentian (118.8 kWp)

At Pulau Tioman, a total of 676.27 kWp of solar PV has been deployed in two phases across selected locations. The solar deployment includes installations at the TNB jetty, office and quarters, providing additional renewable generation within the island electricity system. Figures 7.6 and 7.7 show some of the selected solar PV locations and the installation at Tioman Jetty.



Figure 7.6: Solar PV installation at Pulau Tioman



Figure 7.7: Solar PV installation at Tioman Jetty (69.39 kWp)

The initiative is complemented by a total of 500kW Mini Hydro systems in Mentawak, supporting reduced dependence on diesel generation and strengthening the island's renewable energy mix. Looking ahead, the implementation of the TNB Energy Management System (TEMS) is planned to further strengthen coordinated monitoring, analysis and optimization of distributed energy resources within the island network. Working together with CESS and renewable generation, this capability is intended to support proactive energy management, improve operational efficiency and reduce dependence on conventional diesel generation. Current system overview and monitoring capabilities will continue to evolve as TEMS is implemented as part of the PTH roadmap.

Beyond infrastructure development, the PTH Project demonstrates TNB's commitment to developing a smarter and more sustainable electricity network through digitalization, renewable energy integration and advanced operational technologies. The project provides a scalable reference for future Smart Green Island developments while supporting TNB's smart-grid transformation and Malaysia's long-term decarbonization goals. Carbon-management and emissions-reduction aspects of PTH are further described in Section 7.5.2.

7.1.5 Emerging and Strategic Renewable Energy Development

TNB is also progressing strategic renewable and clean-energy developments that can support the next phase of Malaysia's energy transition. Under the National Energy Transition Roadmap, these include the proposed 2.5 GW Hybrid Hydro-Floating Solar (HHFS) project and 750 MWp Centralized Solar Park, alongside further development of floating solar and renewable-based hydrogen applications.

Kenyir Floating Solar

TNB has developed floating solar pilot projects to demonstrate the potential of utilizing existing water bodies for renewable generation. At Stesen Janaelektrik Sultan Mahmud, Kenyir Dam, a 154 kWp floating solar PV pilot was developed for research and development purposes using the Self-Consumption (SELCO) concept, where generated solar energy is utilized within the station's operational system. The pilot provides a reference for planned expansion of floating solar at Kenyir, including development under the CRESS framework. Figures 7.8 and 7.9 show the Kenyir floating solar pilot.



Figure 7.8: Floating solar pilot project at Stesen Janaelektrik Sultan Mahmud, Kenyir Dam



Figure 7.9: Full view of the floating solar pilot project at Kenyir Dam

Project Renewable Energy and Clean Hydrogen (REACH)

TNB is also progressing Project Renewable Energy and Clean Hydrogen (REACH), which focuses on renewable-based hydrogen production through solar-powered electrolysis. The initiative at Stesen Janakuasa Tuanku Muhriz includes a 500 kWp rooftop solar PV system and a 1 MWh Battery Energy Storage System (BESS), supporting green hydrogen production for industrial applications and reinforcing TNB's decarbonization strategy. The REACH installations are shown in Figures 7.10 and 7.11.



Figure 7.10: Installation of 500 kWp rooftop solar PV under Project REACH



Figure 7.11: Installation of 1 MWh BESS under Project REACH

Together, these emerging initiatives complement TNB's established solar and hydro portfolio and provide additional pathways to expand renewable generation, explore new low-carbon technologies and prepare the electricity system for future energy-transition requirements.

7.2 Electrification Enablement

TNB supports Malaysia's energy transition by accelerating cross-sector electrification and empowering customers to participate in a cleaner and more sustainable energy ecosystem. Guided by its Energy Transition Plan, TNB continues expanding electric vehicle (EV) infrastructure, distributed renewable energy and smart energy solutions to support increasing electricity demand from the transport, commercial and residential sectors. At the same time, TNB promotes energy efficiency within its own operations to reduce operational emissions while demonstrating leadership in sustainable energy management.

