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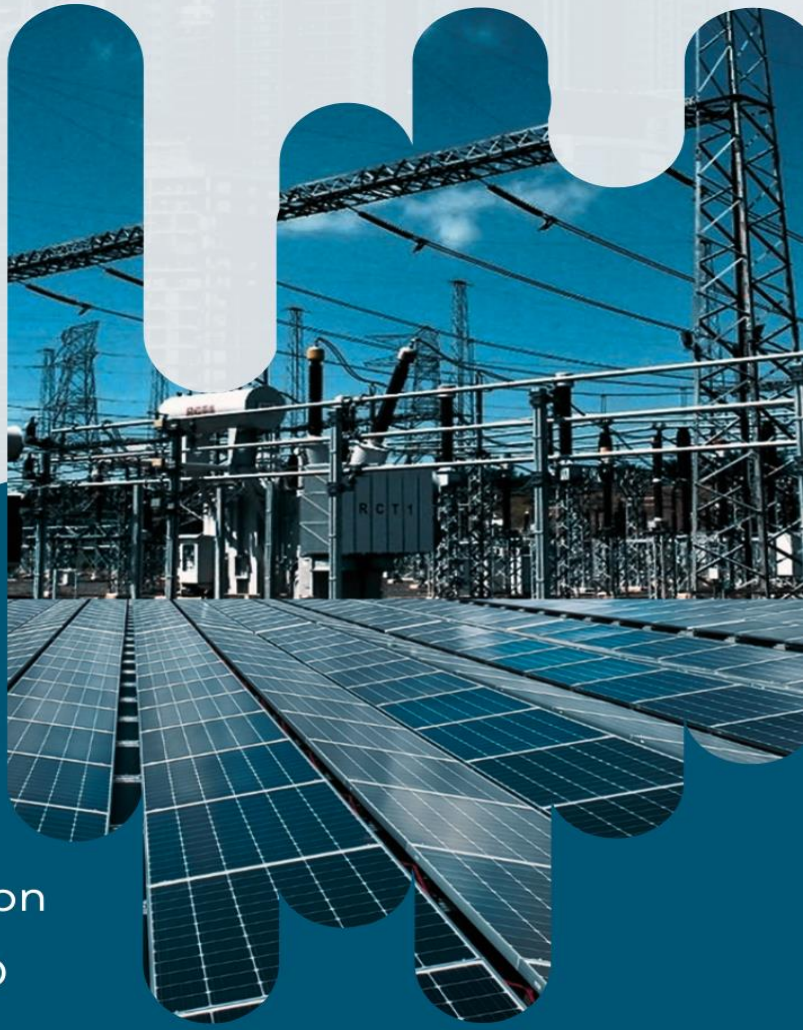
Application of Inverters to Mitigate Fault Current Contribution of Inverter-based Distributed Generation in Distribution Systems

2024



Distribution Network Division

TENAGA NASIONAL BERHAD

TECHNICAL GUIDELINES

APPLICATION OF INVERTERS TO MITIGATE THE FAULT CURRENT CONTRIBUTION OF INVERTER-BASED DISTRIBUTED GENERATION IN DISTRIBUTION SYSTEMS

December 2024

Distribution Network Division
Tenaga Nasional Berhad

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Foreword

In the evolving energy landscape, distribution networks must adapt to the increasing complexity resulting from the integration of renewable energy and advanced technological innovations. The growth of inverter-based distributed generation (DG) presents both opportunities and challenges in ensuring the stability, reliability and security of our distribution systems.

These technical guidelines for the *Application of Inverters to Mitigate the Fault Current Contribution of Inverter-Based Distributed Generation in Distribution Systems* address a critical issue: managing the fault current contribution of inverter-based DG to maintain the operational integrity of our networks. As Malaysia accelerates its energy transition, the adoption of such guidelines is critical to aligning our commitment to sustainability while maintaining the robustness of our distribution networks.

Through a collaborative effort involving experts from TNB Distribution Network Division and TNB Research Sdn. Bhd., these guidelines represent the culmination of rigorous research, practical insights and a forward-looking approach to addressing the challenges posed by inverter-based DG. The recommendations contained herein are designed to assist engineers, planners and technical teams in implementing effective solutions to mitigate fault current contributions, ensure system reliability and optimise grid performance.

As the distribution network becomes more dynamic with the increasing penetration of renewables and distributed generation, the role of technical guidance is essential. By adopting these practices, we can confidently navigate the complexities of grid modernisation while ensuring the reliability and security of electricity supply to our customers.

I encourage all stakeholders, including regulators and industry players, to engage deeply with the principles and recommendations presented in these guidelines. Together, we can drive innovation, enhance operational excellence and support Malaysia’s vision for a sustainable energy future.

Thank you.

Ir. Mahathir Nor bin Ismail
Chief Distribution Network Officer
Tenaga Nasional Berhad

Acknowledgement

The development of the technical guidelines for the *Application of Inverters to Mitigate the Fault Current Contribution of Inverter-Based Distributed Generation in Distribution Systems* represents a significant step forward in addressing the evolving challenges of modern distribution networks. These guidelines serve not only as a technical reference, but also as a testament to our commitment to fostering innovation, reliability and sustainability within the Distribution Network Division.

This achievement would not have been possible without the collective effort and expertise of an exceptional team. First and foremost, I would like to express my sincere gratitude to the visionary leadership of Tenaga Nasional Berhad and the Distribution Network Division, whose unwavering support and encouragement have been the cornerstone of this initiative. Their guidance has inspired us to strive for excellence in developing solutions to enhance the resilience and adaptability of our network.

I would like to acknowledge the invaluable contributions of the technical experts and practitioners whose insights and dedication have been instrumental in the development of these guidelines. Special thanks go to Ir. Hamdan bin Ali, Ir. Lim Chia Yih, Ir. Mohd Shukri bin Ismail, Ir. Ts. Musnazril bin Mustaq Khan, Ahmad Farid bin Mohd Perdaus, Ir. Mohd Fahri bin Zamri, Ir. Muhammad Hafizuddin bin Mohamad, Elmi binti Jani, Ir. Mohd Nazmi bin Abdul Raman and Ir. Ts. Mohammad Rhaiz bin Abdul Aziz @ Mohamad and the teams at TNB Research Sdn. Bhd., Ir. Dr Sheikh Kamar bin Sheikh Abdullah, Mohd Khairun Nizam bin Mohd Sarmin, Muhammad Syahir bin Turiman and Dr Farihan binti Mohamad, whose tireless efforts have ensured the quality and relevance of this document. Their collaborative spirit and technical acumen are greatly appreciated.

I would also like to thank the Energy Commission of Malaysia (ST), the Sustainable Energy Development Authority Malaysia (SEDA), the Malaysian Photovoltaic Industry Association (MPIA) and other stakeholders whose feedback and recommendations have enriched the content of these guidelines. Their input has been instrumental in aligning our efforts with regulatory requirements and operational objectives.

Finally, I would like to thank all the teams and individuals involved in the production, review and publication process, from technical drafting to final design and printing. Their dedication and attention to detail have made this vision a reality.

As we look to the future, I am confident that these guidelines will serve as an important tool in mitigating the challenges posed by inverter-based distributed generation and in supporting our journey towards a more sustainable and resilient energy future.

Thank you all for your contributions, hard work and unwavering commitment to excellence!

Prof. (Adj.) Ir. Ts. Zahari bin Dollah
Head (Asset Management)
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Contents

1.0 Definitions and Acronyms

1.1 Definitions

Terms	Definitions
Act	The Electricity Supply Act 1990 including any regulations made hereunder and any amendments thereto.
Apparatus	Any electrical apparatus and includes the device or fitting in which a conductor is used, or of which it forms part of.
Applicant	A company or person applying for **Short-Circuit Testing and Certification (SCTC)**.
Area EPS	An **EPS/System**, also referred to as a **Distribution System** that serves **Local EPSs/Embedded Distributor's Distribution System**.
Area EPS Operator	The entity, also referred to as the **Distribution System Operator (DSO)**, responsible for designing, building, operating, and maintaining the **Area EPS/Distribution System**.
Certificate Holder	A company or person who already has **SCTC**.
Connection Agreement	An agreement between the **Distributor/Embedded Distributor** and any other entity (owner of **Transmission System/Users**) setting out the terms relating to a connection with the relevant **Distribution System**.
Connection Point	Point of entry or exit of the **Distribution System**.
Consumer (Customer)	A person who is supplied with electricity or whose premises are for the time being connected for the purpose of supply of electricity by a supply authority or **Licensee**
Consumer With Own Generation	A **Consumer** with one or more **Generating Unit(s)** connected to the **Consumer's System**, with or without energy storage system, providing all or part of the **Consumer's** electricity requirements, and which may use the **Distributor's Distribution System or Distribution System of an Embedded Distributor** for the transport of any surplus of electricity being exported.

Terms	Definitions
Current Limiting Reactor (CLR)	An inductive coil having a large inductive reactance and is used for limiting **Short-Circuit Currents** during fault conditions.
DER Operator	The entity responsible for operating and maintaining the **DER**.
DG Operator	The entity responsible for operating and maintaining the **DG**.
Distributed Energy Resources (DER)	A source of electric power that is not directly connected to a bulk power system. **DER** includes both **Generating Units** and **Energy Storage Systems** capable of exporting active power to a **Distributor's Distribution System**.
Distributed Generation (DG)	A decentralised electricity generation, where a **Generator**, including a **Consumer With Own Generation**, whose **Generating Units** are directly connected to the **Distributor's Distribution System** or to the **Distribution System** of an **Embedded Distributor** which is connected to the **Distributor's Distribution System**, and not having any connection with the **Transmission System**.
Distribution Code	A code required to be prepared jointly by **Distributors** in Peninsular Malaysia, Sabah and F.T Labuan and approved by the commission as revised from time to time with the approval of, or by the direction of, the commission. It sets out the principles governing the relationship between the **GSO**, **EC**, **Customers** and all **Users** of the **Distribution System**.
Distribution System	The system of electric lines with voltage levels below 66 kV, within the area of supply owned or operated by the **Distributor**, for distribution of electricity from grid supply points or generating units or other entry points to the point of delivery to customers or other **Distributors** and includes any electrical plant and meters owned or operated by the **Distributor** in connection with the distribution of electricity.

