TNB Technical Guidebook on Grid-interconnection of Photovoltaic Power Generation System to LV and MV Networks

Final

Contributors

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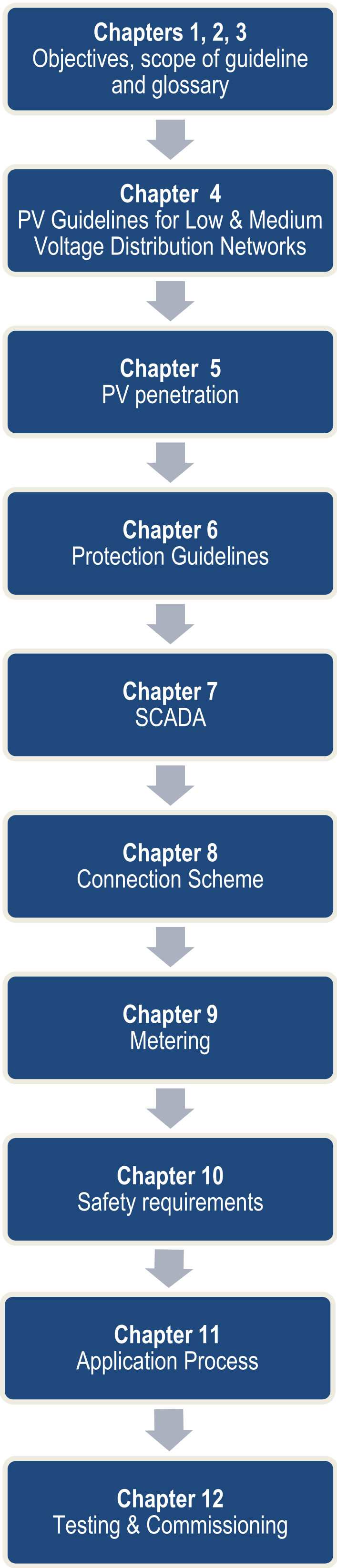
Summary of the Guidebook



1.0 Background & Objectives

Malaysia has been active in efforts to encourage adoption of renewable energy as evidenced in the 8th Malaysia Plan and later. Renewable energy (RE) was marked as the 'fifth fuel' that supplied the energy needs of the country. The Small Renewable Energy Power Programme (SREP) was launched to allow independent producers of renewable power to connect to the distribution network and gain compensation for their energy generation.

Another programme, dubbed Malaysian Building Integrated Photovoltaic Technology Application Project (MBIPV) encouraged the public and commercial sectors to institute solar technology into their premises, providing energy for a portion of their electricity consumption. This has resulted in a number of projects successfully implemented, such as Suria1000, paving the way for more proliferation of solar energy production in the future.

Looking at the variety of options available in terms of RE sources, solar photovoltaics (PV) is evidently suited to Malaysia's situation. The focus of these guidelines, solar photovoltaic (PV) technology, holds high potential for supplying clean energy to the grid. The driving factor for utilisation of PV in Malaysia is its tropical climate, with a high exposure to the sun's rays throughout most days.

Additionally, the parliamentary approval of the Renewable Energy Act, 2011 acts as a catalyst for the entrance of privately operated PV generation into Malaysia’s electricity grid. The large amounts of applicants and future operators of PV plants has led to the need for a set of unifying rules to allow for a smooth transition into implementation of distributed PV generation on the grid. Hence, these guidelines were produced to fulfill that need.

The main objective of this PV Guideline is to provide guidance on the requirements of PV interconnection with TNB Distribution system.
This “Technical Guidebook on Grid-interconnection of Photovoltaic Power Generation System to LV and MV Networks” (“the PV Guidelines”) is intended for use mainly by parties involved in the development and operation of PV generation connected to the TNB distribution network.

This document is focused on providing recommended practice for utility interconnection of PV systems in a manner that will allow the PV systems to perform as expected and be installed at a reasonable cost while not compromising safety or operational issues.

2.0 Scope

This guideline addresses technical issues associated with the connection of PV plant to the distribution network. Also highlighted are processes involved in implementing the projects.

Commercial and internal plant operation issues are not included in this guideline.

This guideline applies to utility-interconnected PV power systems operating in parallel with the utility and utilizing static (solid-state) inverters for the conversion of direct current (dc) to alternating current (ac).

RE developers, operators and parties otherwise involved in the installation and commissioning of PV generation to the grid can utilise these guidelines for:

a) Obtaining background information on PV technology and issues related to grid connection of PV.
b) Finding out the power quality requirements for PV interconnection with medium and low voltage distribution networks.
c) Understanding the interconnecting requirements whether for small, intermediate or large PV systems.
d) Finding out the methods available for interfacing of the PV generator to the grid system (connection schemes), including the compliance requirements for energy metering and SCADA.
e) Understanding the practices to ensure the safety of the personnel and equipment involved in utility-connected PV operations.

3.0 Glossary

Demand	:	The demand of MW or MVAr of electricity (i.e. both Active Power and Reactive Power respectively) unless otherwise stated.
Distributed Resources (DR)	:	Sources of electric power that are not directly connected to a bulk power transmission system. DR includes both generators and energy storage technologies.
Distribution System	:	The system of electric lines with voltage levels below 66 kV, within the Area of Supply owned or operated by the Distributor/Embedded 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/ Embedded Distributor in connection with the distribution of electricity .
Distributor	:	A person who is licensed 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.
FiAH	:	Feed-in Approved Holder
Filter	:	A generic term used to describe those types of equipment whose purpose is to reduce the harmonic current or voltage flowing in or being impressed upon specific parts of an electrical power system, or both.
Harmonic	:	A sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency.
Inverter	:	A machine, device, or system that changes dc power to ac power.
Islanding	:	A condition in which a portion of the utility system that contains both load and distributed resources remains energized while isolated from the remainder of the utility system.
Low Voltage	:	A voltage less than 1,000 volts or 1 kV.
Medium Voltage	:	A voltage equal to or exceeding 1 kV but not exceeding 50 kV.

Nominal	:	The value or range of a parameter being within expected norms or being the normal operating level of that parameter.
Nonlinear Load	:	A load that draws a non-sinusoidal current wave when supplied by a sinusoidal voltage source.
Connection point	:	The point on the Distribution System, electrically closest to the FiAH's plant, at which FiAH generated energy is exported.
TNB	:	Tenaga Nasional Berhad is a Licensee that was issued a Licence on 1st September 1990 which authorizes TNB to own and operate electricity generating, transmitting and distributing facilities and to supply energy to other persons there from.
Total Harmonic Distortion (THD)	:	Harmonic distortion is the departure of a waveform from sinusoidal shape that is caused by the addition of one or more harmonics to the fundamental. Total Harmonic Distortion is the square root of the sum of the squares of all harmonics expressed as a percentage of the magnitude of the fundamental.
Type Test	:	Test of one or more devices made to a certain design to demonstrate that the design meets certain specifications.
Power Factor	:	Power factor (PF) is calculated by dividing the Real Power, P, in the W unit by the Apparent Power, S, in the VA unit.

$$PF = \frac{Real\ power,\ P\ (W)}{Apparent\ power,\ S\ (VA)}$$

Where S is the square root of the sum of the squares of real power and reactive power, Q (unit: Var).

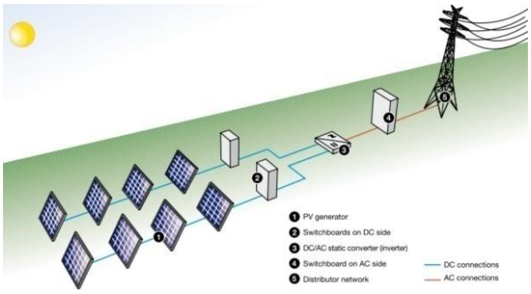
$$S = \sqrt{P^2 + Q^2}$$

4.0 PV Guidelines for Low and Medium Voltage Distribution Networks

4.1 Background : Solar PV technology has progressed by leaps and bounds. Along with that was the creation of a worldwide market for PV panels and equipment to cater for RE needs. PV panels are available in many forms, notably monocrystalline, polycrystalline, and thin-film types.

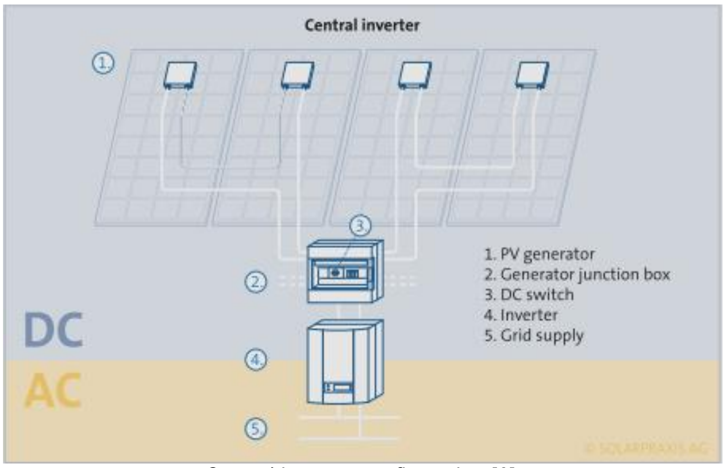
PV systems comprise of a number of components that are integral to its functioning. In grid-connected operation, PV panels output electrical energy converted from sunlight to an inverter, which then convert the DC voltage into an AC sine wave. Inverters rely on power electronic components like the Insulated Gate Bipolar Transistor (IGBT) to perform its duties. At the point of common coupling (PCC), a dedicated transformer is usually needed to step the voltage up to the appropriate level.

When connected to the grid, a PV system can function as a distributed generator (DG) that assists the main generation systems by supplying power into the grid. Large-scale PV systems are made up of a number of arrays that produce reasonably high amounts of power during day time periods.



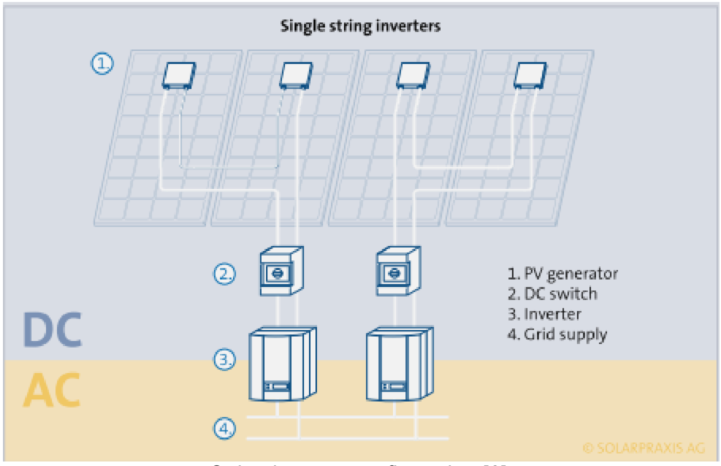
Large scale PV connected to distribution network [2]

Because of the modular nature of PV, constructing a large scale PV plant is only a matter of scale, with higher numbers of panels connected in strings and in parallel, connected to a number of inverters according to the required capacity. This is due to the fact that when more solar panels are connected in series, the output voltage of the string increases. Thus, the number of panels required for a certain voltage level, such as 415 V, is calculated by dividing the required voltage with the voltage output of one panel. These strings are consequently connected to the inverters in parallel to achieve the desired peak output power, expressed in MWp. Inverter configurations are commonly in two modes, string and central.