Cross-sector electrification and prosumer enablement form one of the central pillars of TNB's Energy Transition Plan. The strategy anticipates increasing EV-related electricity demand and identifies grid upgrades, charging-station deployment, smart meters, BESS and digital planning as important enablers for the transition.

Further reference: [TNB Sustainability Report 2025, pp. 64 and 88–89.](#)

7.2.1 EV Facilitation and TNB Electron

TNB supports the EV ecosystem through policy and industry collaboration, development of charging infrastructure and improvements to the electricity-supply connection process. TNB co-founded the Malaysian Zero Emission Vehicle Association and worked with the Energy Commission on the Electric Vehicle Charging Station Technical Guide to strengthen safety and standardization of EV charging infrastructure. Figure 7.12 shows an example from the EV connection guidelines.

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Technical Guidelines
for Interconnection of Electric Vehicle
to Distribution Systems 2020

4.0 EV INTERCONNECTION SCHEME

4.1 Standard

4.1.1 Charging
Standard

: The power supplied by an EVSE can be in AC or DC form. In case of AC power source, on-board charger is necessary to convert the AC power into DC power for appropriate charging operation. SAE J1772 is the charging standards recognized by SAE International. Table 4.1 presents the charging standard of SAE J1772.

Table 4.1 SAE J1772 charging standard [Ref. 12]

Charging Level	Charging Rating			Compatible Connector	Remark
	Voltage (V)	Current (A)	Power (kW)		
AC Level 1	120 V_{AC}	up to 12 up to 144 up to 16	up to 1.44 up to 192	SAE J1772; IEC type 1; CCS/COMBO 1	Single phase, on-board/off-board
AC Level 2	208 V_{AC} to 240 V_{AC}	up to 80	up to 19.2	SAE J1772; IEC type 1; CCS/COMBO 1	Three phase, off-board
AC Level 3	208 V_{AC} to 240 V_{AC}	up to 400	up to 96	To be determined	To be determined
DC Level 1	200 V_{DC} to 450 V_{DC}	up to 80	up to 36	CCS; CHAdeMO; GB/T	Off-board
DC Level 2	200 V_{DC} to 450 V_{DC}	up to 200	up to 90		
DC Level 3	200 V_{DC} to 600 V_{DC}	up to 400	up to 240		

IEC 61851 is the charging standard derived from SAE J1772

Figure 7.12: EV interconnection scheme in the EV connection guidelines

TNB is expanding public EV charging infrastructure under the TNB Electron brand. As of June 2026, 274 charge points had been installed, with a target of 500 charge points by the end of 2026. Deployment focuses on highway rest and service areas, petrol stations along major roads, public commercial premises and TNB premises, supported by partnerships with relevant industry and public-sector stakeholders.

To accelerate public charging deployment, TNB offers a dedicated Green Lane electricity supply application for Charge Point Operators, enabling faster and more efficient grid connections compared with the standard application process. TNB Electron also provides digital charging services that allow users to locate chargers, view charger status, start and monitor charging sessions and make cashless payments.

7.2.2 TNB Fleet Electrification

TNB is progressively electrifying its own operational fleet as part of its greenhouse-gas emission reduction and sustainable-mobility initiatives, demonstrating the practical adoption of EVs while reducing direct emissions from company vehicles. The programme involves replacing internal combustion engine vehicles across a range of fleet categories, including mass-transport vehicles, corporate and pool vehicles, technical operational vehicles, motorcycles, vans and specialised units. TNB aims to electrify 30% of its 4,780 operational vehicles by 2030. Below is the progress as of June 2026:

- Four (4) EV buses have been purchased, with two units supporting UNITEN operations and two units supporting TNB staff transportation.
- Seventy-five (75) corporate and pool EVs have been purchased across pickup, passenger, SUV, van and MPV categories, with selected units under delivery.
- Three hundred and thirty-eight (338) operational EVs have been purchased across technical and support functions, including motorcycles, pickups, vans, SUVs and specialized vehicles, with selected units under delivery.