Terms	Definitions
Distribution System Operator (DSO)	Person(s) responsible for the control and operation of all, or of part of a **Distribution System**, or the **System** of a **User** which operates at **Medium Voltage**.
Distributor	A person who is licensed under Section 9 of the Act and is connected to the grid system and distributes electricity for the purpose of enabling a supply to be given to any premises. “Distribute” means to operate, maintain and distribute electricity through the electricity distribution network.
Electric Power System (EPS)	Facilities that deliver electric power to a load, also referred to as a **System**.
Embedded Distributor	A person who distributes electricity under a **Licence** issued under the **Act** and whose **Distribution System** is connected to the **Distributor’s Distribution System** under a **Connection Agreement** and not having any connection with the **Transmission System;** and who is required to comply with the **Distribution Code** as a **User** at a **Connection Point** with the **Distributor’s Distribution System** and also as a **Distributor** in respect of his own **Distribution System**.
Energy Storage System	A device that stores energy to perform useful processes at a later time.
Equipment Under Test (EUT)	The equipment on which these tests are performed and refers to the utility-interconnected PV inverter.
Fault Current	See **Short-Circuit current**.
Fault Current Contribution	See **Short-Circuit Current Contribution**.
Fault Current Limiter (FCL)	A device which limits the prospective **Fault Current** when a fault occurs without adding impedance to the circuit during normal operation and therefore protecting the grid.
Fault Level	See **Short-Circuit Level**.
Generating Unit	Any **Apparatus** that produces electricity.
Generator	A person who generates electricity under **Licence** under the **Act**.
Grid System	**Transmission System** with directly connected **Generating Unit** and directly connected **Customers.**

Terms	Definitions
Grid System Operator (GSO)	Person(s) responsible for the control and operation of a **Transmission System** or the **System** of a **User** which operates at **High Voltage** or higher.
Guidelines	The Technical Guidelines for the "Application of Inverters to Mitigate the Fault Current Contribution of Inverter-based Distributed Generation in Distribution Systems"
High Voltage (HV)	A voltage normally exceeding **Medium Voltage** but equal to or not exceeding 230,000 volts.
Initial Symmetrical Short-Circuit Current (I_k")	The rms value of the AC symmetrical component of a **Prospective Short-Circuit Current**, applicable at the instant of **Short-Circuit** if the impedance remains at zero-time value.
Interconnection	The result of the process of adding **DER** to an **Area EPS/Distributor's Distribution System**, whether directly or via intermediate **Local EPS/Embedded Distributor's Distribution System** facilities.
Inverter	An **Apparatus** that converts direct current (DC) into alternating current (AC).
Inverter-based DG	A **DG** connected to the grid through a power **Inverter**.
Quality Certification Committee (QCC)	A committee responsible for governing and deciding **SCTC** certification applications.
Licence	A licence issued under section 9 of the **Act** and includes any licence issued under any other law enforced before the promulgation of the **Act**.
Licensee	A person licensed under section 9 of the **Act**.
Local Electric Power System (Local EPS)	An **EPS/System** contained entirely within a single premises or group of premises, also referred to as the **Distribution System** of an **Embedded Distributor** which is connected to the **Distributor's Distribution System**.

Terms	Definitions
Low Voltage (LV)	A voltage normally exceeding extra low voltage but not exceeding 1,000 volts alternating current or 1,500 volts direct current between conductors, or 600 volts alternating current or 900 volts direct current between conductor and earth.
Low Voltage Ride-Through (LVRT)	The ability of electric generators to remain connected during short periods of lower electric network voltage.
Medium Voltage (MV)	A voltage normally exceeding **Low Voltage** but equal to or not exceeding 50,000 volts.
Momentary Cessation	A temporarily cease to energise an **Electric Power System** in response to a disturbance of the applicable voltages or the system frequency, with the capability of immediate restore output of operation when the applicable voltages or the system frequency return to within defined ranges.
National Energy Transition Roadmap (NETR)	Malaysia's comprehensive strategic plan to steer the energy systems away from conventional, fossil fuel-based sources and towards cleaner, more sustainable alternatives.
Peak Short-Circuit Current (I_p)	The maximum possible instantaneous value of the **Prospective Short-Circuit Current**.
Prospective Short-Circuit Current	The current that would flow if the **Short-Circuit** were replaced by an ideal connection of negligible impedance without any change of the supply.
PV Simulator	A simulator that has I-V characteristics equivalent to a PV array.
Short-Circuit	An accidental or intentional conductive path between two or more conductive parts forcing the electric potential differences between these conductive parts to be equal or close to zero.
Short-Circuit Current	An over-current resulting from a **Short-Circuit** in an electric system.
Short-Circuit Current Contribution	A short-circuit current contribution from machines, devices or systems, such as **Inverters**.
Short-Circuit Level	The amount of current that flows on the system during a fault.

Terms	Definitions
Short-Circuit Testing and Certification (SCTC)	A series of in-depth evaluations of the **Short-Circuit Current Contribution** of **Inverters** to be integrated into the **Distribution System.**
Steady-State Short-Circuit Current (I_k)	The rms value of the **Short-Circuit Current** which remains after the decay of the transient phenomena.
Suruhanjaya Tenaga (ST)	The **Energy Commission (EC)** established under the Energy Commission Act 2001.
Sustainable Energy Development Authority (SEDA)	A statutory body formed under the Sustainable Energy Development Authority Act 2011 [Act 726].
Symmetrical Short-Circuit Current	The rms value of the AC symmetrical component of a **Prospective Short-Circuit Current**, the aperiodic component of current, if any, being neglected.
System	An electrical system in which all conductors and equipment are electrically or magnetically connected.
Technical Evaluation	The testing and evaluation of manufacturer's test product for compliance with specification, quality, and suitability in accordance with the process and dates outlined in the **Guidelines**.
Technical Evaluator	Person(s) from the Quality Assurance Unit, **TNB Labs**, responsible for conducting the **Technical Evaluation**.
Tenaga Nasional Berhad (TNB)	A Licensee that was issued a Licence on 1st September 1990 which authorises **TNB** to own and operate electricity generating, transmitting and distributing facilities and to supply energy to other persons therefrom.
Testing Agency	The test and verification authority responsible for performing type tests and overseeing production testing programs to verify conformance of the **DER** to the standard.
TNB Distribution Network (DN)	The Distribution Network Division of **TNB**.
TNB Labs	A wholly-owned subsidiary of TNB Research, a leading provider of quality assurance, scientific services, technical services and advanced diagnostic services.

Terms	Definitions
Transmission System	The system of electric lines with voltage levels at or above 66 kV owned or operated by the transmission system **Licensee**.
Type Test	A test of one or more devices manufactured to a certain design to demonstrate, or provide information that can be used to verify, that the design meets the requirements specified in these **Guidelines**.
User	A term used in various sections of the **Distribution Code** to refer to the persons using the **Distributor's Distribution System**, more particularly identified in each section of the **Distribution Code**, but excluding the **Transmission System Licensee** or **Grid System Operator**.

1.2 Acronyms

A/D	Analogue-to-Digital
AC	Alternating current
COMTRADE	Common format for Transient Data Exchange for power systems
CSV	Comma-Separated Values
DC	Direct current
DG	Distributed generation
GW	Gigawatts
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
kA	kiloampere
kV	kilovolt
LSS	Large-scale solar
NEM	Net Energy Metering
PDF	Portable Document Format
PQIF	Power Quality Data Interchange Format
PV	Photovoltaic
RE	Renewable energy
rms	Root mean square

2.0 Overview

2.1 Introduction

The Malaysian government has taken a substantial step towards addressing climate change and achieving its net-zero emissions target by 2050. In a recent announcement, the government released the **National Energy Transition Roadmap (NETR)** [3], which provides a comprehensive plan outlining the various measures to be implemented. The objective of these measures is to facilitate a transition in the country's energy sector towards the utilisation of cleaner and more sustainable sources.

A significant aspect of the roadmap is the prioritisation of renewable energy (RE). The government has revised its target for installed RE capacity, raising it from the current target of 40% by 2040 to an ambitious 70% by 2050. It is anticipated that this heightened ambition will be largely driven by the installation of solar photovoltaic (PV) systems. In order to achieve this objective, it will be necessary to witness a considerable expansion in solar capacity over the course of the next three decades, with a projected target of 59 GW of installed capacity by 2050.

As **Distribution Systems** evolve to accommodate the increasing penetration of renewable energy systems, a critical challenge is the management of **Fault Currents**. **Fault Currents**, which result from **Short Circuits** or other disturbances in the network, can present risks to the reliability of the system, the integrity of the equipment and the safety of personnel. The efficacy of conventional **Fault Level** management techniques, such as the utilisation of fixed impedance devices, such as **Current Limiting Reactors (CLRs)**, may be compromised or rendered impractical in the context of evolving network dynamics.

In response to these challenges, the deployment of **Inverters** represents a promising solution to mitigate the increasing **Fault Level** resulting from the integration of **Inverter-based Distributed Generation (DG)** into the **Distribution System**. **Inverters** offer the potential to actively control their **Fault Current Contribution** and thus reduce the stress on the grid during fault events.

		In light of the aforementioned feature, **TNB** is putting forth a novel proposition for prospective **DG Operators**, with the objective of mitigating the anticipated **Short-Circuit Current Contributions** from solar **Inverters** in areas characterised by high **Fault Levels**. However, in order to realise the full potential of **Inverters** for **Fault Level** mitigation, it is first necessary to gain a comprehensive understanding of their performance characteristics and operational capabilities.
2.2	Scope of Guidelines	The **Guidelines** focus on the management of **Fault Levels** through **Inverter** applications for the integration of **Inverter-based DGs** with a capacity of more than 425kW into existing high **Fault Level** areas in the **Distribution System**. It places particular emphasis on adherence to standards, comprehensive test procedures and the interpretation of results, with specific reference to maximum **Short-Circuit Current Contribution** and controlled **Short-Circuit Current Contribution**.
2.2.1	Fault Level Mitigation Strategies	The **Guidelines** address the increase in **Fault Levels** due to the integration of **Inverter-based DG** into the **Distribution System**. This is achieved by utilising the capabilities of **Inverters** through current limiting techniques, which serve to reduce the **Inverter Short-Circuit Current Contribution**.
2.2.2	Compliance Requirements	The **Guidelines** address compliance with relevant regulatory standards and industry specifications for the integration and operation of **Inverters** in **Distribution Systems**.
2.2.3	Testing and Evaluation Procedures	The **Guidelines** set forth comprehensive procedures for assessing the maximum **Short-Circuit Current Contribution** of **Inverters** and their ability to control **Short-Circuit Currents** during fault events. This includes the configuration of the test setup, the instrumentation required, the data collation, the methodologies used in the data analysis, and the format of the resulting report. This type test is mandatory for **DG Operators** opting to mitigate **Fault Levels** using **Inverters** for **Inverter-based DGs** with a capacity greater than 425kW in existing high **Fault Level** areas of the **Distribution System**.