Central inverter configuration [6]

Central inverter designs rely on a single inverter unit that accepts DC outputs from multiple PV panel strings connected in parallel [6]. To cater for the different levels of solar radiation throughout the day, a single inverter is divided into multiple output units. For a 2 MW central inverter, it can be composed of four 500 kW output units, configured in a master/slave system. In this way, a one output unit is designated the master, while the rest operate as slaves. The slaves will be activated according to the output power of the solar array at any given moment. To prevent excessive wear and tear, the master role is cycled among the output units in turns to balance out the operating times of each unit.



String inverter configuration [6]

String inverters have smaller capacities than central inverters, due to the fact that each can handle only a string of PV panels. For PV plants equipped with tracking systems, string inverters are a better choice. This allows separation of tracker control for each string, thus increasing the effectiveness of the entire PV plant. The panels can track the sun more accurately relative to their ground location.

Through various local PV projects, it has been proven that PV is suitable as a practical means of energy generation in Malaysia. However it must be noted that, especially for large-scale PV, caution needs to be taken as to its impact on the distribution network it is connected to. With higher penetration of PV, meaning a higher ratio of PV power injection compared to loading, significant grid stability issues may arise. Grid voltage fluctuation is a notable concern.

Traditional networks are conceptualised as systems with large generators connected away from the load side, so power transfer occurs from the higher voltage level to the point of consumption at lower voltage levels. With an RE source such as PV connected near loads, there can be a considerable difference in power flow. PV is an intermittent energy source; therefore there can be high amounts of power injection during periods of high solar radiation, even though the demand is at low levels, for example during mornings where there is less activity in households. This can cause an undesirable overvoltage condition. Overvoltages are not a rare occurrence, and there are measures in distribution systems to compensate for them, such as on-load tap changers. Still, PV constitutes an additional burden to the voltage control system already in place.

These issues can be handled in the presence of regulatory standards that are closely adhered to by all PV operators. This chapter addresses the power quality guidelines that need to be adhered in grid-connected PV systems for LV as well as MV networks.

4.2 Regulations : For TNB, the operation of renewable energy interconnection is regulated by the following authorities.

a) Suruhanjaya Tenaga
b) SEDA Malaysia

This document is prepared in compliance to operational conditions terms as stated in the following document:

a) The Malaysian Distribution Code, 2012
b) Renewable Energy (Technical & Operational Requirements) Rules 2011

4.3 Scope : PV systems which are connected to TNB Low Voltage Distribution Network through

a) 230V – Single phase
b) 400V – Three phase

PV systems which are connected to TNB Medium Voltage Distribution Network through:

a) 11kV
b) 22kV
c) 33kV

4.4 Connection Requirement

The quality of power provided by the PV system is governed by practices and standards on voltage, flicker, frequency, harmonics and power factor.

Deviation from these standards represents out-of-bounds condition and may require the PV system to sense the deviation and properly disconnect from utility system.

Power quality parameters (harmonics and voltage) must be measured at the utility interface/point of common coupling unless stated otherwise. At PCC, the power quality requirements must comply to Malaysian Distribution Code and this Technical Guidebook.

a) The measurement before and after energising the PV must be taken and submitted to TNB for approval by the developer.
b) All measurement at site will be done with the representative from regulating body and TNB.

4.5 Normal Voltage Operating Range : The PV systems Injects current into utility and does not regulate voltage.

LV PV systems should be capable of operating within the voltage range in Table 4.1.

Table 4.1: Normal operating condition at PCC (LV)

Nominal Voltage (V)	Steady state voltage limits
400	+10% and -6%
230	+10% and -6%

MV PV systems should be capable of operating within the limits as below;

Table 4.2: Normal operating condition at PCC (MV)

Nominal Voltage (kV)	Steady state voltage limits
6.6	±5%
11	±5%
22	±5%
33	±5%

Table 4.1 and Table 4.2 are adopted from the TNB Technical Guidebook for the Connection of Generation to the Distribution Network.

4.6 Voltage fluctuation : Power generation from solar PV constantly varies due to the changing solar irradiation throughout the day. The varying power generation injected into the utility network is bound to create voltage fluctuations at the interconnection point and other buses upstream on the grid.

The maximum voltage fluctuation range allowed for LV and MV due to varying solar radiation is 6%. Beyond this, there is a danger of utility and consumer equipment getting heated up.

The TNB Technical Guidebook for the Connection of Generation to the Distribution Network states :-

TNB also specifies momentary voltage change requirement as below;

- 1 % - series voltage change that may lead to flickering problems
- 3 % - single voltage change due to switching ON or OFF of any loads

A DG shall not regulate the voltage at the Point of Common Coupling (PCC) and should operate satisfactorily within the limits of a specified voltage range as governed by relevant power system voltage standards.

4.7 Harmonic

The harmonic of a wave is a component frequency of a wave that is an integer multiple of the fundamental frequency .In the presence of non-linear loads such as computer power supplies and other appliances, alternating current (AC) can be distorted by introduction of various harmonic frequencies. Harmonics can be measured by percentage of the fundamental frequency or by calculating total harmonic distortion (THD).When present at high levels; these harmonics are detrimental to the electrical system and its loads.

The PV system output should have low current-distortion levels to ensure that no adverse effects are caused to other equipment connected to the utility system.

Total harmonic current distortion shall be less than 5 % at rated inverter output at cable connected to PCC. Each individual harmonic shall be limited to the percentages listed in Table 4.3.

Even harmonics in these ranges shall be less than 25 % of the lower odd harmonic limits listed.

Table 4.3 – Current distortion limits (IEC 61727-2003 Table 1)

Odd harmonics	Distortion limit (%)
3 – 9	< 4.0
11 – 15	< 2.0
17 – 21	< 1.5
23 – 33	< 0.6
Even harmonics	Distortion limit (%)
2 – 8	< 1.0
10 – 32	< 0.5

Note:

- *The harmonic current injection should be exclusive of any harmonic currents due to harmonic voltage distortion present in the utility grid without the PV system connected.*
- *Type tested inverters meeting the above requirements should be deemed to comply without further testing.*

4.8 Power factor

The power factor is defined as the ratio between the applied active (true) power - and the apparent power.

a) For LV, PV systems shall have a leading or lagging power factor greater than 0.9 when the output is greater than 10 % of the rated inverter output power.
b) For MV, PV systems shall have a leading or lagging power factor greater than 0.9.

Setting of plant power factor is identified during power system study.

The IEC 61727 states that :-

The PV system shall have a lagging power factor greater than 0.9 when the output is greater than 50 % of the rated inverter output power.
Notes:

- *Special design systems that provide reactive power compensation may operate outside of this limit with TNB approval.*
- *Most PV inverters designed for utility-interconnected service operate close to unity power factor.*

4.9 DC Injection

The PV system shall not inject DC current greater than 1 % of the rated inverter output current into the utility interface under any operating condition.

4.10 Flicker

Flicker is due to rapidly changing loads that cause fluctuate in the customer's voltage. Even a small change in voltage can cause noticeable. Flicker is an irritation issue.

The operation of the PV system should not cause voltage flicker in excess of values stated in Table 4.5;

Table 4.4– Reference: TNB LV Planning Guidelines

Distribution system voltage level which the fluctuating load is connected	Absolute short term flicker severity (P_{st})	Absolute long term flicker severity (P_{lt})
LV Systems	1.0	0.8
11kV – 33kV	0.9	0.7
Above 33kV	0.8	0.6

4.11 Voltage unbalance

Voltage unbalance is defined as the ratio of the negative sequence voltage component to the positive sequence voltage component.

Negative Phase Sequence Voltage (%): 2% for 1 minute duration when multiple single-phase PV units are installed and it should be distributed evenly among the three phases of the power system.

The TNB Technical Guidebook for the Connection of Generation to the Distribution Network states :-
Negative Phase Sequence Voltage (%) : 2% for 1 minute duration

The Malaysian Grid Code states:-
The maximum negative phase sequence component of the phase voltage on the Distribution System (Voltage Unbalance) shall remain below 1% unless abnormal conditions prevail.

Infrequent short duration peaks with a maximum value of 2% are permitted for Voltage Unbalance.

The unbalance voltage shall not exceed 1% for 5 occasions within any 30 minute time period at the terminals of a user's installation.

4.12 Interconnection Method

For LV, interconnection could be done through direct or indirect connection method. Schematic diagrams for the recommended practice for PV interconnection for single-phase and three-phase connections are included in the Appendix A. The design must include an appropriate rating of LVCB for protection purposes near metering side mounted between meter and incoming.

For MV, the proposed configuration of the interconnection is in Fig 4.1.

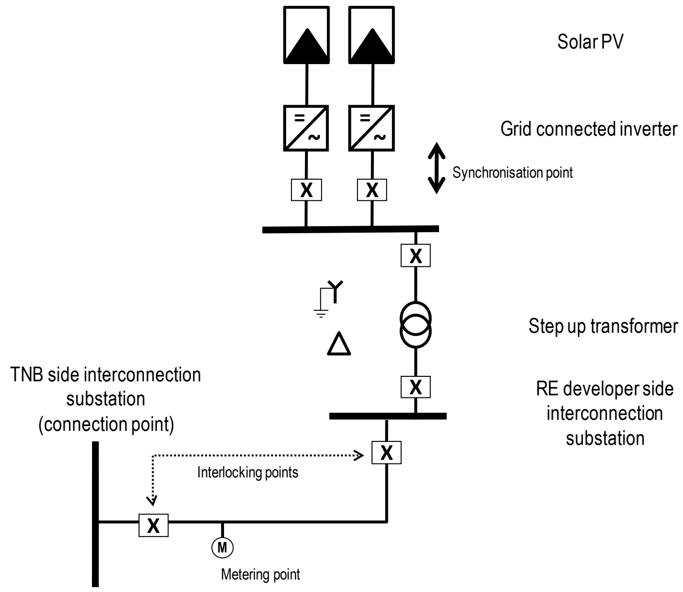


Fig 4.1 Proposed interconnection on MV system

Further details on interconnection methods are discussed in Chapter 5.

The interconnection feeder is a critical part in the operation of MV solar PV generation. It is where the interlocking scheme is adopted to control sequence of operation between TNB and RE side.
Further details on interlocking scheme are discussed in Chapter 6.