TNB remains committed to progressively electrifying its operational fleet towards 2030. This supports sustainable mobility, reduction of direct emissions and practical experience in the operation of EVs across a range of use cases.

7.2.3 Wider Electrification and Demand Readiness

For buildings and energy-intensive customers, TNB's digital energy-management solutions, including the Virtual Energy Manager, consolidate electricity data across factories, data centres, hotels and offices. The platform enables customers to identify energy-efficiency opportunities, optimise consumption patterns, reduce energy costs and improve the monitoring and reporting of electricity-related emissions. At network level, smart-meter deployment and AI- and data-driven planning improve visibility of changing load patterns and support timely investment in

emerging electrification demand, including EV charging, data centres and distributed energy resources.

TNB also empowers prosumers through rooftop solar deployment under GSPARX. During 2025, 47 MWp of rooftop solar capacity was commissioned, bringing cumulative installed capacity to 216 MWp across residential, commercial and industrial customers. This enables customers to generate renewable electricity while supporting the broader development of distributed renewable energy.

Within its own operations, TNB continues to improve energy efficiency through its Green Building Programme and behavioural initiatives. The TNB Platinum Campus operates in accordance with Green Building Index (GBI) Platinum standards, integrating intelligent building-management systems and rooftop solar photovoltaic installations to optimise building performance and reduce electricity consumption of approximately 25%. These efforts are complemented by the “Drip by Drip, Watt by Watt” initiative, which promotes more efficient electricity and water use across TNB offices.

For further information on TNB Electron, EV charging infrastructure, fleet electrification and the Virtual Energy Manager, please refer to [TNB Sustainability Report 2025, pp. 64 and 88–89](#).

7.3 Loss Reduction & Efficiency

Loss Reduction & Efficiency focuses on reducing technical and non-technical losses, improving voltage management and increasing overall network efficiency. For 2025, the Focus Group material records a distribution-network loss figure of 5.69% and a transmission-network loss figure of 0.91%. TNB continues to strengthen loss monitoring and improvement activities through data-driven measurement, network optimization and targeted operational actions.

2025 Loss Indicator	Performance
Distribution-network losses	5.69%
Transmission-network losses	0.91%

7.3.1 Losses Improvement Workgroup

Technical losses are an inherent component of the electricity system and arise from the physical characteristics of network equipment such as transformers, cables and overhead lines. Their mitigation requires a combination of network design optimization, load balancing, reactive-power management, demand-side management, appropriate conductor sizing and the use of digital network information to support better operating decisions.

Non-technical losses arise from factors such as electricity theft, metering inaccuracies, administrative errors or unauthorized consumption. These losses can be reduced through improved monitoring, advanced metering, data analytics, enforcement and customer awareness.

TNB has endorsed transformer-tail measurement across selected 11/0.4 kV distribution substations to improve the accuracy of loss accounting, enable continuous monitoring of transformer loading and facilitate load balancing across the low-voltage network. In May 2026, a dedicated technical working group was established to refine the implementation approach, including assessment of Online Feeder Pillar and Ground Mounted Metering Kiosk applications, work procedures, installation requirements, data acquisition and low-voltage loss calculation methodologies.

7.3.2 Voltage Management through VRDT

The Voltage Regulating Distribution Transformer (VRDT) is a special-design distribution transformer with a load tap-changing mechanism that dynamically manages voltage fluctuation, particularly where increasing DER penetration affects the low-voltage network. By regulating output voltage through its built-in on-load tap changer, VRDT supports improved voltage stability and reduces the likelihood that high-voltage conditions will limit new DER connections or require generation curtailment.