2.2.4	Interpretation of Test Results	The **Guidelines** provide guidance on the interpretation and analysis of test results obtained from **Inverter Short-Circuit** tests, including assessment of maximum **Short-Circuit Current Contribution**, and controlled **Short-Circuit Current Contribution**.
2.3	Purpose	The purpose of these **Guidelines** is to establish a systematic framework for the assessment and implementation of mitigation strategies utilising **Inverters** in response to the rising **Fault Level** resulting from the integration of **Inverter-based DG** into **Distribution Systems**. The objective of these **Guidelines** is to facilitate the integration of **Inverter** technologies into **Distribution Systems** while ensuring safety, reliability and compliance with regulatory requirements. This will be achieved by establishing standardised test procedures and best practices.
2.4	Right to Amend Guidelines	**TNB** reserves the exclusive right to amend, modify or revise any clause, requirement or provision of these **Guidelines** at its sole discretion without prior notice to any party. It is the **Applicant's** responsibility to ensure compliance with the latest version of the **Guidelines**. By submitting an application or continuing to comply with the requirements set forth herein, the **Applicant** acknowledges and agrees to comply with any updates or changes made by **TNB**.

3.0 Impact of Increased Fault Levels and Mitigation Measures

3.1 Types of Fault Currents

Protection systems are an essential component of the design and operation of power systems. Their primary function is to detect anomalies between phases or between phases and the ground. The formation of accidental conduction paths results in a **Short-Circuit** phenomenon, whereas the blocking of current gives rise to an open-circuit phenomenon. In the majority of instances, **Short-Circuit** faults are more prevalent; thus, the term “fault” is typically employed to denote a **Short-Circuit** [4].

The occurrence of a **Short-Circuit** is contingent upon the contact of energised electrical components at different voltages. This results in a reduction of impedance between nodes to a near zero value, thereby redirecting the current from its intended path. **Short circuits** have the potential to release currents that are orders of magnitude larger than the normal operating current, which can result in the generation of heat and magnetic force, as well as damage to equipment and endanger safety.

The most common causes of faults in **Distribution Systems** are insulation breakdown, mechanical issues and thermal issues [5]. Insulation breakdown is caused by system overvoltage, which can result from lightning strikes and switching surges, as well as from improper fabrication or installation, or from the ageing or contamination of the insulation. Mechanical issues may be caused by contact with animals or trees, vehicle collisions, or natural disasters. Thermal issues may arise as a consequence of overcurrent or overvoltage conditions.

Faults can be classified into two main categories: symmetrical and asymmetrical. Symmetrical faults, defined as three-phase faults, result in balanced fault conditions, frequently accompanied by the occurrence of high **Fault Currents**. Asymmetrical faults occur when the current flow between phases is unbalanced, resulting in the generation of currents with different magnitudes and phase angles. Examples of asymmetrical faults include line-to-line, line-to-ground and double line-to-ground faults.

Distribution substations are designed to withstand **Short-Circuit Currents**. However, it is not possible to completely eliminate **Short Circuits**. Instead, the goal is to detect and clear the fault quickly while minimising its impact.

3.2 Fault Current Contribution from DG

The contribution of **DGs** to **Fault Currents** is dependent on the specific type of **DG**, which can be broadly classified as synchronous generators, induction generators, and **Inverter**-based units. However, the response of each type to a fault and its contribution to the **Fault Current** may vary.

The contribution of **Inverter-based DGs** to **Fault Current** has been demonstrated to be no greater than 200% of their rated current in a number of studies [6]-[10]. The **Fault Current Contribution** of different types of **DG** can be summarised in Table 3-1.

Table 3-1. Estimation of **Fault Current Contributions** for different types of **DGs** [11].

Type of DGs	Fault Current Contributions
Inverter-based	1-2 times the **Inverter** rated current, with a duration spanning from a half cycle to several cycles, depending on the control method employed.
Synchronous generator with separate exciter source	5-10 times the generator rated current in sub-transient and transient cycles, 2-4 times the generator rated current in steady-state condition.
Inductor generator or self-excited generator	5-10 times the generator rated current in the first few cycles, negligible after 5-10 cycles.

Furthermore, the influence of **DGs** on **Fault Level** is also contingent upon the following factors [12]:

- The distance of the **DG** from the fault, as the increased cable impedance over longer distances will reduce the **Fault Current**.
- Whether or not there is a transformer between the fault location and the contributing **DG** (which is often the case for voltage regulation purposes), as the **Short-Circuit** impedance of the transformer can help to limit the **Fault Current**.

- The configuration of the network between the **DG** and the fault, as different paths for the flow of the **Fault Current** will alter the magnitude of the **Fault Current** (due to cable impedances and other installed equipment).
- The method of coupling the **DG** to the network. Directly connected **DGs** will contribute significantly higher **Fault Currents** than **DGs** connected via power electronic interfaces.

3.3 Impact of High Fault Current

The increasing prevalence of **DGs** in **Distribution Systems** has been observed to correlate with an increase in **Short-Circuit Currents**, which can exacerbate the severity of downstream faults [13]. Although a single **DG** may not have a considerable impact on **Fault Currents**, the collective effect of multiple **DG** connections can significantly disrupt **Fault Current** levels and protection systems. [14].

The occurrence of high **Fault Currents** can result in thermal stress within power system equipment, due to the resistive heating that ensues as a consequence of the increased current flow. Such a sudden rise in temperature has the potential to accelerate the deterioration of the insulation materials used in these components. To illustrate, in a transformer, an elevated temperature results in accelerated deterioration of the insulating materials situated between the windings. This deterioration diminishes the dielectric strength and heightens the probability of insulation failure.

Similarly, power cables are susceptible to thermal damage to their insulation, which reduces the insulation resistance and increases the likelihood of faults. Even circuit breakers, which are designed to interrupt **Fault Currents**, are not immune to thermal stress on their contacts due to arcing during fault clearance [15].

Furthermore, high fault contributions from **DGs** can render some relays to be blinded [16]. Changes in the **Fault Levels** within the power system can affect the operation of protection devices. The integration of the **DG** would have negative impacts on these devices, including [14]:

- Reverse power flow
- False tripping
- Blinding of protection
- Unintentional islanding
- Unsynchronised reclosing
- Loss of main supply

3.4	Mitigation Measures for Increased Fault Levels	Clause 5.4.9 of the **Distribution Code** stipulates that the **DG Operator** is obliged to minimise its **Fault Current** contribution in response to a reasonable request from the **Distributor**. Mitigation measures for increased **Fault Levels** include the introduction of higher impedances, such as the utilisation of **Current Limiting Reactors (CLRs)** or transformers with higher short-circuit impedance. These measures serve to restrict the magnitude of **Fault Currents**. However, this may result in an increase in network losses and the necessity for maintaining the voltage profile. Conversely, **Fault Current Limiters (FCLs)** are capable of detecting the rapid rise in **Fault Current** and injecting a pyrotechnic charge to open the main current path. Nevertheless, this necessitates the replacement of contacts and fuses following each operation.
3.5	Inverter Momentary Cessation	**Momentary Cessation**, also referred to as “blocking”, is defined as the phenomenon of no current being injected into the grid by the **Inverter** during low or high voltage conditions that fall outside of the continuous operating range. The phenomenon of **Momentary Cessation** can be attributed to the blocking of power electronic firing commands, which in turn prevents the **Inverter** from generating active or reactive current (and, consequently, no active or reactive power) [17].

4.0 Regulatory Framework and Standards

4.1 Relevant Regulations and Standards

The effective implementation of **Inverter** applications to mitigate increased **Fault Levels** in the **Distribution System** necessitates compliance with the various regulations and standards set forth by regulatory authorities and industry organisations. These regulations and standards, enumerated in Table 4-1, provide guidelines and requirements for the deployment and operation of **Inverter** technology in the **Distribution System**.

Table 4-1. Regulations and standards relevant to the integration of **Inverter**.

No.	Regulation	Standards & Guidelines
1.	Suruhanjaya Tenaga (ST)	Distribution Code for Peninsular Malaysia, Sabah & F.T. Labuan
2.	Suruhanjaya Tenaga (ST)	Guidelines on Large Scale Solar Photovoltaic Plant for Connection to Electricity Networks
3.	Suruhanjaya Tenaga (ST)	Guidelines for Solar Photovoltaic Installation Under the Programme of NEM Rakyat and NEM GoMEn in Peninsular Malaysia
4.	Suruhanjaya Tenaga (ST)	Guidelines on the Connection of Solar Photovoltaic Installation for Self-Consumption
5.	Tenaga Nasional Berhad (TNB)	Electricity Supply Application Handbook (ESAH)
6.	Tenaga Nasional Berhad (TNB)	Technical Guidelines for Interconnection of Distributed Generator to Distribution System
7.	Tenaga Nasional Berhad (TNB)	Technical Guideline for Connection of Indirect Solar PV Power Generation for Net Energy Metering (NEM 3.0)
8.	International Electrotechnical Commission (IEC)	IEC 60909-0: 2016: Short-circuit currents in three-phase a.c. systems – Part 0: Calculation of currents
9.	Institute of Electrical and Electronics Engineers (IEEE)	IEEE Std 1547-2018: IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces

4.2	Compliance Requirements for Inverters	Compliance with the various regulatory requirements and industry standards ensures that **Inverters** meet the specified performance criteria and safety standards, thereby enabling them to be seamlessly integrated and operated within **Distribution Systems**.

4.2.1	Short-Circuit Current in Three-Phase A.C. Systems (*IEC 60909-0:2016*)	A complete calculation of **Short-Circuit Currents** should yield a representation of the currents as a function of time at the location of the **Short-Circuit**, from the inception of the **Short-Circuit** until its end. This representation should correspond to the instantaneous voltage value at the outset of the **Short-Circuit** (see Figure 4-1).

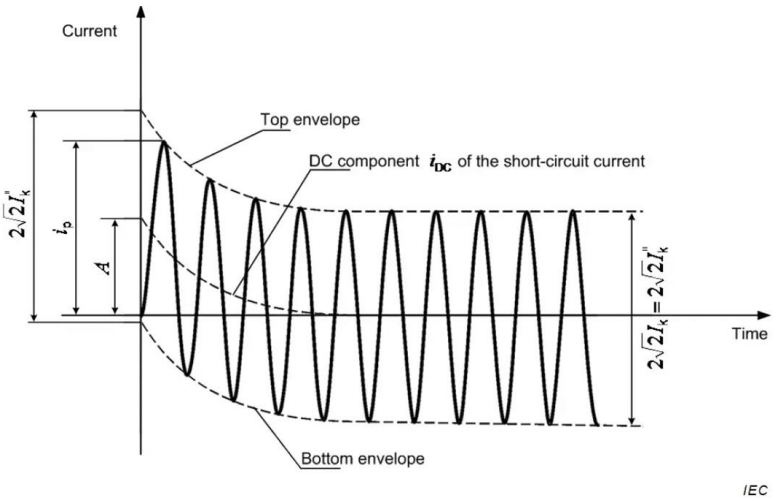

Figure 4-1. **Short-Circuit Current** with constant AC component.