4.13 Short circuit level

By regulation, TNB is required to ensure that short circuit level of the network is within the equipment ratings. The regulation specifies that network maximum sub-transient 3-phase symmetrical short circuit shall be within 90% of the equipment designed short-time make & break capacity. The following is typical equipment ratings in distribution network in TNB

Table 4.5– Typical Equipment ratings in TNB Distribution Network

Nominal Voltage [kV]	Rated Voltage [kV]	Fault Current [kA]
33	36	25
22	24	20
11	12	20
0.4	1.0	31.5

5.0 PV penetration

5.1 LV Penetration Level

A large penetration of PV will increase current injection to the LV network. Undesirable overvoltage in the LV networks might occur if the magnitude of PV current injection is greater than the load of the LV networks.
Recommendation for PV penetration limits as follows:

a) Maximum allowable solar capacity connected to a single LV feeder is 54kW. This is to endure that, under worst case scenario without load, the voltage limit of 230V+10% will not be violated.

b) Maximum allowable solar capacity connected to LV feeder pillars is 90% of transformer capacity & each solar connection capacity must be < 250A (180kW).

c) For PV connection more than 180kW, connection limit to LV is subject to the finding of Power System Study (PSS). However, limit of 425kW for LV connection is applicable.

5.2 MV Penetration

Total capacity of RE generation connected to a MV distribution network is to be limited to the demand of local distribution network. The demand is determined by using current trough load of the source at 132kV.

Recommended MV penetration limits based on the MV connection points are:

a) Connection at PMU (132/11kV, 132/33kV)
   - Maximum allowable capacity of solar PV is 85% of daytime PMU trough load

b) Connection at PPU (33/11kV)
   - Maximum allowable capacity of solar PV is 90% of transformer capacity and
   - Maximum allowable capacity of solar PV is 85% of daytime trough load of the source PMU

c) Connection at PE, SSU (11kV)
   - Maximum allowable capacity of solar PV is 50% of cable capacity from connection point to the source and maximum allowable capacity is 2MW

6.0 Protection Guidelines

6.1 Background and Summary : In protection systems, voltage magnitude and frequency are the 2 basic fundamental characteristics to be used to detect failures in the electrical system. Unintended Islanding is not allowed, therefore DG to be shut down when the TNB main supply is off.

Synchronisation is to be done at grid interface. Re-synchronising only proceeds once TNB gives approval after system is normalised.

Normalisation requirements are as follows:

a) Frequency difference <0.2 Hz
b) Voltage magnitude difference < 10%
c) Voltage angle difference < 10 deg
d) Interlocking logic are satisfied

DG protection scheme is under developer responsibility and RE developer is to declare the protection scheme and settings to TNB.

Protection interfacing requirements are as follows:

a) Unit Protection (Current Differential)
b) OCEF / Non Directional OCEF
c) Interlocking scheme
d) Reverse Power Relay

For TNB and RE developer interconnection cable, the protection scheme includes unit protection (CD) with direct fiber optic connection, OCEF and Reverse Power Relay.
Interlocking facilities shall operate in the following manner, referring to the diagram below:

a) A trip – B to trip
b) B close position – A cannot close
c) A open position – B cannot close
d) Earth switch B ON – A cannot close

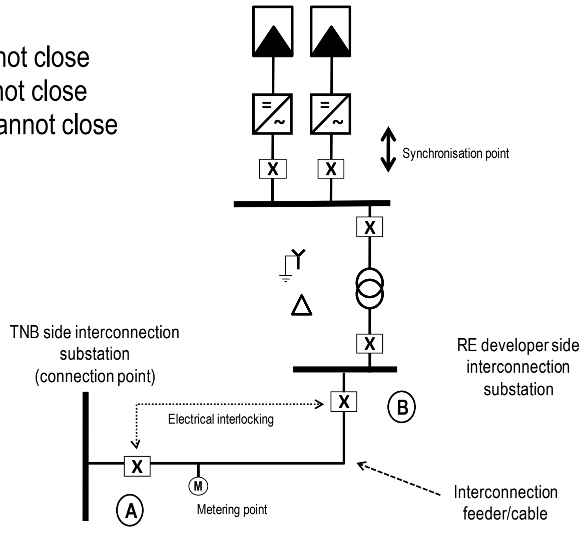


Fig 6.1 Interlocking & synchronization of MV system

6.2	**Normal inverter operating range**	:	The voltage operating range for PV inverter shall be used: a) as a protection function that responds to abnormal utility condition b) not as a voltage regulation function
6.3	**Frequency**	:	The utility, i.e. TNB shall maintain the system frequency and the PV system shall operate in synchronism with TNB frequency. TNB shall operate with nominal 50 Hz system with ±1Hz range band.
6.4	**Synchronisation**	:	Synchronisation is an act of matching, within allowable limits, the following required DG parameters with the TNB utility supply parameters as follows: a) Frequency difference <0.2 Hz b) Voltage magnitude difference < 10% c) Voltage angle difference < 10 deg Synchronisation devices are to be provided & maintained by RE developer. During operation, synchronisation is to be done on RE developer side by matching TNB grid parameters as mentioned above.
6.5	**Inverter**	:	Inverter can be categorized into 2 types: a) Line commutated b) Self commutated For interconnection with TNB, self commutated inverter is preferred for MV and LV connections. Only grid connected inverters are allowed to be connected with TNB system.
6.6	**Non islanding/ anti-islanding inverter**	:	Non islanding inverters are unable to supply the load without the presence of the utility electrical supply. For personnel safety reasons, PV plant is not allowed to be energized during outage of TNB grid (loss of mains). RE developer is to prove the anti islanding capability of the plant during pre-commissioning tests.
6.7	**Inverter Interconnection**	:	PV system with inverter shall use abnormal voltage or frequency sensing for fault detection.
6.8	**Inverter as UPS**	:	For any interconnection with TNB, the usage of PV inverter as a UPS to the grid is strictly prohibited.
6.9	**PV inverter fault current contribution**	:	The fault current contribution by the inverter will be limited usually by inverter control. Based on IEEE 1547, the short circuit current typically ranges between 100% and 200% of the rated inverter current. TNB may request RE developer to carry out mitigation to reduce the fault current contribution from the RE plant where necessary.

6.10 Protection schemes : The basic requirements for the design of the protection schemes are:

a) For any internal fault in the PV system, the PV must not cause problems to the utility system and its customers.
b) For any distribution network fault outside the PV plant, the PV system must be protected from any damaging effect.

PV system directly connected to TNB distribution system, the following protections are required:

a) Under Voltage
b) Over Voltage
c) Under Frequency
d) Over Frequency
e) PV active islanding detection (Non islanding inverter)

RE developer shall be required to provide other protection devices to complement special or existing features of the existing substation, such as busbar protection, arc protection etc.

6.11 Additional protection requirement : For interconnecting feeder protection, the protection scheme must follow the existing TNB practises.

a) Underground cable protections (MV systems)
    - Main unit protection (Current Differential Relay).
    - Back up Overcurrent and Earth Fault Protection.
b) Power transformer (above 5 MVA transformer to include transformer unit protection).
    - Main Unit Protection
    - Main Transformer Guard Protection
    - Main Restricted Earth Fault Protection
    - Back up Overcurrent and Earth Fault Protection.
    - Back up Standby Earth Fault protection
c) Local transformer
    - Main Overcurrent and Earth Fault Protection
d) Low voltage network
    - Fuse
e) All protection relays shall undergo and pass acceptance testing, and made listed in the latest TNB Accepted Relays List.

6.12 The coordination of auto re-closure in TNB network : PV tripping needs to be coordinated with the TNB feeder reclosing practises to eliminate any possibility of out of phase reclosing. PV system shall cease to energize the TNB network circuit to which it is connected prior to re-closure by the TNB network.

6.13 PV inverter technical protective requirement : The PV inverter shall cease to energise the TNB grid for faults on the TNB grid where it is connected. A PV system shall sense the TNB utility conditions and cease to energise the utility line:

a) When the sensed voltage and frequency lies outside the inverter operating range.
b) During islanding conditions.
c) When excess DC current injection is sensed as mentioned in LV and MV guidelines.

6.14 PV inverter shutdown or tripping : The term shutdown or tripping of the inverter refers to action where the inverter ceases to energise the utility line. When the inverter ceases energising the utility:

a) It does not completely disconnect from the utility
b) It does not completely turn off
c) The inverter controls remain active
d) The connection to the utility remains and is maintained for the inverter to continue sensing utility conditions

The maintained connection and continued sensing is necessary for a minimal period as mentioned in clause 6.15.

6.15 PV reconnect timing : After the inverter tripping, no inverter reconnection will take place until the TNB voltage and frequency are maintained within the limits for a stabilisation period of 5 minutes. This is applicable for LV or MV interconnections.

The PV stabilisation period starts once the inverter detects the voltage and frequency to be within the normal range.

6.16 Distance between PCC and inverter : The developer must consider the distance of PCC to the inverter to avoid significant voltage drop and losses.

6.17 Failure of PV protection or control equipment : The failure of PV system equipment shall include:

a) Failure of protection equipment
b) Failure of control equipment
c) Loss of control power

PV plant must be disconnected from the grid during any of the above conditions. During contingency periods when TNB uses generator sets to provide alternate supply, PV shall not be connected to the grid.

6.18 Voltage disturbance : The inverter should sense abnormal voltage and respond according to the conditions in Table 6.1. The voltage values shall be in root mean squares (rms) values and measured at PCC. Consideration shall be given to monitoring voltage in this clause in order to avoid problems due to voltage drop in various transformer, wiring or feeder circuit. When the inverter sense the voltage lies outside its operating limits, the recommended action shall be as in Table 6.1 or Table 6.2.

a) For LV interconnection, inverters must comply to IEC 61727

Table 6.1 LV voltage disturbance (IEC61727)

Voltage (at PCC)	Maximum trip time (s)
V<50%	0.10
50%≤V<85%	2.00
85%≤V≤110%	Continuous operation
110%<V<135%	2.00
135%≤V	0.05

b) For MV interconnection, based on contingency operating condition at PCC, all inverters must comply to the following parameters:

Table 6.2 MV voltage disturbance

Voltage (at PCC)	Maximum trip time (s)
V<50%	0.10
50%≤V<90%	2.00
90%≤V≤110%	Continuous operation
110%<V<135%	2.00
135%≤V	0.05

6.19 Frequency disturbance : The under frequency and over frequency levels and the corresponding inverter trip time shall be as follows:

a) When the utility frequency is outside the nominal 50 Hz value by ±1 %.
b) Trip time shall be within 0.20 s.
c) Applicable for both LV and MV interconnection.

6.20 Islanding protection : During islanding, PV system shall cease to energise the grid in case of voltage and frequency situation stated in clause 6.18 and 6.19. During islanding detection, the PV system shall cease to energise the TNB grid network through the PCC within 2 seconds of the formation of an island due to:

a) Safety issues
b) Power quality problem
c) Inverter technical limit

6.21 Phase measurement requirements : Over voltage and under voltage detection shall be provided for all 3 phases.

6.22 Fault clearance sequence for inverter based distribution generation : During abnormal conditions, the inverter shall disconnect either shortly before or after the utility substation open depending on the voltage characteristics sensed; IEC 61727 states that a voltage > 135% of nominal will be damaging to inverter. Unwanted tripping is less serious for PV than other generation technologies because PV can restart as soon as fault is cleared and the voltage is back to normal value.