1. Improved Voltage Stability: VRDT continuously regulates output voltage to maintain stable voltage levels despite changes in load or generation.
2. Better Integration of DERs: VRDT supports compliance with voltage limits in areas with higher DER penetration and helps reduce high-voltage constraints.
3. Operational Efficiency: Improved voltage management and better network utilization can contribute to more efficient operation and lower network losses. Figure 7.13 illustrates the VRDT operating concept.

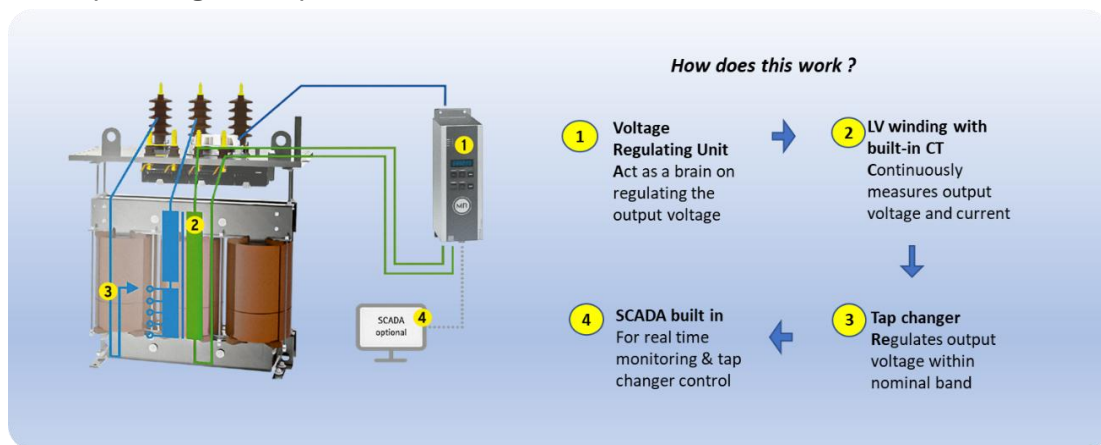


Figure 7.13: VRDT operation scheme

7.4 Flexibility & Low-Carbon Resources

TNB strengthens grid flexibility by using energy storage, demand-side management and digital grid capabilities to support increasing renewable energy penetration. As renewable generation becomes more variable, these initiatives improve the grid's ability to maintain stability, reliability and resilience while reducing dependence on conventional thermal generation for system balancing.

Comprehensive reference: [TNB Sustainability Report 2025](#) provides the full reference for TNB's Energy Resource Planning, Energy Transition and grid resiliency initiatives summarized under this component.

The Energy Transition Plan positions grid-scale and community storage as important components of a flexible electricity network. Strategic planning prioritizes storage, automation, advanced analytics and demand-side participation to minimize renewable curtailment, optimize dispatch and strengthen network readiness in capacity-constrained and high-variable-renewable-energy areas.

The 100 MW/400 MWh BESS in Santong provides peak management and energy shifting to accommodate variable renewable output. Its operational functions include ramp-rate control and renewable-output firming. The equivalent 100 MW/400 MWh Lahad Datu BESS provides reserve capacity and supports system stability in Sabah. At distribution level, TNB is piloting three Community Energy Storage Systems in Elmina Township to absorb excess rooftop-solar generation and discharge during peak demand, thereby supporting local-network stability and additional solar hosting capacity.

Demand-side flexibility is enabled through smart meters, myTNB and the Time-of-Use tariff, which provide customers with clearer visibility of electricity consumption and price signals that encourage load shifting from peak to off-peak periods. TNB is also advancing network monitoring, forecasting and management capabilities to improve the optimization of transmission and distribution power flows.

The Santong and Lahad Datu projects establish a foundation for future large-scale storage, while community-level storage remains at the pilot stage. TNB is also assessing potential longer-duration storage using existing hydro assets and continues to evaluate broader demand participation and digital network-management solutions. TNB's fleet electrification initiatives described in Section 7.2 also contribute to the wider transition towards lower-carbon energy use.