I_p	is **Peak Short-Circuit Current**
I_k"	is **Initial Symmetrical Short-Circuit Current**
I_k	is **Steady-State Short-Circuit Current**
i_{DC}	is decaying (aperiodic) component of **Short-Circuit Current** or DC component
A	is initial value of the DC component i_{DC}

4.2.2	Connection Requirements (*Distribution Code: 7.8.3.4*)	The generation must comply with the planning and criteria specified in section 5.4 of the Distribution Planning Code and the operation criteria specified in section 6.5 of the Distribution Operating Code, as well as the standard practices on the **Distributor's Distribution System**. The **TNB** and **SEDA** technical guides provide guidance on planning and design. The **Distributor** and the customer must agree in writing on the particular technical requirements for connection, including **Fault Level**.

4.2.3 Short-Circuit Levels (*Distribution Code: 5.4.9*)

The **Distribution System** must be designed to withstand the maximum sub-transient three-phase symmetrical **Short-Circuit Fault Levels** without exceeding 90% of the switchgear's **Short-Circuit** breaking and making capacity. Furthermore, the short-time current rating of the connected equipment must be within 90% of the **Short-Circuit Current** rating of the **Distribution System**.

Short-Circuit Levels must be calculated in accordance with IEC 60909, taking into account the contribution of generating units and motors to the **Short-Circuit Levels**.

The **DG Operator** must provide the **Distributor** with details of the design **Short-Circuit Level** and the actual prospective maximum upon request. The **DG Operator** must also minimise its **Fault Current Contribution** on reasonable request from the **Distributor**.

4.2.4 Short-Circuit Ratings (*ESAH: 1.1.4.5*)

All equipment proposed for installation and connection to **TNB** supply must comply with the following **Short-Circuit** ratings:

Table 4-2. Equipment **Short-Circuit** ratings.

System	Short-Circuit Rating
500 kV	50 kA, 1s
275 kV	40 kA, 3s for bulk station (50kA , 1s for Power Substation and 275kV within 500kV substation)
132 kV	31.5 kA, 3s (40kA, 3s for substation adjacent to Power Station, or within 500/275kV substation)
33 kV	25 kA, 3s
22 kV	20 kA, 3s
11 kV	20 kA, 3s
6.6 kV	20 kA, 3s
400/230 V	31.5 kA, 3s

4.2.5 Low Voltage Ride-Through (*Distribution Code: 6.5.5.1*)

In the event of a disturbance in the transmission system, the **Distribution System** may experience a temporary low voltage or sag. The LSS plant must maintain continuous operation even during fluctuations in the **Distribution System** voltage, as the **LVRT** curve requirements shown in Figure 4-2.

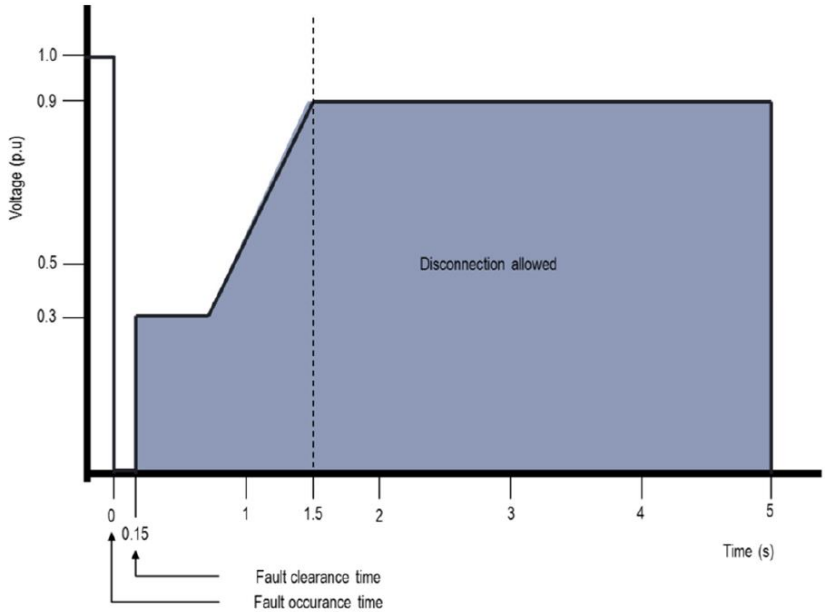

Figure 4-2. **LVRT** curve requirements in **Distribution System**.

4.2.6	Low Voltage Ride-Through Performance (*IEEE Std 1547-2018: 6.4.2.3.3*)	For Category III **DER**[1], during temporary voltage disturbances, for which the applicable voltage on the phase that has the least voltage magnitude is within the **Momentary Cessation** operation region, the **DER** • Shall not trip. • Shall cease to energise. • Shall restore output as specified in 6.4.2.7 of IEEE Std 1547-2018.
4.2.7	Fault Current Characterisation for Electronically Coupled DER (*IEEE Std 1547-2018: 11.4.2*)	The objective of **Fault Current** characterisation is to determine the controller response of the **DER** under certain fault conditions. The **DER Operator** must provide the **Distribution System Operator**[2] with oscillographic voltage and current data for all three phases measured during **Type Testing**. The sequence impedance characteristics of the external source used during the **DER Type Tests** must be provided. The **DER** must be type tested for maximum **Short-Circuit Current** levels.

[1] IEEE 1547-2018 Category III compliant **Inverters** that are required to use **Momentary Cessation** in specific circumstances.
[2] **Distribution System Operator** refers to **Area EPS Operator** in IEEE Std 1547-2018.

5.0 Short-Circuit Test for Utility-Interconnected Inverters

5.1 Purpose	These requirements are in place to ensure that the **Inverter-based DG** responds as intended to **Short-Circuit** faults in the **Distribution System** in accordance with the technical specifications of IEC TS 62910-2020 [1], and the test procedures of IEEE Std 1547.1-2020 [2]. The fault response characterisation of the device must be performed using the test procedures specified in this subsection.
5.2 Scope	These requirements set out a definitive test procedure for evaluating the **Short-Circuit Currents** of utility-connected **Inverters**, including direct and indirect connections. These procedures are primarily intended for large-scale systems where **Inverters** are connected to utility **Medium Voltage (MV) Distribution Systems**. However, these requirements can also be applied to **Low Voltage (LV)** installations in areas where there is a requirement to mitigate increased **Fault Levels**. The assessment of the **Short-Circuit Current** performance is specific to the configuration and mode of operation of the **Inverter** under test. The **Inverter** must be assessed in each of its factory or user-defined configurations, as variations can affect their **Short-Circuit Current** performance. The measurement procedures are designed to be universally applicable. This ensures that the **Short-Circuit Current** characteristics observed at one test site remain applicable to all other sites.
5.3 Test Circuit and Equipment	The circuits and equipment described in this subsection are developed to allow tests that simulate the full range of anticipated grid faults, including: • Single phase to ground fault (any phase). • Two phase isolated fault, between any two phases. • Two phase grounded fault, involving any two phases. • Three phase **Short-Circuit** fault. A full discussion of these faults may be found in Annex A of IEC TS 62910-2020. The grid simulator described in 5.3.3 is informative examples and are not intended to restrict design flexibility. Other designs may be used to achieve equivalent test functionality.

5.3.1 Test Circuit

The test circuit comprises a DC source, the **EUT**, a grid fault simulator, and the grid. A **PV Simulator** (or PV array) provides input energy for the **EUT**. The output of the **EUT** is connected to the grid via a grid fault simulator, as shown in Figure 5-1.

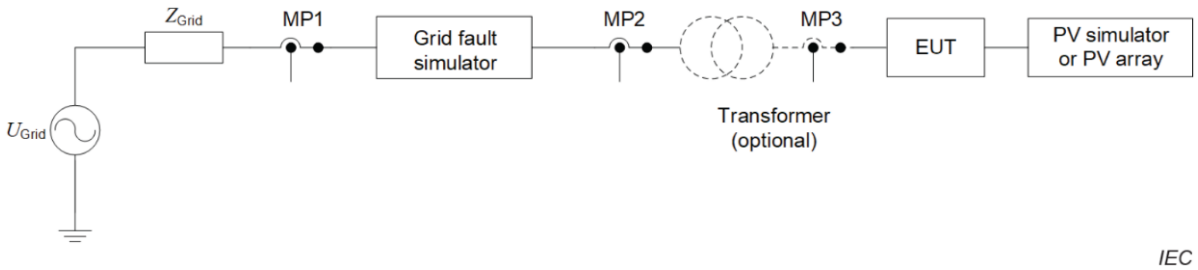

Figure 5-1. Testing circuit diagram.

NOTE MP1 is the measurement point between the grid and the grid fault simulator; MP2 is the measurement point at the high voltage side of the transformer (optional); MP3 is the measurement point at the **Low Voltage** side of the transformer.

5.3.2 Test Equipment

The test equipment shall be as specified in this subsection.

5.3.2.1 Measuring Instruments

The waveforms shall be measured using a device with a memory function, such as a storage or digital oscilloscope or a high-speed data acquisition system. The oscilloscope or data acquisition system shall have an accuracy of at least 0.2% of full scale. The measuring instrument's analogue-to-digital (A/D) converter shall have a resolution of at least 12 bits to maintain the required measurement accuracy.

Voltage and current transformers are the sensors required for measurement. The transducers shall have an accuracy of 0.5% of full scale or better. It is necessary to select the transducer measuring range based on the normal value of the signal to be measured. The selected measuring range shall not exceed 150% of the normal value of the measured signal. Table 5-1 sets out the transducer accuracy requirements.

Table 5-1. Accuracy of measurements.

Measurement Device	Accuracy
Data acquisition device	0.2% full scale
Voltage transformer	0.5% full scale
Current transformer	0.5% full scale

5.3.2.2 DC source

A PV array, PV array simulator or controlled DC source with PV characteristics may be used as the DC power source to supply input energy for the **Short-Circuit** test. The DC power source used as the input source for the **EUT** shall be capable of supplying the maximum input power to the **EUT** and other power levels during the test, at the minimum and maximum input operating voltages of the **EUT**.

The **PV Simulator** shall emulate the current/voltage characteristics of the PV module or PV array for which the **EUT** is designed. A **PV Simulator** should have a response time that is no longer than the MPP tracking response time of the **EUT**.

In the case of an **EUT** without galvanic isolation between the DC and AC side, the output of the **PV Simulator** should not be earthed.

The equivalent capacitance between the **PV Simulator** output and the earth should be as low as possible to minimise the impact on the **EUT**.

A PV array used as the **EUT** input source should be capable of matching the **EUT** input power levels specified by the test conditions. The test period should be selected to ensure that the solar irradiance remains stable and does not vary by more than 5% throughout.