6.23 Utility interface disconnect switch : PV interconnection must incorporate utility interface disconnect switch to allow disconnection of PV system output from the interconnecting with TNB for safe utility line works. The switch shall be manual, lockable, load break disconnect switch that:

a) Provide clear indication of switch position
b) Visible and accessible to maintenance and operational personnel
c) Provide visual verification of the switch contact position when the switch is in open position

7.0 SCADA

7.1 SCADA and Automation (Adopted from TNB DG Guidebook) : In general, SCADA facility is required for PV interconnection with total capacity of more than 2MW. The PV interface/connection point must be equipped with Remote Terminal Units (RTU) c/w Marshalling cubicle and communication system from PV plant to TNB control centre.

However, when the proposed connection point is already equipped with SCADA facility, RE developer is to provide the equipment & accessories to integrate the new equipment with existing system.

The RTU shall have capabilities to monitor the following, subject to TNB's discretion:

a) Frequency (Hz)
b) Voltage (V)
c) Current (A)
d) Real Power Energy flow (kW or MW)
e) Reactive power energy flow (kVAR or MVAR)
f) Energy meters
g) Breaker status
h) Relay indication, where appropriate

Where appropriate, derived values, for example the real power from voltage and current phasors would be acceptable.

a) If remote control of switches that are in the jurisdiction/area of responsibility of TNB are required to be installed at TNB's control centre, this shall be able to be executed via RTUs. RTU must be able to be communicate with TNB Master system using IEC 60870-5-101 TNB matrix or protocol determined by TNB.
b) The facility to control the circuit breaker through Local/Remote/Supervisory must be included in the interfacing substation.
c) All RTU must be listed in TNB's approved list.

8.0 Connection Scheme

8.1 Background : The connection scheme clauses take into the following considerations.

a) Safety
b) Connection with least alteration to existing network
c) Cost
d) Compliance to regulatory requirements

For LV, connection is to be made in accordance to MS IEC 1857.

As for MV, connection is to be made to a busbar at a substation. No connection is to be made directly to an overhead line or cable.

8.2 Connection types : The connections types are as follows

a) Type 1 – LV single phase
b) Type 2 – LV three phase
c) Type 3 – MV 11 kV, PE
d) Type 4 – MV 11 kV, PMU/PPU
e) Type 5 – MV 33 kV

8.3 Feedings method : The feedings method can be sub categorised as

a) Direct Feed – Connection point at TNB

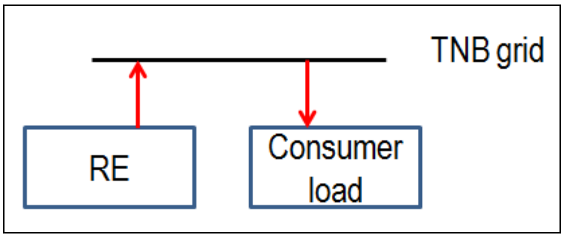


Fig 8.1 Connection to TNB grid (direct)

b) Indirect Feed - Connection point at customer (only applicable for LV)

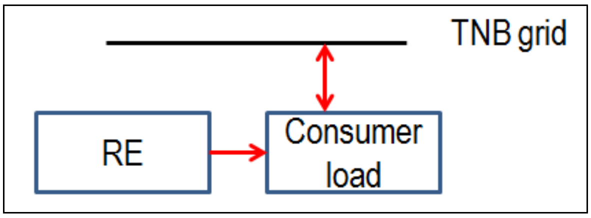


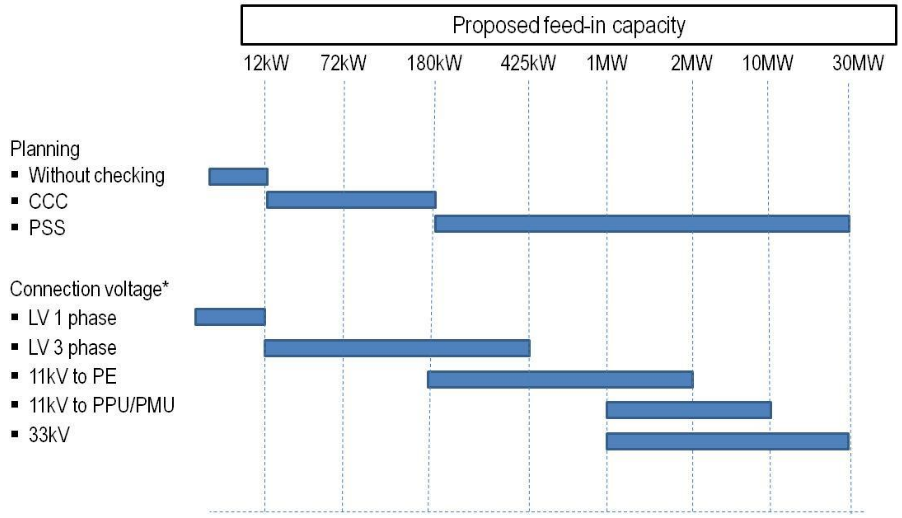
Fig 8.2 Connection to TNB grid (indirect)

8.4 RE connections : Table 8.1 shows the customer categories options for various RE connections.

Table 8.1 – Customer categories for various RE connections

RE generation connection	Customer category/available connection point			
	LV 1phase (a)	LV 3phase (b)	11kV (c)	33kV (d)
Type 1: LV single phase	√	√	NA	NA
Type 2: LV three phase	√	√	√	NA
Type 3: MV 11kV, PE	NA	NA	√	NA
Type 4: MV 11kV, PMU/PPU	NA	NA	NA	√
Type 5: MV 33kV	NA	NA	NA	√

Table 8.2 – Planning process and point of connection based on proposed RE output



8.5 Type 1 – LV single phase : Type 1 is applicable for PV < 12kWp. Typically for residential, terrace units. Connection is by single phase.

8.6 Type 2 – LV three phase Type 2 is applicable for PV connection up to 425kWp (subject to recommendation of PSS). Connection confirmation check (CCC) is required for 12<kWp<180.

8.6 Type 1 & 2 LV Connections : a) Direct Connection

FiAH output is connected directly to TNB grid.

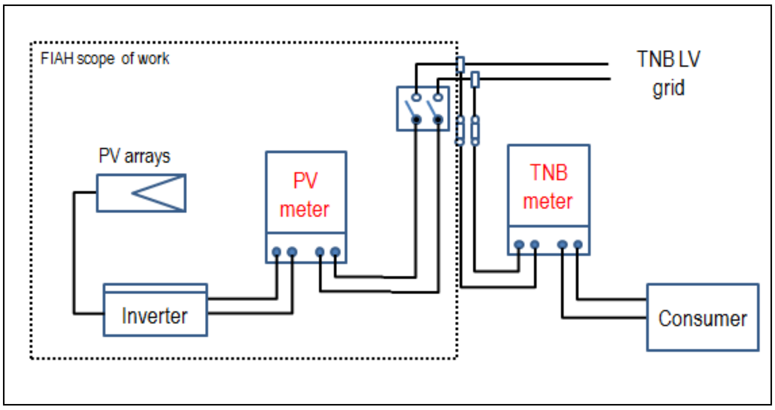


Fig 8.3 – PV direct connections diagram for LV

b) Indirect Connection

Indirect connection is allowed for special case & requires additional verification & supplementary agreement with TNB

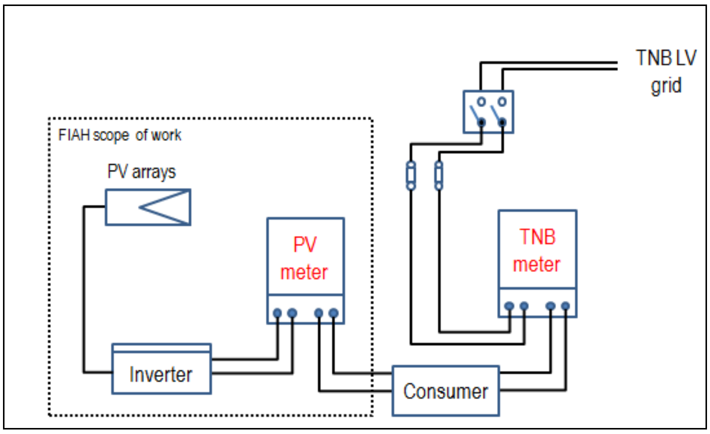


Fig 8.4 – PV indirect connections diagram for LV

8.7 Type 3 – MV 11kV (PE) : Type 3 is applicable for PV plant with output between 425kW to 2,000kW. Details of connection point are to be identified based on findings of PSS.
Connection point at nearby PE

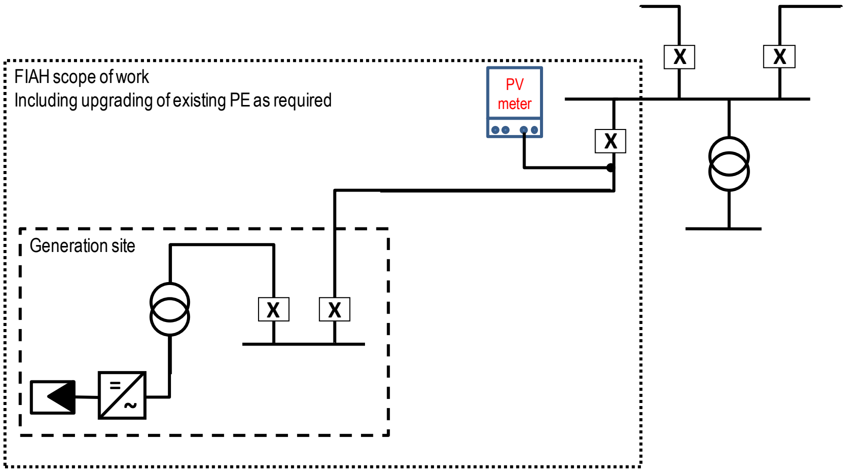


Fig 8.5 - PV connections diagram at PE

8.8 Type 4 – MV 11kV (PMU/PPU) : For PV plants with output more than 2MW, the connection point is at the nearby PMU/PPU as shown in Fig 8.6.