Further reference: [TNB Sustainability Report 2025, pp. 43, 45–47 and 85–86.](#)

7.5 Carbon Management & Emissions

TNB manages emissions through structured carbon accounting, emissions-intensity monitoring and performance tracking against short-, medium- and long-term targets. TNB monitors Scope 1, Scope 2 and selected Scope 3 emissions, as well as Scope 1 emissions intensity. Emissions associated with electricity delivery, including electricity generated by TNB and purchased from Independent Power Producers, are calculated using the relevant grid emission factors.

TNB's Carbon Management Strategy is structured around three pillars: Reduce, Capture and Offset. It targets a 5% annual reduction in Scope 1 emissions intensity from the 2024 baseline, a 35% reduction by 2035 and Net Zero emissions by 2050. Governance is supported through established sustainability committees that set targets, monitor performance and endorse implementation plans. The key carbon-management targets are summarized in Figure 7.14.

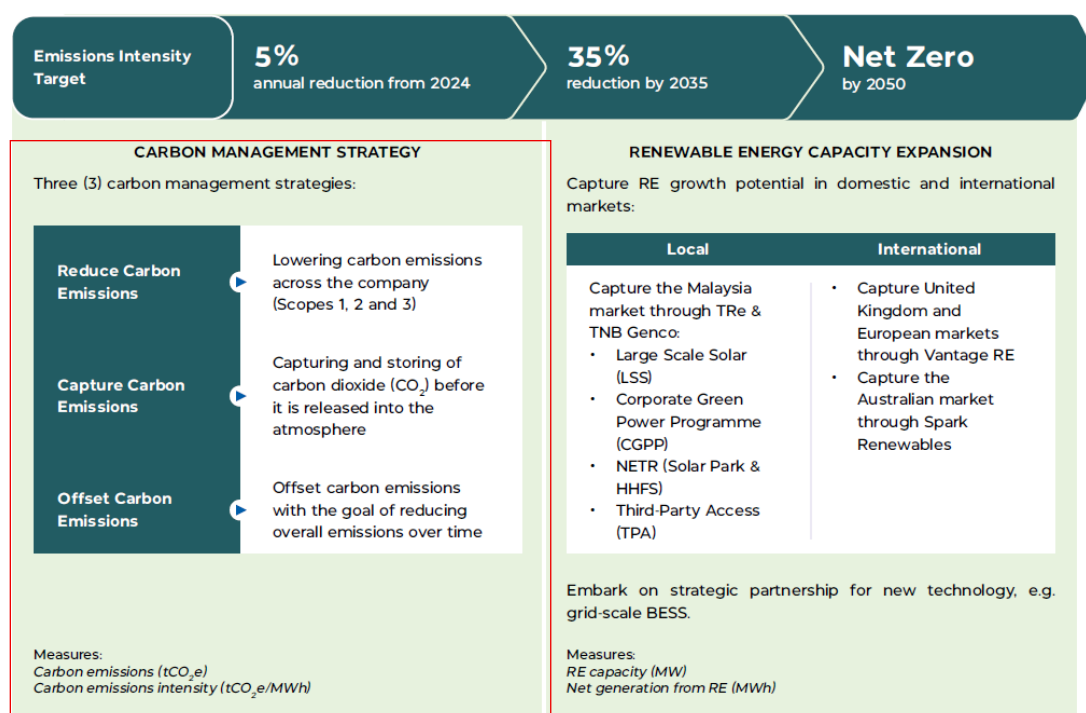


Figure 7.14: TNB carbon management targets and decarbonization pathways

Further reference: [TNB Sustainability Report 2025, pp. 58–59.](#)

7.5.1 Emissions Monitoring and Operational Reduction

TNB tracks greenhouse-gas performance through digital data collection and its ESG Dashboard, which monitors sustainability indicators across the organization. Scope 2 emissions from facilities are calculated using the National Grid Emissions Factor published by the Energy Commission, while relevant emissions information undergoes internal review to improve consistency and reliability.