5.3.3 Converter-based Grid Simulator

The test circuit utilising a back-to-back converter is shown in Figure 5-2. The test circuit is comprised of a voltage source with low internal resistance, which can be combined with broadband amplifiers (linear or forced switching type) capable of faithfully reproducing three sinusoidal voltages with controlled harmonic content and adjustable amplitude, fundamental frequency, and phase relationship within broad margins.

The converter shall meet the following requirements when used:

- It shall be capable of independently controlling the amplitude and phase angle of the three phases.
- It shall incorporate impedances ZA, ZB, and ZC, which can be adjusted to reproduce the ohmic and inductive components of the **Short-Circuit** impedances typical of the grid.
- It shall be capable of reproducing the phase voltages and relative phase angles occurring on the **LV** side of the transformers in the event of each of the various fault types.

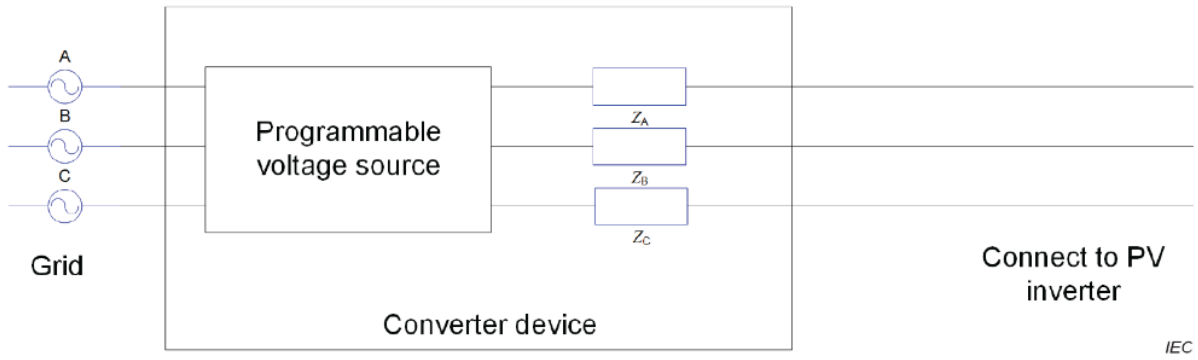

Figure 5-2. Converter device example.

In the event that the programmable voltage source is of the bi-directional, controlled output voltage type and is capable of replicating the influence of **Short-Circuit** impedances that are typical of the grid, it may be possible to omit the impedances ZA, ZB, and ZC.

5.4 Type Test

The tests to characterise the **Inverter-based DG** response to **Short-Circuit** faults on the **Distribution System** must be carried out in accordance with the requirements set out in this subsection.

5.4.1 Test Protocol

The **Short-Circuit** test protocol is designed to verify that the **EUT** responds appropriately to voltage drops (due to grid faults). The **EUT** must demonstrate that it can:

- Appropriately detect the simulated fault.
- Ride through the event and continue operation as specified in the applicable curves.
- Not suffer any damage from the event.

The response to the voltage drop specified in Table 5-2 shall be recorded over the **EUT** operating period with two ranges of output:

a) part load (between 0.1 *Pn* and 0.3 *Pn*);
b) full load (above 0.9 *Pn*);

and with two fault conditions:

c) three-phase drop;
d) two-phase drop or single-phase drop.

The tests should be carried out at least twice at each test point listed in Table 5-2.

Table 5-2. Test specification for **Short-Circuit Current**.

Drop Depth [a]	Minimum Duration [b]	Drop Phase [c]	EUT output conditions [d]
0%	0.15 seconds	Three-phase	Full load (above 0.9 *Pn*)
			Part load (0.1 *Pn* and 0.3 *Pn*)
		Two-phase	Full load (above 0.9 *Pn*)
			Part load (0.1 *Pn* and 0.3 *Pn*)
		Two-phase to ground	Full load (above 0.9 *Pn*)
			Part load (0.1 *Pn* and 0.3 *Pn*)
		Single-phase to ground	Full load (above 0.9 *Pn*)
			Part load (0.1 *Pn* and 0.3 *Pn*)
30%	0.7 seconds	Three-phase	Full load (above 0.9 *Pn*)
			Part load (0.1 *Pn* and 0.3 *Pn*)
		Two-phase	Full load (above 0.9 *Pn*)
			Part load (0.1 *Pn* and 0.3 *Pn*)
		Two-phase to ground	Full load (above 0.9 *Pn*)
			Part load (0.1 *Pn* and 0.3 *Pn*)
		Single-phase to ground	Full load (above 0.9 *Pn*)
			Part load (0.1 *Pn* and 0.3 *Pn*)
60%	1.1 seconds	Three-phase	Full load (above 0.9 *Pn*)
			Part load (0.1 *Pn* and 0.3 *Pn*)
		Two-phase	Full load (above 0.9 *Pn*)
			Part load (0.1 *Pn* and 0.3 *Pn*)
		Two-phase to ground	Full load (above 0.9 *Pn*)
			Part load (0.1 *Pn* and 0.3 *Pn*)
		Single-phase to ground	Full load (above 0.9 *Pn*)
			Part load (0.1 *Pn* and 0.3 *Pn*)
90%	1.5 seconds	Three-phase	Full load (above 0.9 *Pn*)
			Part load (0.1 *Pn* and 0.3 *Pn*)
		Two-phase	Full load (above 0.9 *Pn*)
			Part load (0.1 *Pn* and 0.3 *Pn*)
		Two-phase to ground	Full load (above 0.9 *Pn*)
			Part load (0.1 *Pn* and 0.3 *Pn*)
		Single-phase to ground	Full load (above 0.9 *Pn*)
			Part load (0.1 *Pn* and 0.3 *Pn*)

[a] Drop depth is the residual voltage during the **LVRT** test period which meets the requirements specified in 4.2.5.

[b] The minimum duration times are cumulative including all prior test conditions in the sequence at the same or lower magnitude.

[c] Drop phase should be agreed prior to the test; the value of two-phase voltage should be the line voltage.

[d] The test should be carried out at a specified K-factor provided by the manufacturer meeting any additional requirements imposed by **Distribution Code** and/or local guidelines. The recommended K-factor setting is 2.

5.4.2 Test Curve	The **LVRT** response characteristic shall meet the requirements of the **LVRT** curve specified in 4.2.5. The **EUT** should continue to operate without disconnection for 0.15 seconds when the voltage drops to 0% of the rated voltage; for 0.7 seconds when the voltage drops to 30% of the rated voltage; and for 1.5 seconds when the voltage drops to 90% of the rated voltage.
5.4.3 Test Procedure	This test procedure provides a means manufacturers, utilities or independent **Testing Agencies** to verify the suitability of **Inverters** for connection to the **Distribution System**. Certification through this process is the guarantee that the equipment has been proven to be suitable for its intended use by all relevant parties.
5.4.3.1 Pre-Test	Prior to the fault simulation tests, the **EUT** should run in normal operating mode. The **LVRT** curve specified in 4.2.5 should be used to identify voltage drop points, including the highest, lowest, and inflection points, as well as other random points in the curve.
5.4.3.2 No-Load Test	Prior to the load test, the fault emulator shall be adjusted to simulate symmetrical and asymmetrical voltage drops without the **EUT** connection and to validate that the measured results are as intended. This step ensures that the amplitude of the voltage and the duration of the drop can match the requirements in Figure 5-3.
5.4.3.3 Tolerance	The tolerances for the depth and duration of the voltage drop during the no-load test shall be in accordance with the requirements set out in Figure 5-3. The tolerance for the voltage magnitude is ±5% of the rated voltage for the period before and during the voltage drop. The tolerance for the voltage magnitude is ±10% of the rated voltage during the period after the voltage has been recovered. The tolerances shall be measured between 0 and +5% of the rated voltage for the lowest point and the inflection point under no-load conditions and the tolerances shall be measured between -5% and 0 of the rated voltage for the highest point under no-load conditions.

The duration of each voltage drop is determined according to the requirements of the applicable **LVRT** curve. The tolerance range for drop and rise duration is preferably 40 ms.

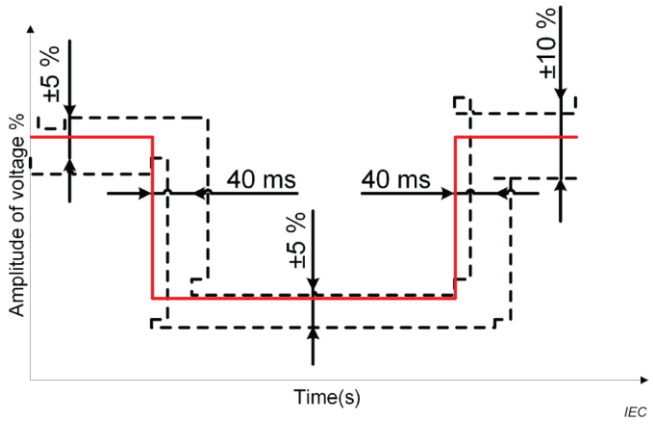

Figure 5-3. Tolerance of voltage drop.

5.4.3.4 Load Test

Tests under load shall be carried out only after the no-load test results have successfully met the performance requirements. The parameters of the grid fault simulator should be consistent with the no-load test.

With the **EUT** connected to the grid fault simulator device and the **PV Simulator** (or PV array), the output power should be set to (0.1 ~ 0.3) *P*n and above 0.9 *P*n separately. Additional load tests at other power levels should be performed in accordance with the specific requirements set out in 5.4.1 of these **Guidelines**.

During the **Short-Circuit** test, MP1, MP2, and MP3 (shown in Figure 5-1) shall be selected as the test points for measuring and recording voltage and current values.

The waveform and data of the measured voltage and current at the measuring points shall be recorded by the data acquisition device from time *A* prior to the voltage drop to time *B* after the subsequent voltage rise.

5.5 Assessment Criteria

5.5.1 Maximum Short-Circuit Current Contribution

Measure and analyse the peak current response of the **Inverter** during a **Short-Circuit** fault under various load conditions. Determine the highest level of current contributed to the fault by the **Inverter**.

Immediately after the **Short-Circuit** fault occurs, evaluate the response of the **Inverter**. Determine how quickly the **Inverter** detects the fault and begins to limit its contribution to the **Fault Current**.

The steady-state response of the **Inverter** to the **Short-Circuit** fault must be analysed. The **Inverter** must be able to maintain continuous operation while limiting its contribution to the **Fault Current** within acceptable limits.