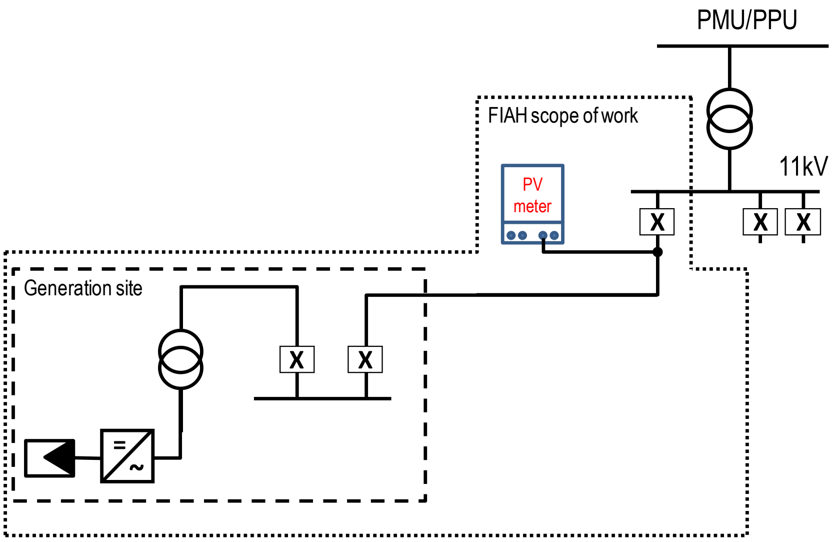


Fig 8.6 –PV connections diagram at PMU/PPU (11kV)

8.9 Type 5 – MV 33kV : The metering installation for 33 kV PV interconnections are shown in Fig 8.7.

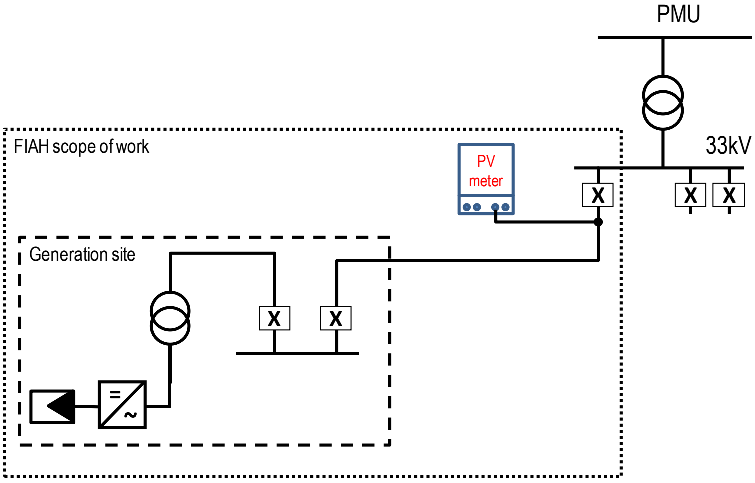


Fig 8.7 – PV connections diagram at PMU (33kV)

8.10 Multiple-feed In cases where multiple sources of generations are produced and owned by within a common site, multiple-feed configuration is allowed to optimise the number of interconnection feeders at PMU/PPU/PE.

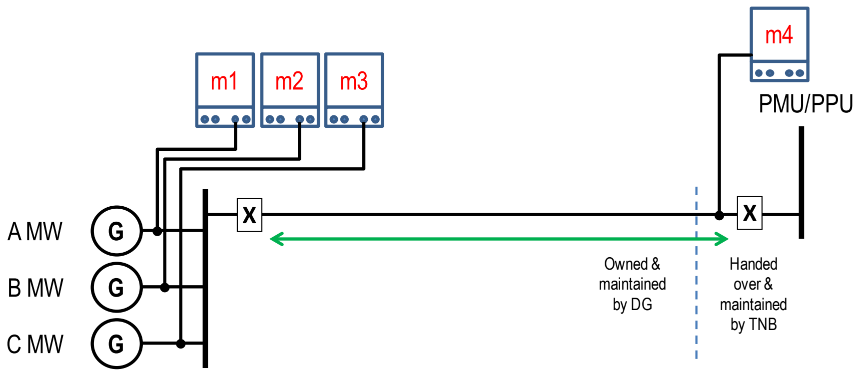


Fig 8.8 – Multi-feed configuration

8.11 Interconnection feeder

Interconnection feeder (IF) is the link between RE developer side and TNB. Features of the IF is as shown below:

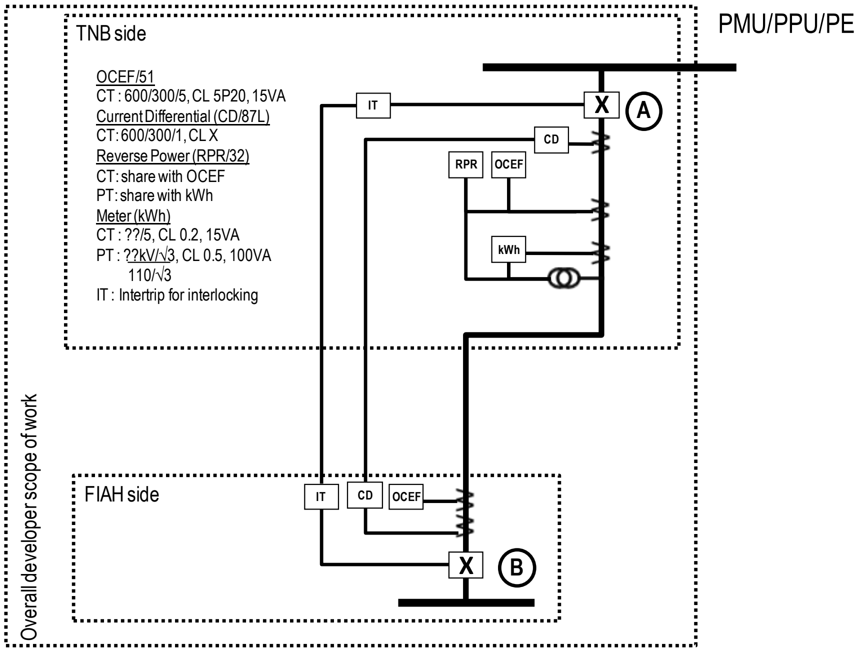


Fig 8.9 – Interconnections diagram between TNB and FiAH

8.12 Boundary of ownership & operation

The boundary of ownership & operation generally is located at the connection point to the existing network. This is the point which energy is injected into TNB's distribution network. In most cases, it is where the energy meter is located.

The interconnection cable belongs to RE developer until the cable termination at the PMU/PPU/PE.

RE developer is to provide the necessary system expansion required within the scope as stipulated in the T&O Requirements and handover to TNB.

8.13 Equipment specifications

Equipment that is to be handed over to TNB must comply to the latest TNB technical specification and that are approved to be used in the system.

8.14 Approval process :

RE developers are responsible to carry out necessary modification at the connection point to facilitate connection of generated energy. All equipment to be used in TNB's network is subject to acceptance process by TNB.

Approval process include:

a) Single line diagram approval
b) Shop drawing approval
c) Factory Acceptance Test
d) Site Acceptance Test
e) Commissioning test

Prior to commissioning, the solar PV plant must be tested to ensure that the performance is up to the required standard, installations are according to the approved scheme, settings are done as approved, etc.

9.0 Metering

9.1 Metering : All energy meters used for measuring the export of electricity by FiAH (LV & MV) shall follow TNB specifications. The meters shall be procured from TNB. TNB shall determine the point at which every supply line shall terminate in any premise in view of ease of accessibility to TNB's personnel.

At any point in the premises at which supply line or lines terminate, the RE developer/FiAH shall provide the meter board or meter panel or meter cubicle according to TNB's specifications for the installation of meter and their accessories. TNB may change any meter and its accessories or their positions in any premise as deemed necessary at any time for purposes of maintenance and meter reading.

9.2 Low Voltage

For low voltage supply without metering CT, the metering scheme is divided into 2 categories:

a) Single Phase Whole Current Supply:
This metering scheme applies to individual domestic and non-domestic FiAHs including housing area.

b) Three Phase Whole Current Supply:
This metering scheme applies to individual domestic and non-domestic FiAHs including housing area.

For low voltage connection requiring metering CT, developer/FiAH shall provide low voltage CTs for the meter installation. The CTs shall be of the single ratio and single purpose type based on specifications that have been approved by TNB. The low voltage metering CTs shall be subjected to testing by TNB and a metering panel must be provided.

9.3 Medium Voltage

For MV connections, TNB will confirm the size of CT for any interconnection after receiving Borang Maklumat Awal (BMA).

The Electrical Consultant/Registered Electrical Contractor shall ensure clear understanding of TNB metering requirements.

For details on the metering requirement, RE developers shall refer to the latest Electricity Supply Application Handbook.

10.0 Safety Requirements (Adopted from MS 1837:2010 – Installation of grid connected photovoltaic (PV) system)

10.1 Background : The installation of grid-connected PV systems shall comply with the requirements of MS IEC 60364 or MS IEC 60364-7-712. The provisions of this section are aimed at ensuring that these requirements are met, taking into account a range of system topologies and earthing arrangements.

10.2 By-pass diodes : By-pass diodes shall be used in the PV modules. If by-pass diodes are not embedded in the PV module encapsulation, they shall comply with all the following requirements:

a) Have a voltage rating at least $2 \times V_{OC\ STC\ MOD}$ of the protected module.
b) Having a current rating at least $1.3 \times I_{SC\ STC\ MOD}$.
c) Be installed according to the module manufacturer's recommendations.
d) Be installed so no live parts are exposed and;
e) Be protected from degradation due to environmental factors.

10.3 Over-current protection : ***Discrimination***

Over-current protection within the PV string shall be graded in such a way that lower level protection trips first in the event of fault currents flowing from higher current sections to lower current sections of the PV array.

PV Strings

- All PV strings shall be protected with an over-current protection device with load breaking disconnecting facilities. These over-current protection devices shall be installed in positive active conductors. Suitably rated circuit breakers used for over-current protection may also provide load breaking disconnecting facilities.
- The rated trip current I_{TRIP} of over-current protection devices for PV strings shall be as specified by the PV module manufacturer or I_{TRIP} shall be determined by the following formula:

$$1.5 \times I_{SC\ STC\ MOD} \leq I_{TRIP} \leq 2 \times I_{SC\ STC\ MOD}$$

PV Array and PV sub-arrays

- Over-current protection device is not required for PV array and PV sub-arrays.

10.4 Disconnecting means	:	▪ Disconnecting means shall be provided in PV arrays according to selection and installation, to isolate the PV array from the inverter and vice versa and to allow for maintenance and inspection tasks to be carried out safely. ▪ Selection and installation: o Only device with DC rating which is able to extinguish electrical arc shall be used. o Suitably rated circuit breakers used for over-current protection may also provide load breaking disconnecting facilities. ▪ For PV strings and PV sub-arrays: o No separate disconnection device is required if suitably rated circuit breakers are used for the over-current protection which also provides load breaking disconnecting facilities. ▪ For PV array: o A readily available load breaking disconnection device, which interrupts both positive and negative conductors, shall be installed in the PV array cable. This device shall be lockable in the off position.
10.5 Emergency Switching Devices	:	▪ The PV array (DC) load-breaking disconnection device and the inverter (AC) load breaking disconnection device shall be used as the emergency switching devices, and therefore shall be readily accessible. ▪ The emergency switching devices shall comply with the requirements for devices for emergency switching including emergency stopping as contained in MS IEC 60364 or MS IEC 60364-7-712. ▪ If the emergency switching device is manually operated, the remote operating device shall be located in a readily accessible point.
10.6 Earth Fault Protection	:	▪ All metal casings and frames shall be earthed according to MS IEC 60364 or MS IEC 60364-7-712.
10.7 Lightning Protection	:	▪ Lightning protection measures may be required in some PV installations. The need for lightning protection shall be assessed in accordance with MS IEC 62305-1. ▪ A lightning protection system has the task of preventing severe damage caused by fire or mechanical destruction if a direct lightning strike occurs on a building or structure. Lightning protection systems consist of three essential components: o An air termination system, consisting of metallic masts or rods of sufficient height to divert lightning currents through their structure o A down conductor of sufficient cross sectional area to conduct lightning currents to earth o An earth termination system

- For ground mounted or freestanding PV arrays, the need for a lightning protection system shall be assessed in accordance with MS IEC 62305-1.
- The installation of a PV array on a building has a negligible effect on the probability of direct lightning strikes and therefore it does not necessarily imply that a lightning protection system shall be installed if none is already present. However, if the physical characteristics or prominence of the building do change significantly due to the installation of the PV array, it is required that need for a lightning protection system be assessed in accordance with MS IEC 62305-1.
- When a PV array is protected by a lightning protection system, the metal structure of the PV array shall be bonded to the lightning protection system, unless the minimum safety clearances as specified in MS IEC 62305-1, can be achieved.