Operational emission-reduction initiatives include heat-rate monitoring, coal blending, boiler and condenser cleaning, compressor washing, equipment upgrades and digital modelling to identify performance gaps. TNB also continues improving SF₆ gas management through recycling. During 2025, 8,211 kg of SF₆ gas was recycled, contributing to approximately 192,956 tCO₂e of avoided emissions. Nature-based offset initiatives are also supported through tree-planting programmes.

7.5.2 PTH Carbon Management & Emissions Reduction

The PTH Project supports TNB's commitment to sustainability by accelerating the transition from conventional diesel-based electricity generation towards a cleaner and lower-carbon hybrid electricity system. Through the integration of 33 kV submarine cable interconnection, Solar PV, CESS and intelligent energy management, the project aims to improve energy efficiency, increase renewable energy utilization and reduce greenhouse-gas emissions across selected island electricity systems.

Island electricity supply has traditionally depended largely on diesel generation, resulting in high fuel consumption and carbon emissions. The transition towards hybrid electricity systems under PTH provides an opportunity to progressively reduce reliance on fossil-fuel generation while supporting secure and reliable electricity supply for local communities and the tourism sector.

In addition to infrastructure development, PTH incorporates carbon-management principles by monitoring energy performance, evaluating renewable-energy utilization and assessing the environmental benefits achieved through cleaner electricity generation. This supports TNB in understanding the carbon-reduction impact of Smart Green Island initiatives while contributing to wider sustainability and decarbonization objectives.

Key carbon-management capabilities include:

- Monitoring renewable-energy generation and utilization across the hybrid electricity system.
- Assessing diesel-fuel displacement through increased utilization of Solar PV and CESS.
- Supporting estimation of greenhouse-gas emissions resulting from cleaner electricity generation.
- Monitoring operational energy performance to support continuous improvement initiatives.
- Providing data to support sustainability reporting and future Environmental, Social and Governance (ESG) disclosures.
- Establishing a digital foundation for future carbon-performance monitoring and environmental analytics.

Carbon management under PTH leverages operational data collected from Solar PV generation, CESS, energy-management capabilities, conventional generation and distribution-network assets. This information provides visibility of renewable-energy generation, electricity demand,

storage utilization, diesel-generator operation, fuel consumption and overall network energy performance. The resulting information supports evaluation of renewable-energy contribution, diesel-fuel displacement and operational efficiency, providing a basis for estimating greenhouse-gas emissions reduction and measuring sustainability performance.

Carbon-management capability is progressively being embedded within PTH through the deployment of renewable-energy systems, CESS and energy-management capabilities. The continued roadmap focuses on strengthening collection and analysis of operational energy data, developing methodologies to estimate emissions reduction based on diesel-fuel displacement, enhancing sustainability-performance monitoring through digital dashboards, supporting future ESG reporting requirements and continuously improving renewable-energy utilization and operational efficiency.

The initiative is expected to contribute to:

- Increased utilization of renewable energy across island electricity systems.
- Progressive reduction in diesel-fuel consumption through cleaner-energy integration.
- Lower greenhouse-gas emissions are associated with electricity generation.
- Improved operational energy efficiency through intelligent energy management.
- Enhanced visibility of sustainability performance using operational data.
- Stronger capability to support TNB's ESG reporting and decarbonization initiatives.
- A scalable Smart Green Island model supporting replication of lower-carbon island electricity systems in the future.

For more info on CCU and SF6 gas management, please refer to [TNB Sustainability Report 2025 page 62 and 63](#).

7.5.3 Cleaner Energy and Customer Participation

Renewable energy integration, floating solar at Kenyir, Project REACH and the broader PTH renewable-energy story contribute to TNB's carbon-reduction pathway and are described in Section 7.1. PTH-specific carbon-management and emissions-reduction capabilities are described in Section 7.5.2, while responsible asset-management measures are described in Section 7.6.