5.5.2 Controlled Short-Circuit Current Contribution

The **Inverter** must be able to control **Short-Circuit Currents** to 0%. Ensure that the peak current response of the **Inverter** during a **Short-Circuit** fault remains within the specified limit of 0% by carrying out a thorough measurement and analysis. The initial response of the **Inverter** to the **Short-Circuit** fault must be examined to verify its ability to rapidly adjust and control the current output to 0%.

The **Inverter** must be evaluated to confirm its ability to maintain the **Short-Circuit Current** at 0% for the duration of the fault. The allowable tolerance of the **Short-Circuit Current** must be less than 10%. It is essential to confirm that the **Inverter** effectively controls the current output to prevent any deviation from the desired level.

5.6 Data Requirements

The line-to-ground voltage waveform, each phase current waveform, and the neutral current waveform measured at MP1, MP2 and MP3 (for the test circuit in Figure 5-1) for each **Short-Circuit Current** type tested shall be provided, such as in COMTRADE (IEEE Std C37.111) or PQDIF (IEEE Std 1159.3) format, at a minimum sampling rate of at least 10 kHz. The data window shall include a minimum of 100 ms of pre-fault data and shall be sufficiently long to capture the entire **Short-Circuit Current** transient.

The data should be accompanied by a clearly labelled diagram of the test setup, including descriptions of the elements and parameters used in the test. The **EUT** parameters (e.g. K-factor and priority mode) and input power source (e.g. DC source) that affect the **EUT Short-Circuit Current** response should be provided. The test data shall include the AC source complex positive, negative and zero-sequence impedances and source voltage.

6.0 Short-Circuit Testing and Certification of Inverters

6.1 Overview

The **Short-Circuit Testing and Certification (SCTC)** scheme comprises a series of comprehensive assessments of the **Short-Circuit Current Contribution** of **Inverters** intended for integration into the **Distribution System**. In order to demonstrate that it is capable of minimising the effects of **Short-Circuit Current Contributions** in accordance with the specifications set out in these **Guidelines**, the **Inverter** must undergo the requisite certification process.

The certificate is valid for an indefinite period, provided that no modifications are made to the product that could potentially impact the performance of the **Inverters** in mitigating **Fault Current Contributions**. **Certificate Holders** are obliged to adhere to the established certification standards, including both hardware and software modifications. Failure to comply with these standards may result in the suspension of certification, and in the event of continued non-compliance after a designated period, the certification may be revoked.

This section provides a detailed description of the **SCTC** scheme for **Inverters** for **DN**. The document serves to direct all pertinent parties through the certification process.

6.2 Types of Applicants

A single certificate shall be issued for each product. In the event that an overseas manufacturer has multiple local trading companies, only one of these trading companies is permitted to submit an application on behalf of the overseas manufacturer.

Only four (4) categories of business entities are eligible to apply for this certification.

- Local Manufacturer: A company that produces goods within the country in which the certificate is being sought. It is incumbent upon the **Applicant** to undertake manufacturing process of at least one major component of the product, assemble the product to completion, conduct testing and carry out all activities in the country.
- Local Assembler: A company that carries out the final assembly of a product in the country of manufacture. It is incumbent upon the **Applicant** to assemble the product to completion, conduct testing and perform all activities within the country.

- Overseas Manufacturer: A company that manufactures products outside of the country in which the certificate is being sought. The **Applicant** is required to undertake the manufacturing process of at least one major component of the product, assemble the product to completion, conduct testing and carry out all activities overseas.
- Design Houses: The **Applicant** is the proprietor of the design of the product, conduct testing and provide a report on the product.

6.3 Quality Certification Committee (QCC)

This subsection sets out the roles and responsibilities of all parties involved in the **SCTC** scheme. The **TNB Quality Certification Committee (QCC)**, is responsible for the governance and decision-making processes relating to **SCTC** certification applications. This includes approving or rejecting new applications and suspending or revoking existing certifications as necessary.

A quorum for a **QCC** meeting **Inverter Certification** shall consist of a minimum of the following members:

- Chairman: **Head (Asset Management) of TNB DN**
- Members: **Relevant departments within TNB DN**
- Secretariat: **TNB Labs**

6.3.1 Roles and Responsibilities of the QCC Chairman

The **QCC Chairman** is responsible for signing the **SCTC** certificate once the application has been approved. The Chairman is also responsible for leading the **QCC** in the following areas:

- Reviewing the compiled report prepared by the **QCC Secretariat** based on the terms and conditions of the **SCTC** scheme.
- Reviewing issues related to complaints, appeals and cases of certificate misuse or abuse.
- Ensuring the implementation of the certification policies, terms and conditions
- Monitoring the overall effectiveness of the processes and administration of the **SCTC** scheme.
- Promoting continuous improvement of the **SCTC** scheme and its processes.

6.3.2 Roles and Responsibilities of QCC Members

The **QCC Members** are responsible for supporting the **QCC Chairman** in meeting all the objectives set out in 6.3.1. The **QCC Members** are also responsible for assisting the committee in the following areas:

- Reviewing the evaluation report produced by the **QCC Secretariat**.
- Reviewing issues related to complaints, misuses, appeals, etc.
- Ensuring compliance with the implementation of the certification policy.

6.3.3 Roles and Responsibilities of the QCC Secretariat

The **QCC Secretariat** is responsible for:

- Conducting **Technical Evaluations**, including documentation reviews and physical assessments.
- Preparing the **Technical Evaluation** report and presenting it at **QCC** meetings.
- Suggesting improvements in the implementation of the **SCTC** scheme.

6.4 SCTC Terms and Conditions

The following are the terms and conditions of the **SCTC** scheme:

- The product design, including hardware and software, must remain unchanged during the certification period. Any changes that affect the system performance in **Short-Circuit Current Contributions** are prohibited.
- Any change to any of the features must be notified in writing to the **QCC Secretariat** and shall be subject to the appropriate procedures imposed by the **SCTC** scheme.
- The certificate is the document that approves the specified equipment and states that it can be connected to the **Distribution System**.
- **QCC** reserves the right to suspend or revoke this certificate immediately, with or without notice, if there are any deviations or omissions from the sample(s) evaluated.
- **QCC** reserves the right to suspend or revoke this certificate if the equipment is no longer available on the market.
- The certificate does not exempt the equipment from any further tests and inspections as required by **TNB.**
- **QCC** reserves the right to require further tests to be carried out by the **Certificate Holder** whenever the product design is reviewed or changed.
- This certificate is valid from the date of approval until any changes or upgrades are made to the equipment.
- Upon commissioning of the system, the **DG Operator** must submit an annual report to the **QCC Secretariat** to prove that the actual setting and model of the equipment remains the same as tested during the **Short-Circuit** testing.

6.5	Process Flow of the SCTC	Figure 6-1 shows the process for applying the **SCTC**. The process must be applied to new applications or existing **Certificate Holders** that require reassessment due to changes in product design. This includes changes in hardware, software or electrical ratings that may affect performance in terms of **Short-Circuit Current Contribution**.

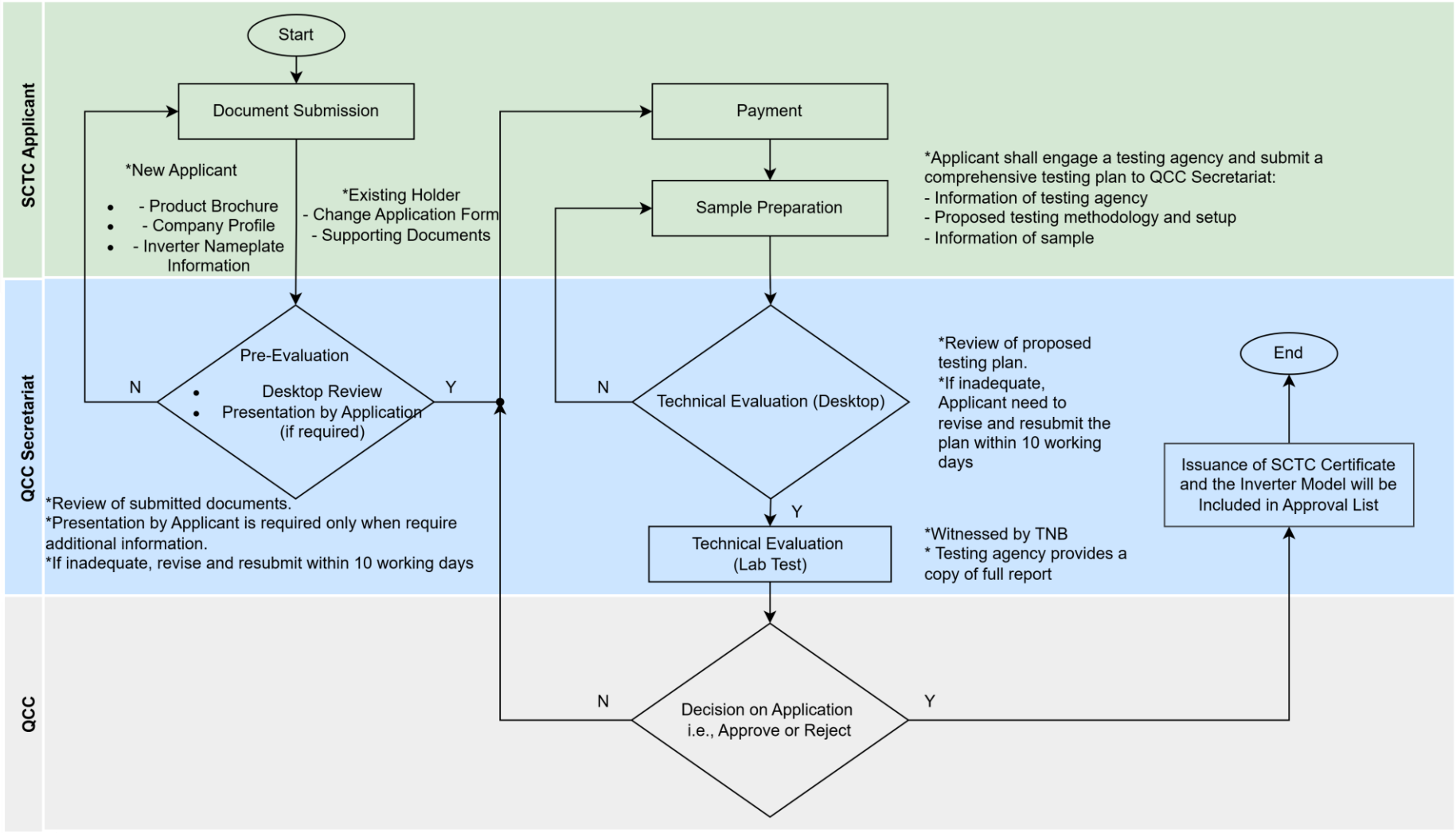

Figure 6-1 Process Flow of **SCTC** Application

6.5.1	Submission of Documents	The **Applicant** must provide complete documentation to the **QCC Secretariat** before the product can be evaluated for new applications. The documentation must be in English. If the original document is not in English, the **Applicant** must translate it into English. The documentation package must consist of: • Product brochure • Company profile • **Inverter** nameplate information The **Inverter** nameplate information shall include: • Manufacturer name • Model name • Serial number • Software and firmware version • Rated AC voltage • Rated AC output power • Maximum AC output apparent power • Maximum AC output current **Certificate Holders** must notify the **QCC Secretariat** of product changes in writing by submitting the Change Request Form with supporting documentation of the product changes.
6.5.2	Pre-evaluation	The **QCC Secretariat** is responsible for the pre-evaluation process, which involves desktop evaluation of the submitted documentation to ensure that it is adequate. The relevant **Technical Evaluator** may request a technical presentation of the product from the **Applicant** or existing **Certificate Holder** if additional information is required. The **Technical Evaluator** will decide whether to approve or reject the application. If the application is approved, the **Applicant** will be required to prepare a sample and make payment. If the application is rejected, the **Applicant** will be asked to revise and resubmit the application within 10 working days.
6.5.3	Payment	The fee covers all stages of the certification process, including: • Administrative work • Laboratory testing • Travel expenses for laboratory testing

If the application is returned at the pre-evaluation or **Technical Evaluation** stage, the **Applicant** will be responsible for covering the administrative costs and the cost of re-evaluating the previous non-conformity.