10.8 Over-voltage Protection :

- Basically over-voltage protection measures include:
  - Equipotential bonding
  - Avoidance of wiring loops
  - Installation of SPDs
  - Shielding

- Wiring Loops:
  - To reduce the magnitude of lightning induced over-voltages, the PV array wiring shall be laid in such a way that the area of conductive loops is minimum.

- Surge protective device (SPD):
  - SPDs are a very common method of protecting electrical systems and equipment against over-voltages. When these devices are used, the recommendations of MS IEC 61643-12shall be observed.
  - Many commercial PV inverters are fitted with SPDs on the PV input (DC) terminals, and this shall be considered when specifying the over-voltage protection of the PV array.

- Selection:
  - The selection of SPDs shall be in accordance to MS IEC 61643-12.

- Usage and installation:
  - The usage and installation of SPDs shall be in accordance to MS IEC 61643-12. The SPDs on the DC side shall be installed closest possible to the inverter.

- SPD specifications to protect PV array and inverter (DC terminal):
  - The specifications for SPDs to protect PV arrays and inverter (DC terminal) are as follows:
    - SPDs of Class 11 (in this context, Class 11 refers to the test specifications of SPDs rather than insulation class).
    - Have a maximum continuous operating voltage (U_C) with $U_C > V_{OC\ STC\ GEN}$
    - Have a maximum discharge current (I_{max}) (8/20µs) with $I_{max} > 40kA$ (or at least 20kA)
    - Have a nominal discharge current (I_n) (8/20µs) with $I_n > 20kA$ (or at least 10kA)
    - Have voltage protection level (U_p) with $1.3 \times V_{OC\ STC\ GEN} < U_p < 1.1kV$

   - ➢ Have a voltage protection level at I_n (U_p) with (L-PE) $< 2.5kV$
- SPDs specifications to protect inverter (AC terminal):
  - o The specifications for SPD to protect inverter (AC terminal) shall be suitably rated for AC use and in accordance to MS IEC 61643-12 and in conjunction with MS IEC 61643-1.

- Shielding:
  - o When the PV array frame is bonded to a lightning protection system, the PV array cable shall be shielded by one of the following methods, and the shielding conductor shall be connected to earth at both ends:
    - ➢ With a metallic cable armour or shield with an equivalent cross-sectional area of $10mm^2$ Cu or
    - ➢ With a metallic conduit suitable as a bonding conductor or
    - ➢ With an equipotential bonding conductor with a cross sectional area of at least $6mm^2$

10.9 Switching device :

- All switching devices shall comply with all the following requirements:
  - o Be rated for AC side as AC and be rated for DC side as DC use and able to extinguish electrical arcs.
  - o Have a voltage rating greater than $V_{OC\ STC\ ARRAY}$
  - o Not have exposed metallic live parts in connected or disconnected state
  - o Interrupt all poles

10.10 Current breaking devices :

- In addition to the requirements of switching devices, circuit breakers and any other load breaking disconnection devices used for protection and/or disconnecting means shall comply with the following requirements:
  - o Not be polarity sensitive (as fault currents in a PV array may flow in the opposite direction of normal operating currents).
  - o Be rated to interrupt full load and prospective fault currents from the PV array and any other connected power sources such as batteries, generators and the grid, if present, and;
  - o When over-current protection is incorporated, the trip current shall be rated according to over current protection systems.

- Plugs, sockets and couplers
  - o Plugs, sockets and couplers shall comply with all the following requirements:
    - ➢ Be rated for AC side for AC use and be rated for DC side for DC use
    - ➢ Have a voltage rating greater than $V_{OC\ STC\ ARRAY}$
    - ➢ Be protected from contact with live parts in both the connected and disconnected state
    - ➢ Have a current rating equal to or greater than the cable to which they are fitted
    - ➢ Require a deliberate force to disconnect
    - ➢ Have a temperature rating suitable for their installation location
    - ➢ If multipolar, be polarized
    - ➢ Comply with Class 11 and
    - ➢ If exposed to the environment, be rated for outdoor use, be UV resistant and be at least IP 56 compliant
  - o Plugs and socket outlets normally used for connection to AC mains power as described in MS 589, shall not be used in PV arrays wiring.

10.11 Fuses :

- Fuses used in PV arrays shall comply with all the following requirements:
  - Be rated for AC for AC use and be rated for DC for DC use
  - Have a voltage rating equal to, or greater than $V_{OC\ STC\ ARRAY}$
  - Be rated to interrupt full load and prospective fault currents from the PV array and connected power sources such as batteries, generators and the grid, if present and
  - Have a current rating of ≥ 1.5 and ≤ 2 time $I_{SC\ STC\ STRING}$
- Fuse holders shall comply with all the following requirements:
  - Have a voltage rating equal to, or greater than $V_{OC\ STC\ ARRAY}$
  - Have a current rating equal to, or greater than, the corresponding fuse and
  - Provide a degree of protection not less than IP 2X

10.12 Earthing :

- The PV system and interface equipment shall be earthed in accordance with Malaysian National Standard of MS 1837:2010 Installation of grid connected photovoltaic (PV) system.
- There are three possible reasons for earthing a PV array:
  - Equipotential bonding to avoid uneven potentials across and installation
  - Protective earthing to provide a path for fault currents to flow and
  - Lightning protection
- An earth conductor may perform one or more of these functions in an installation. The dimensions and location of the conductor are very dependent on its function.

10.13 Earthing of equipment :

- Equipment earthing refers to the bonding to earth of all frames of the PV array including any structural metalwork. Equipment earthing shall be done with at least a 10 mm^2 earthing conductor.

10.14 Earthing conductors :

- All PV array earthing conductors shall comply with the material, type, insulation, identification, and installation and connection requirements as specified in MS IEC 60364 or MS IEC 60364-7-712.

10.15 Earthing arrangement (Adopted from TNB DG Guidebook)

- System containing PV operating in parallel with the Distribution System is normally earthed through the Distribution network.
- Earthing islanded systems, prior to islanding protection operation, can also be complex and may require switched earths. Protection systems should take into account the earth switching and its complexities.

10.16 Operation :

- It is important that for the safety of operating staff and public, both the Distributor and the PV Operator must coordinate, establish and maintain the necessary isolation and earthing when work and/or tests are to be carried out at the interface/connection point.
- The safety coordination applies to when work and/or tests that are to be carried out involving the interface between the distribution network and the PV Plant and it is the responsibility of the Distributor and PV Operator to comply with the requirements of statutory acts, regulations, sub – regulations, individual license conditions, Standardized Distributor's Safety Rules and the Malaysian Grid Code.

10.17 Operation and safety requirements (Adopted from TNB DG Guidebook) :

- For purposes of safety coordination procedure, the following requirements are prerequisites:
  - At each point of interface/connection between the distribution network and the PV Plant, the boundary of ownership is clearly defined;
  - The Distributor and the PV Operator provide each other with the operating diagrams of their respective side of the point of interface/connection;
  - The Distributor and the PV Operator must exchange information on safety rules and / or instruction as practiced in their respective system.
- The above information must be included in the Connection Operation Manual.

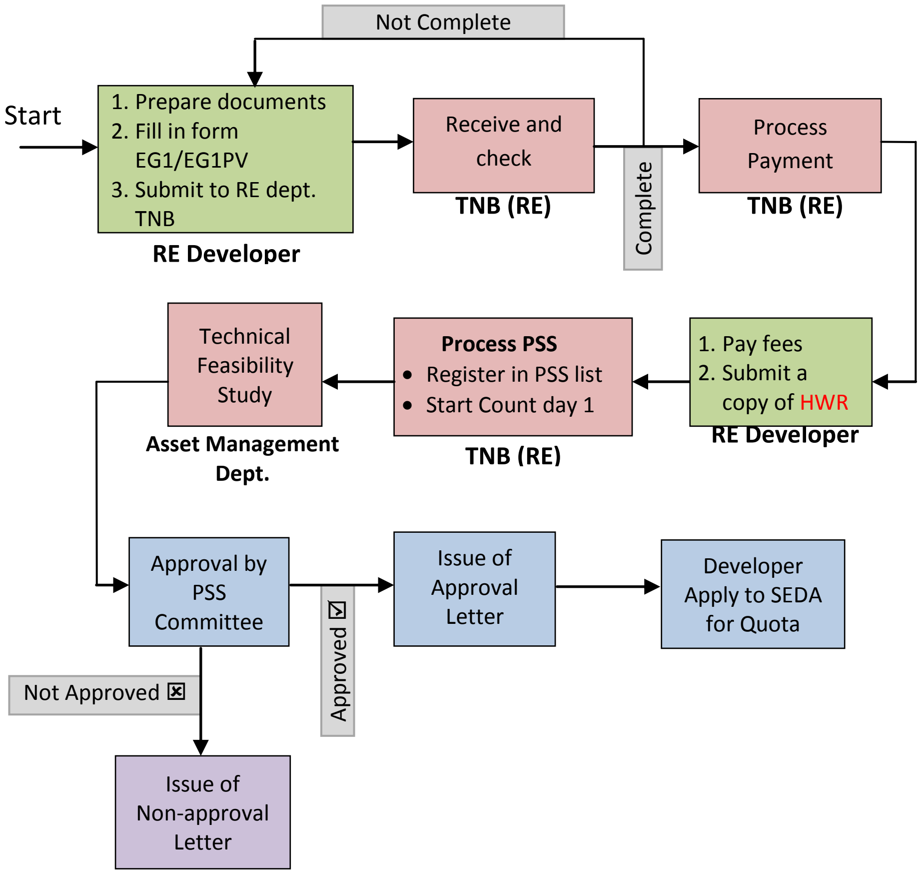
- All switching operations shall be carried out according to the procedures as defined in the Standardized Distributor's Safety Rules (TNB Safety Rules), which shall include but not limited to the following:
  a) Coordination;
  b) Isolation/ Islanding
  c) Earthing;
  d) Recording;
  e) Testing;
  f) Commissioning;
  g) Cancellation; and
  h) Reenergizing.

10.18 MV connections

- Additional safety procedures are stipulated in the IOM document and to be complied at all times.

11.0 Application Process

11.1 Application process flow



RE developers are required to provide the following details when applying for the Power Systems Study (PSS):

- RE Developer General Information
- RE Plant/facility Installer Information
- Details of Installation Equipments:
  - i) Photovoltaic equipment
  - ii) Step-up transformer
  - iii) Circuit breaker rating
  - iv) System Compliance

12.0 Testing & commissioning

12.1 Testing : There are 2 types of testing required:

a) Inverter compliance tests
b) Interconnection compliance tests

Inverter compliance test

FiAH is responsible to ensure that the inverter unit(s) are in compliance to the requirements in Chapters 4, 6 and 10 of this guideline.
Certified results of tests must be submitted for verification.