TNB also enables customers to purchase low-carbon electricity through the Green Energy Tariff (GET). The programme allows participating customers to obtain renewable electricity attributes without installing their own renewable generation and supports customer participation in the transition towards lower-carbon energy use.

7.5.4 Performance and Roadmap

TNB maintains its annual emissions-intensity reduction ambition, targets a 35% reduction by 2035 and pursues Net Zero by 2050. Supporting measures include renewable capacity expansion, progressive reduction of coal capacity, development of carbon-capture and utilization pathways and broader assessment of Scope 3 emissions across the value chain. Progress in 2025 was reflected through the following initiatives and emissions performance:

- TNB's 2025 initiatives, including heat-rate improvements, coal blending, renewable optimization and solar rooftops, delivered a calculated 4.8% reduction in emissions intensity before the effects of operational and external factors. Actual reported emissions intensity was 0.565 tCO₂e/MWh, compared with the 2024 baseline of 0.5571 tCO₂e/MWh; excluding identified external factors, the reported value was 0.537 tCO₂e/MWh.
- Total Scope 1 emissions were approximately 39.31 million tCO₂e and Scope 2 emissions were 0.314 million tCO₂e in 2025.
- TNB's renewable portfolio contributed estimated annual emissions avoidance of 6.3 million tCO₂e.

7.6 Sustainable Infrastructure

Full reference: Sustainable Infrastructure should be read together with [TNB Sustainability Report 2025](#), which provides the comprehensive reference for TNB's sustainable materials, waste management, climate resilience, asset lifecycle and environmental-management initiatives.

TNB integrates sustainability into infrastructure and asset lifecycles through responsible procurement, materials innovation, waste recovery, recycling, environmental controls and climate-risk management. The approach considers impacts from sourcing and project delivery through operation, maintenance, refurbishment and end-of-life management, with the objective of reducing virgin-material demand, extending asset value and minimizing environmental liabilities.

7.6.1 Waste Management and Circularity

TNB adopts a category category-based Waste Management Strategy (WMS), designed to ensure that each waste stream is managed according to its type, following regulatory requirements. Waste streams are managed according to their characteristics and relevant regulatory requirements, with applicable 4R principles - Reduce, Reuse, Recycle and Recovery - applied before safe disposal.

Scheduled waste is managed through established procedures covering classification, safe storage, packing and labelling, inventory control, disposal and monitoring. Coal ash is characterized and managed through plant-specific procedures, while fly ash and bottom ash are supplied through licensed and approved vendors for beneficial use where technically feasible.

TNB has also developed green products using Coal Bottom Ash, including cable trench covers, underground cable bases, concrete components, bricks and Green Cable Protection Slabs. In 2025, 5,400 concrete and 3,100 polymer Green Cable Protection Slabs were produced and installed for pilot testing at selected TNB project sites, supporting industrial-waste valorisation and resource efficiency.

Further reference: [*TNB Sustainability Report 2025, pp. 130–137.*](#)

7.6.2 Sustainable Assets and Materials

TNB assesses biodegradable ester-based transformer oils and high-energy-efficiency transformer designs. The evaluation considers biodegradability, leakage impact, fire safety, lifecycle performance, asset longevity, maintenance requirements and efficiency benefits. Used transformers, switchgear, transformer oil, e-waste and other hazardous materials are managed through licensed vendors for reuse, recovery or recycling. Further reference can be found in Section 2.5.3.

TNB also operates an SF₆ Recycling Centre to recover and recycle sulphur hexafluoride from high-voltage switchgear, reducing the need to source new SF₆ gas, cutting fugitive greenhouse-gas emissions and supporting responsible asset management. These initiatives complement the exploration of lower-impact materials and equipment across the electricity network.