The **QCC Secretariat** will provide a quotation based on the number of man-days required. The **Applicant** is required to make payment to the **QCC Secretariat**. The **Technical Evaluation** will not commence until proof of payment has been received.

6.5.4 Sample Preparation

Upon payment, the **Applicant** shall prepare the product sample(s) and appoint a **Testing Agency** to perform the **Short-Circuit** test. The **Type Test** shall be performed at:

- Laboratory(s) listed in the TNB Approved Laboratory and capable of performing the **Short-Circuit** test as specified in Section 5.0 of these **Guidelines**.
- Manufacturer's laboratory capable of performing the **Short-Circuit** test as specified in Section 5.0 of these **Guidelines**. The **Applicant** may proceed with this laboratory after approval by the **QCC Secretariat**.
- Any independent laboratory capable of performing the **Short-Circuit** tests as specified in Section 5.0 of these **Guidelines**. The **Applicant** may proceed with this laboratory after approval by the **QCC Secretariat**.

The **Applicant** shall submit a test plan to the **QCC Secretariat** within 10 working days after payment has been made.

The test plan shall include,

1) Product specifications for each sample, specifying:
   - Manufacturer
   - Model
   - Serial number
   - Software and firmware version
   - Rated AC voltage
   - Rated AC output power
   - Maximum AC output apparent power
   - Maximum AC output current

2) Proposed test procedure in accordance with Section 5.0 of these **Guidelines**, consisting of:
   - Detailed test protocol as required in Table 5-2.
   - A clearly labelled diagram with descriptions of all equipment and its parameters, including DC and AC sources and measuring instruments.

3) Proposed **Inverter** settings, including K-factor and required **Inverter** priority modes to achieve maximum and controlled **Short-Circuit Current Contribution** during **LVRT**. These settings shall be consistent during the actual test.

4) Information of **Testing Agency**, specifying:
   - Name
   - Address
   - Supporting documentation, such as proof of accreditation

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6.5.5 Technical Evaluation (Desktop)

The purpose of the desktop **Technical Evaluation** is to ensure that the test plan meets the requirements of **TNB** and the international standards as specified in these **Guidelines**. The desktop **Technical Evaluation** will commence on the condition that:

- Payment has been received.
- A complete set of test plans has been submitted and meets the requirements of Section 6.5.4 of these **Guidelines**.
- Product samples are ready for evaluation and meet all requirements.

The **Technical Evaluator** has the right to request further evidence to support his/her findings. In this case, the **Applicant** must respond to the **Technical Evaluator** within 10 working days. Failure to respond will result in the evaluation being terminated and the application being returned.

6.5.6 Technical Evaluation (Laboratory Testing)

Laboratory testing is the main part of the product verification process, testing the capabilities of the samples as specified in Section 5.0 of these **Guidelines**. The tests are conducted jointly by the **QCC Secretariat** and representatives of **TNB**.

Prior to testing, the **Applicant** must demonstrate that the samples have identical product specifications and are configured with the same settings as originally proposed during sample preparation.

The **Testing Agency** shall produce a detailed test report, including, but not limited to

- Introduction
- Test setup and equipment
- Test results
- Analyses and discussion and conclusion.

The test report shall be retained by the **Applicant** and the **Testing Agency**, and a copy of the report shall be submitted to the **QCC Secretariat**.

Test results shall be reported using both a secured PDF file for written results and a CSV file for tabular results. The PDF file shall be issued by **the Testing Agency**, or other applicable testing body, and shall include reference to the associated tabular CSV format filename(s). The PDF file shall also include references to any other files required to demonstrate compliance with these **Guidelines**, such as oscillographic data recorded in accordance with the requirements of Section 5.6 of these **Guidelines**.

For traceability purposes, the report shall include references to any certificates of compliance or report numbers relating to the evaluation of the **Inverter.** The report shall include the date of issuance of the report and the name of the person responsible for the issuance of the report.

Additional guidelines for the test report are given in **Appendix B**.

6.5.7 Decision on Application

The **QCC Secretariat** is responsible for compiling and preparing the **Technical Evaluation** report and presenting it at the **QCC** meetings. The decision on the application will be made during the **QCC** meetings.

If the evaluated product is found not to meet the expected requirements, the **QCC** may request the **Applicant** to correct the issue(s) and have the product re-evaluated. In this case, the **Applicant** will be given 10 working days to respond and may pay to start the re-evaluation process. Failure to respond with acceptable evidence within the specified time will result in the application being stopped and returned to the **Applicant**.

In situations where the product is rejected outright, the application will be returned to the **Applicant**.

6.5.8 Issuance of SCTC Certification

Upon **QCC approval**, the **QCC Secretariat** will issue **SCTC** certification for the product. The product will also be added to the **Inverter** Approval List for connection to the **Distribution System**. The certificate will be endorsed by the **QCC Chairman** within 15 working days from the date of the **QCC** meeting.

The successful **Applicant** must collect the **SCTC** certificate in person. Collection by a third party courier service is not permitted in order to protect the confidentiality of the **Certificate Holder** and the confidential information contained in the Certificate.

The **Certificate Holder** shall maintain the integrity of this Certificate by consistently complying with this policy and not modifying the product design without notifying **TNB**. The holder shall ensure that any firmware updates do not affect the established configuration of the **Inverter** for **Fault Current** mitigation purposes, as demonstrated during testing.

After commissioning of the **DG**, the **DG Operator** must submit an annual report to the **QCC Secretariat** demonstrating that the **Inverter** settings are maintained in the field. The report may include pictures of the current **Inverter** setting, and the **QCC Secretariat** may request a site surveillance if necessary. The **DG Operator** must cooperate fully during the visit.

Appendix A (informative)
Bibliography

Bibliographic references are resources that provide additional or helpful material but are not required to be understood or used to implement these guidelines. References to these resources are made for informational purposes only.

[1] "Technical Specification Utility-interconnected photovoltaic inverters – Test procedure for under voltage ride-through measurements," in *IEC TS 62910:2020*, vol., no., pp.1-64, Jul. 2020.

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[5] "IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE Buff Book)," in *IEEE Std 242-2001 (Revision of IEEE Std 242-1986) [IEEE Buff Book]*, vol., no., pp.1-710, 17 Dec. 2001.

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[15] Leslie Hewitson, Mark Brown, Ramesh Balakrishnan, Practical power system protection, Elsevier, 2005.

[16] B. Hussain, S. M. Sharkh and S. Hussain, “Impact studies of distributed generation on power quality and protection setup of an existing distribution network,” *SPEEDAM 2010*, Pisa, Italy, 2010, pp. 1243-1246.

[17] Reliability Guideline BPS-Connected Inverter-Based Resource Performance, North American Electric Reliability Corporation, Sep. 2018.

Appendix B (informative)
Sample of Test Report

TEST REPORT

Short-Circuit Current Requirements for the Connection of Utility-Interconnected Inverters to TNB Distribution Network

Report Reference Number	:
Date of Issue	:
Total Number of Pages	:
Testing Laboratory Name	:
Address	:
Laboratory Certificate of Compliance	:
Test Item Description	: Solar Photovoltaics Inverter
Model/Type	:
Output AC Voltage [V]	:
Nominal Output Power [kVA]	:
Maximum Output Current [A]	:
Manufacturer's Name	:
Manufacturer's Address	:
Factory's Name	:
Factory's Address	:
Tested by (Name and Signature)	:
Approved by (Name and Signature)	:

Test Item Particulars	
Equipment Mobility	**:** Permanent Connection
Operating Condition	**:** Continuous
Mass of Equipment [kg]	**:**
Test Case Verdicts	
Test Case Does Not Apply to the Test Object	**:** N/A
Test Item Meets Requirements	**:** P(ass)
Test Item Does Not Meet Requirements	**:** F(ail)
Testing	
Date of Receipt of Test Item	**:**
Date(s) of Performance of Test	**:**

General Remarks

The test results presented in this report relate only to the object(s) tested. The report must state compliance of the tested objects with the requirements outlined in the TNB's "Technical Guideline for the Application of Inverters to Mitigate Fault Current Contribution of Inverter-based Distributed Generation in Distribution Systems".

This report must not be reproduced in full or in part without the written consent of the issuing testing laboratory and the TNB Quality Certification Committee (QCC).

This Test Report consists of the following documents:

1. Test Results (pdf and csv)
2. Annex 1: Copy of marking plate
3. Annex 2: Pictures of the unit
4. Annex 3: Test equipment setup

General Product information
Description of the Product's Electrical Circuit
Difference of the Models
Hardware Version
Model 1 :
⋮ :
Model *n* :
Software Version
Model 1 :
⋮ :
Model *n* :

Requirement	Result – Remark	Verdict
Certification Requirements The certification applicant shall complete this section to ensure compliance with the SCTC requirements.		
The short-circuit test must be conducted to validate the response of each Equipment Under Test (EUT 1…n) in mitigating short-circuit current contributions under Low Voltage Ride-Through (LVRT) conditions. The test report must include the type and model of inverters tested, the test conditions, and the results recorded. All details must be documented in this Short-Circuit Test Verification Report.		
Inverters must comply with the requirements detailed in Section 5.0 of TNB's "Technical Guidelines for the Application of Inverters to Mitigate the Fault Current Contribution of Inverter-based Distributed Generation in Distribution Systems" to be approved for connection to the TNB distribution system.		
During commissioning, no parameters related to electrical connections subject to SCTC may be modified without prior agreement with TNB. Customer access to such parameters is strictly prohibited.		
If modifications to the inverter(s) be necessary, the Certification Holder is required to reapply for SCTC certification prior to implementing any modifications.		
TNB shall be notified immediately of any operational incidents or failures that affect compliance with SCTC certification.		
TNB reserves the right to request compliance testing after any modification, failure or replacement of equipment that may affect the short-circuit current contributions.		