Interconnection compliance tests

Prior to commissioning, the solar PV plant must be tested to ensure that the performance is up to the required standard, installations are according to the approved scheme, settings are done as approved, etc.
Connection of PV plant should not have detrimental impact to the operation of TNB grid.

Tests to prove the following items shall be carried out in the commissioning process:

a) Anti islanding on loss of mains,
b) Interlocking scheme
c) Equipment functional tests
d) Power Quality measurement

12.2 Intergrated Operation Manual (IOM)

Purpose of IOM is to outline duties and responsibilities of both parties at the interconnection between TNB and FiAH. IOM is also to set out the necessary procedures to be followed to ensure safety to the operating personnel and to avoid damage to the equipment at the interconnection point.

IOM is jointly prepared by TNB and FiAH representative.

IOM has to be completed before commissioning process could be considered.

12.3 Power Quality measurement

Power quality background measurements are to be done at the point of connection to ascertain the existing power quality before commissioning. Measurement shall capture the following parameters are:

c) 7-day voltage regulation profile
d) THD voltage
e) Unbalanced voltage
f) Flicker voltage

Same measurements are to be repeated after commissioning to identify power quality due to connection of the solar PV plant.

12.3 Commissioning tests

Commissioning tests of the installation must be carried out according to the TNB standard commissioning requirements of the relevant equipment.

The testing of equipment that is to be handed over to TNB, shall be witnessed by TNB personnel.

All tests must be carried out by qualified company & individuals.

Test equipment must have valid calibration certificate for the results to be accepted by TNB.

12.4 Anti-islanding test

Anti islanding test reports performed by the manufacturer in the laboratory is to be used as reference.
Tests to be done at site are as follows:

a. Anti islanding test – as per inverter manufacturer recommendation

b. Cease to energize functionality test – to check inverter operation when interface cable is shut off
   i. Interface cable to be shut off
      - Outcome expected = No inverter reconnection before time delay lapse

   ii. Interface cable to switch back on
      - Outcome expected = Inverter shall only starts to generate again after 5 minutes

c. Revised setting – Developer shall require to retest any parameter that initially set at factory but has been change at site
      - Outcome = Inverter operate normally with the new settings (if any)

All test results must be certified by the professional engineer.

12.5 Reliability run

Under RE Technical and Operational Requirement, all RE plants with MV interconnection are subjected to reliability run except for PV. For PV, only plants with capacity > 1 MW need to undergo Reliability Run process.

FiAH must prove that the plant experienced forced outages not exceeding 3 times for at least 7 consecutive days to be accepted.

The Reliability Run report to be submitted to SEDA by FiAH.

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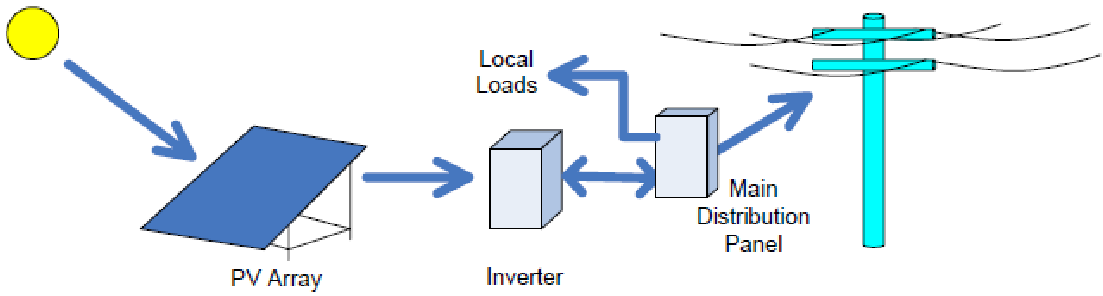
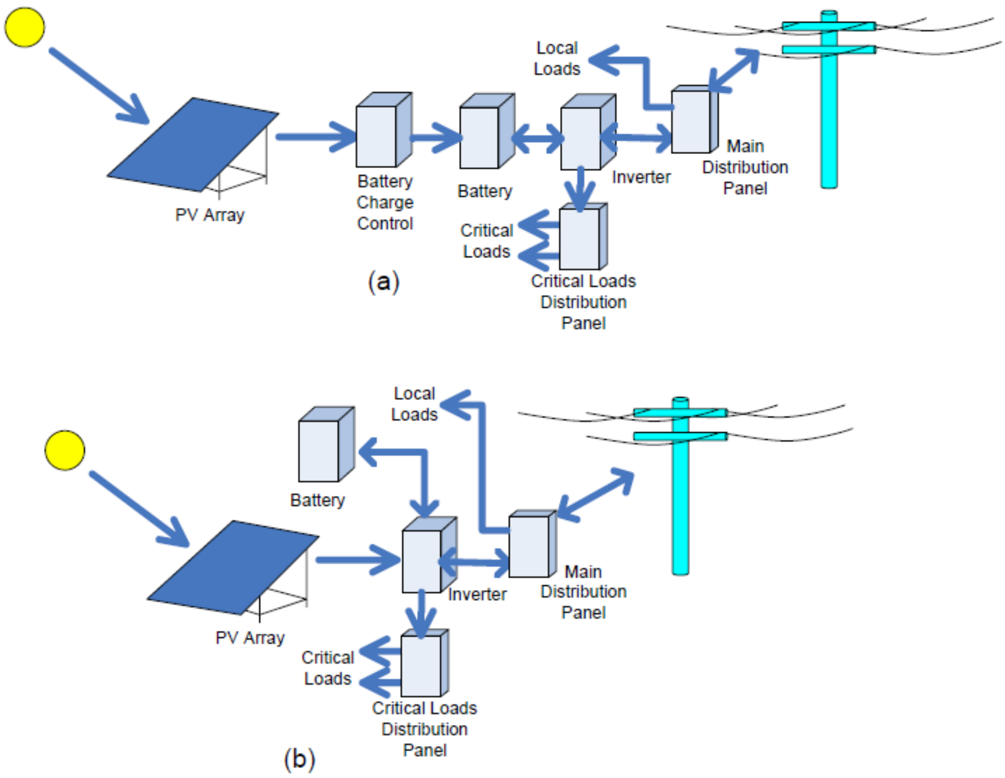
APPENDIX A – THE EXAMPLE OF PV SYSTEM DESIGNS