7.6.3 Climate Resilience and Asset Lifecycle

TNB incorporates climate resilience, resource efficiency and sustainable asset practices into its broader infrastructure and sustainability planning. These efforts are aimed at strengthening the resilience of electricity assets, reducing environmental impact and improving the efficient use of resources. Detailed climate-resilience initiatives, risk-management approaches and performance disclosures are provided in the [*TNB Sustainability Report 2025*](#). Key 2025 initiatives and targets include:

- **Coal Ash Management** – In 2025, TNB generated 981,530.80 MT of coal ash, of which 523,545.94 MT (53%) was recycled for beneficial use, while 457,984.86 MT (47%) was sent for safe disposal.
- **Waste Reduction and Recycling** – TNB’s category-based Waste Management Strategy targets a 20% reduction in total waste generated and a 50% annual recycling rate by 2030, measured against a 2023 baseline.

- Sustainable Asset Technologies – TNB intends to complete the assessment of high-efficiency transformers and alternative insulating fluids by the end of 2027, supporting the adoption of more sustainable infrastructure solutions.

7.6.4 Repurpose Hydroelectric Station – Gemersek Pangsun

TNB also explores opportunities to extend asset value through adaptive reuse. One example is the repurposing of the Gemersek Pangsun Hydroelectric Station into a glamping destination, demonstrating how retired infrastructure can continue generating environmental, social and economic value. Details can be found here: [Tenaga Nasional Berhad’s Gemersek Pangsun](#).

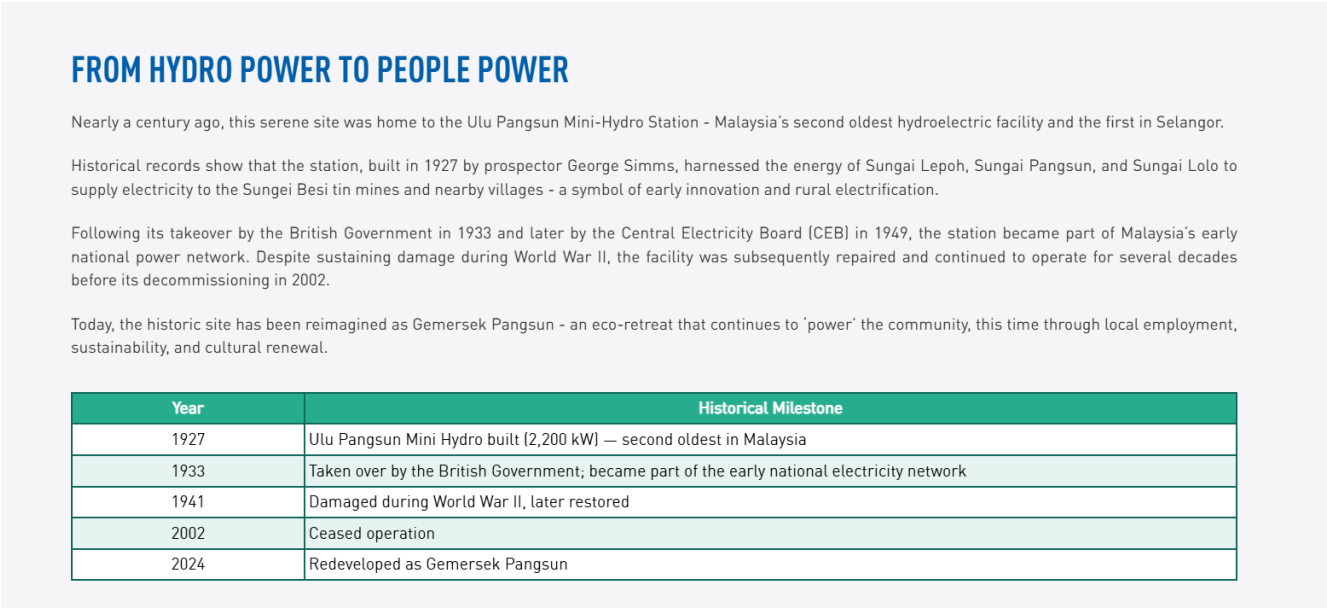


Figure 7.15: Repurposing Ulu Pangsun Mini-Hydro Station