TEST RESULT 1: MAXIMUM SHORT-CIRCUIT CURRENT CONTRIBUTION DURING THREE-PHASE FAULT (EUT AT FULL LOAD)					**TEST VERDICT** **P / F**		
EUT Parameter							
Loading: [kW]		Priority: Mode		K - : Factor	Inverter I_{max}: [A]		
Phase A							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase B							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase C							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]

** Observation: throughout the voltage drop, the inverter shall not trip

** Attach oscillographic images of voltage and current for all three phases measured.

TEST RESULT 2: MAXIMUM SHORT-CIRCUIT CURRENT CONTRIBUTION DURING THREE-PHASE FAULT (EUT AT PARTIAL LOAD)					**TEST VERDICT** **P / F**		
EUT Parameter							
Loading: [kW]		Priority: Mode		K- : Factor	Inverter I_{max}: [A]		
Phase A							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase B							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase C							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]

** Observation: throughout the voltage drop, the inverter shall not trip

** Attach oscillographic images of voltage and current for all three phases measured.

TEST RESULT 3: MAXIMUM SHORT-CIRCUIT CURRENT CONTRIBUTION DURING TWO-PHASE FAULT (EUT AT FULL LOAD)					**TEST VERDICT** **P / F**		
EUT Parameter							
Loading: [kW]		Priority: Mode		K- : Factor	Inverter I_{max}: [A]		
Phase A							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase B							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase C							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]

** Observation: throughout the voltage drop, the inverter shall not trip

** Attach oscillographic images of voltage and current for all three phases measured

TEST RESULT 4: MAXIMUM SHORT-CIRCUIT CURRENT CONTRIBUTION DURING TWO-PHASE FAULT (EUT AT PARTIAL LOAD)					**TEST VERDICT** **P / F**		
EUT Parameter							
Loading: [kW]		Priority: Mode		K- : Factor	Inverter I_{max}: [A]		
Phase A							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase B							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase C							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]

** Observation: throughout the voltage drop, the inverter shall not trip

** Attach oscillographic images of voltage and current for all three phases measured

TEST RESULT 5: MAXIMUM SHORT-CIRCUIT CURRENT CONTRIBUTION DURING TWO-PHASE TO GROUND FAULT (EUT AT FULL LOAD)					**TEST VERDICT** **P / F**		
EUT Parameter							
Loading: [kW]		Priority: Mode		K- : Factor	Inverter I_{max}: [A]		
Phase A							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase B							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase C							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]

** Observation: throughout the voltage drop, the inverter shall not trip

** Attach oscillographic images of voltage and current for all three phases measured

TEST RESULT 6: MAXIMUM SHORT-CIRCUIT CURRENT CONTRIBUTION DURING TWO-PHASE TO GROUND FAULT (EUT AT PARTIAL LOAD)					**TEST VERDICT** **P / F**		
EUT Parameter							
Loading: [kW]		Priority: Mode		K- : Factor	Inverter I_{max}: [A]		
Phase A							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase B							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase C							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]

** Observation: throughout the voltage drop, the inverter shall not trip

** Attach oscillographic images of voltage and current for all three phases measured

TEST RESULT 7: MAXIMUM SHORT-CIRCUIT CURRENT CONTRIBUTION DURING SINGLE-PHASE TO GROUND FAULT (EUT AT FULL LOAD)					**TEST VERDICT** **P / F**		
EUT Parameter							
Loading: [kW]		Priority: Mode		K- : Factor	Inverter I_{max}: [A]		
Phase A							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase B							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase C							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]

** Observation: throughout the voltage drop, the inverter shall not trip

** Attach oscillographic images of voltage and current for all three phases measured

TEST RESULT 8: MAXIMUM SHORT-CIRCUIT CURRENT CONTRIBUTION DURING SINGLE-PHASE TO GROUND FAULT (EUT AT PARTIAL LOAD)					**TEST VERDICT** **P / F**		
EUT Parameter							
Loading: [kW]		Priority: Mode		K- : Factor	Inverter I_{max}: [A]		
Phase A							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase B							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase C							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]

** Observation: throughout the voltage drop, the inverter shall not trip

** Attach oscillographic images of voltage and current for all three phases measured

TEST RESULT 9: CONTROLLED SHORT-CIRCUIT CURRENT CONTRIBUTION DURING THREE-PHASE FAULT (EUT AT FULL LOAD)					**TEST VERDICT** **P / F**		
EUT Parameter							
Loading: [kW]		Priority: Mode		K- : Factor	Inverter I_{max}: [A]		
Phase A							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase B							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase C							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]

** Observation: throughout the voltage drop, the inverter shall not trip

** Ik shall be 0 A_{rms} and 0 p.u (with allowable deviation of <10% or <0.10 p.u]

** Attach oscillographic images of voltage and current for all three phases measured

TEST RESULT 10: CONTROLLED SHORT-CIRCUIT CURRENT CONTRIBUTION DURING THREE-PHASE FAULT (EUT AT PARTIAL LOAD)					**TEST VERDICT** **P / F**		
EUT Parameter							
Loading: [kW]		Priority: Mode		K- : Factor	Inverter I_{max}: [A]		
Phase A							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase B							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase C							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]

** Observation: throughout the voltage drop, the inverter shall not trip

** Ik shall be 0 A_{rms} and 0 p.u (with allowable deviation of <10% or <0.10 p.u]

** Attach oscillographic images of voltage and current for all three phases measured

TEST RESULT 11: CONTROLLED SHORT-CIRCUIT CURRENT CONTRIBUTION DURING TWO-PHASE FAULT (EUT AT FULL LOAD)					**TEST VERDICT** **P / F**		
EUT Parameter							
Loading: [kW]		Priority: Mode		K- : Factor	Inverter I_{max}: [A]		
Phase A							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase B							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase C							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]

** Observation: throughout the voltage drop, the inverter shall not trip

** Ik shall be 0 A_{rms} and 0 p.u (with allowable deviation of <10% or <0.10 p.u]

** Attach oscillographic images of voltage and current for all three phases measured

TEST RESULT 12: CONTROLLED SHORT-CIRCUIT CURRENT CONTRIBUTION DURING TWO-PHASE FAULT (EUT AT PARTIAL LOAD)					**TEST VERDICT** **P / F**		
EUT Parameter							
Loading: [kW]		Priority: Mode		K- : Factor	Inverter I_{max}: [A]		
Phase A							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase B							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase C							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]

** Observation: throughout the voltage drop, the inverter shall not trip

** Ik shall be 0 A_{rms} and 0 p.u (with allowable deviation of <10% or <0.10 p.u]

** Attach oscillographic images of voltage and current for all three phases measured

TEST RESULT 13: CONTROLLED SHORT-CIRCUIT CURRENT CONTRIBUTION DURING TWO-PHASE TO GROUND FAULT (EUT AT FULL LOAD)					**TEST VERDICT** **P / F**		
EUT Parameter							
Loading: [kW]		Priority: Mode		K- : Factor	Inverter I_{max}: [A]		
Phase A							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase B							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase C							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]

** Observation: throughout the voltage drop, the inverter shall not trip

** Ik shall be 0 A_{rms} and 0 p.u (with allowable deviation of <10% or <0.10 p.u]

** Attach oscillographic images of voltage and current for all three phases measured

TEST RESULT 14: CONTROLLED SHORT-CIRCUIT CURRENT CONTRIBUTION DURING TWO-PHASE TO GROUND FAULT (EUT AT PARTIAL LOAD)					**TEST VERDICT** **P / F**		
EUT Parameter							
Loading: [kW]		Priority: Mode		K- : Factor	Inverter I_{max}: [A]		
Phase A							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase B							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase C							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]

** Observation: throughout the voltage drop, the inverter shall not trip

** Ik shall be 0 A_{rms} and 0 p.u (with allowable deviation of <10% or <0.10 p.u]

** Attach oscillographic images of voltage and current for all three phases measured

TEST RESULT 15: CONTROLLED SHORT-CIRCUIT CURRENT CONTRIBUTION DURING SINGLE-PHASE TO GROUND FAULT (EUT AT FULL LOAD)					**TEST VERDICT** **P / F**		
EUT Parameter							
Loading: [kW]		Priority: Mode		K- : Factor	Inverter I_{max}: [A]		
Phase A							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase B							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase C							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]

** Observation: throughout the voltage drop, the inverter shall not trip

** Ik shall be 0 A_{rms} and 0 p.u (with allowable deviation of <10% or <0.10 p.u]

** Attach oscillographic images of voltage and current for all three phases measured

TEST RESULT 16: CONTROLLED SHORT-CIRCUIT CURRENT CONTRIBUTION DURING SINGLE-PHASE TO GROUND FAULT (EUT AT PARTIAL LOAD)					**TEST VERDICT** **P / F**		
EUT Parameter							
Loading: [kW]		Priority: Mode		K- : Factor	Inverter I_{max}: [A]		
Phase A							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase B							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]
Phase C							
Pre-fault Current		Peak Current	Initial Short-circuit Current, Ik”		Uninterrupted Short-circuit Current, Ik		Time to Reach Steady State
[A_{rms}]	[p.u]	[A]	[A_{rms}]	[p.u]	[A_{rms}]	[p.u]	[ms]

** Observation: throughout the voltage drop, the inverter shall not trip

** Ik shall be 0 A_{rms} and 0 p.u (with allowable deviation of <10% or <0.10 p.u]

** Attach oscillographic images of voltage and current for all three phases measured

ANNEX 1: Copy of Marking Plate(s)

* Please provide images of the **EUT**(s)' marking plate

ANNEX 2: Pictures of the Unit(s)

*Please provide images of the **EUT**(s) during type testing

ANNEX 3: Test Equipment Setup

No.	Item	Remark
1	Annex 3.1: Test Procedure	Detailed test procedure for each tests conducted
2	Annex 3.2: Single-line Diagram	Single-line diagram to illustrate test setup
3	Annex 3.3: Test Instruments	List of test instruments including - Grid Simulator (Manufacturer, Model, S/N, Last Calibrated) - PV Simulator 1 (Manufacturer, Model, S/N, Last Calibrated) - Power Analyser (Manufacturer, Model, S/N, Last Calibrated) - Oscilloscope (Manufacturer, Model, S/N, Last Calibrated)