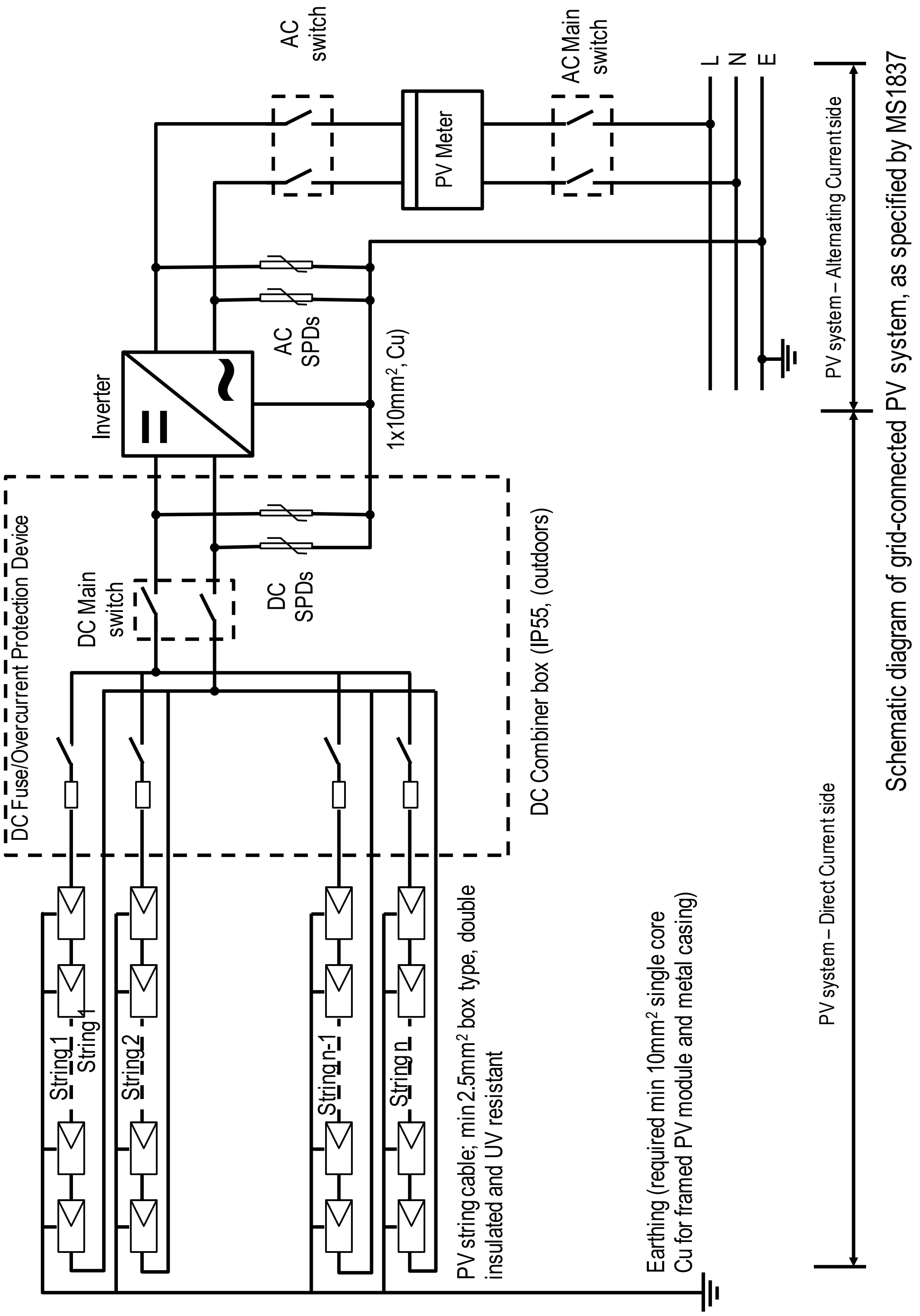


A1 – Grid connected PV systems with no storage

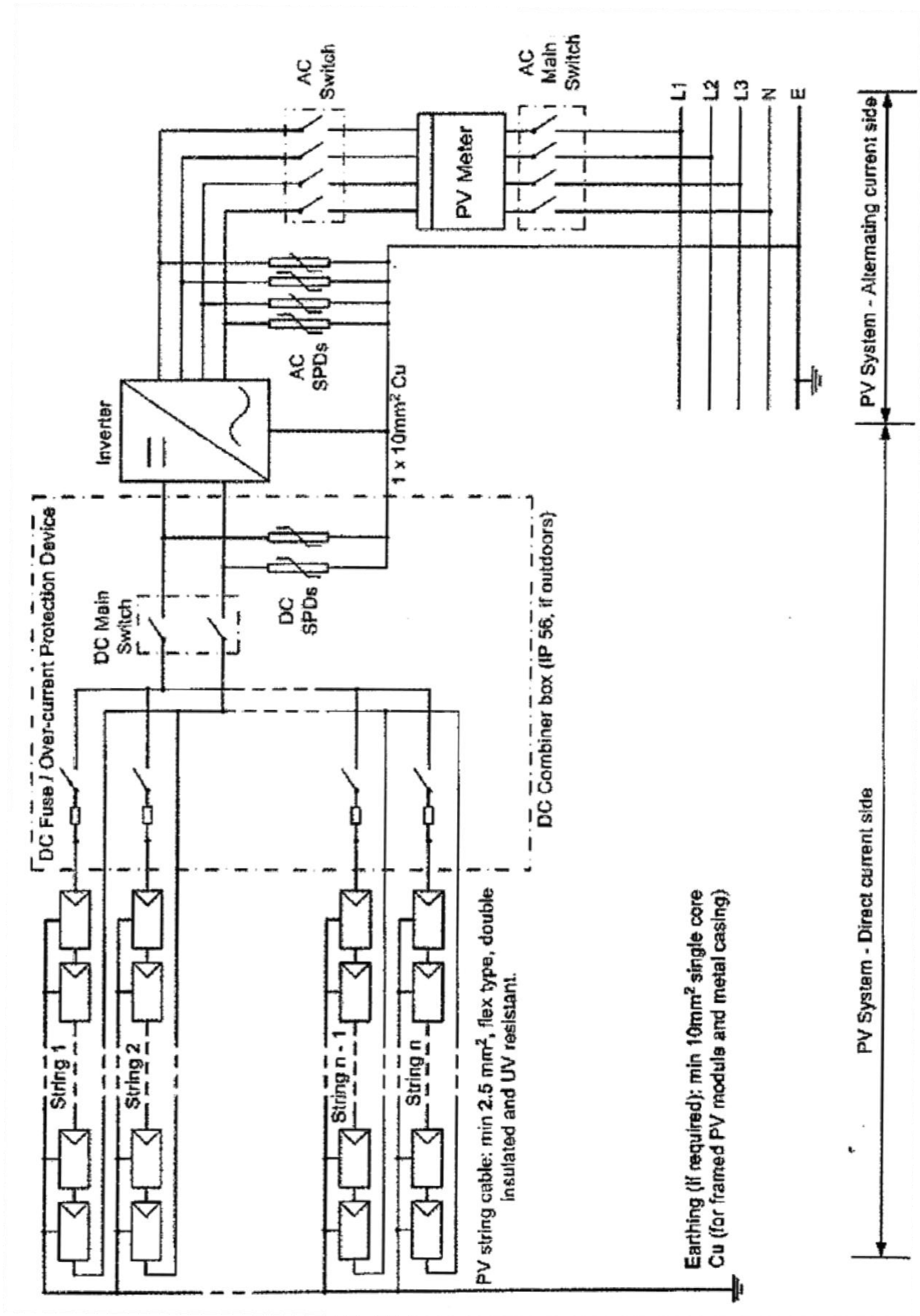


A2 – Grid connected PV systems with storage using (a) separate PV charge control and inverter charge control, and (b) integrated charge control

APPENDIX B – LOW VOLTAGE PV INTERCONNECTION SCHEMATICS

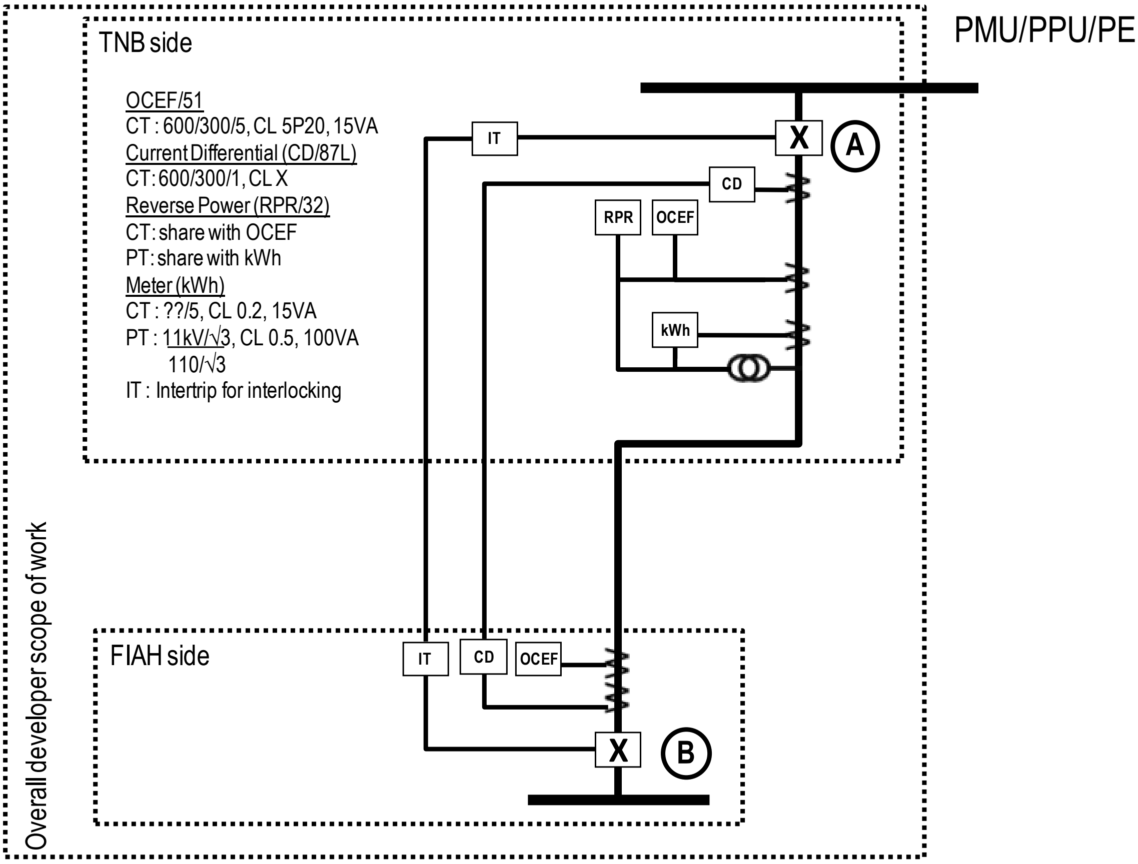


Schematic diagram of a grid-connected PV system (single-phase) as specified in MS IEC 1837



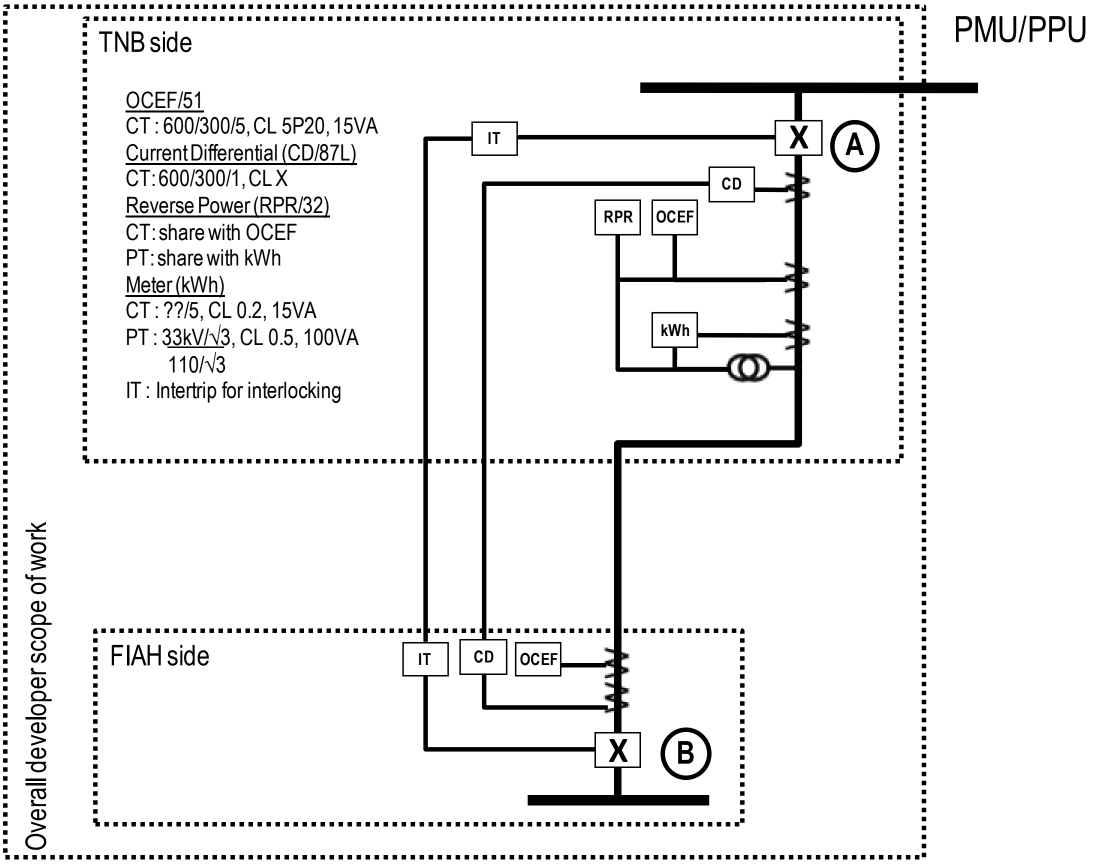
Schematic diagram of a grid-connected PV system (three-phase), as specified in MS IEC 1837

APPENDIX C – SCHEMATIC OF TYPICAL INTERCONNECTION FEEDER at 11kV



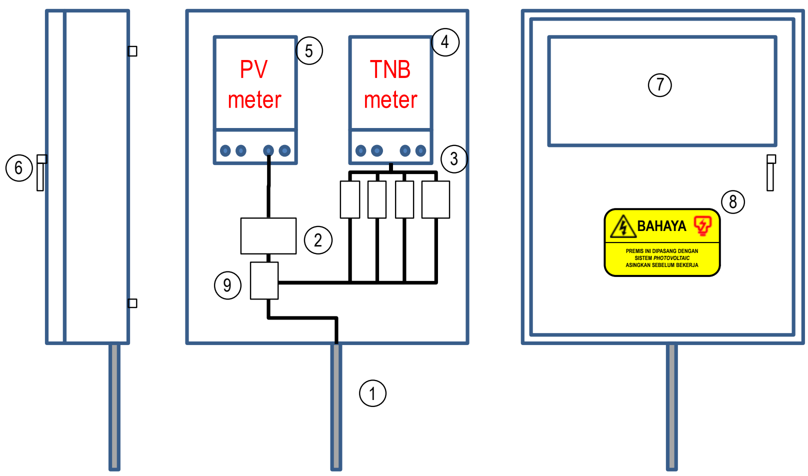
CT ratio of ?? is to be determined based on capacity of plant output.

APPENDIX D – SCHEMATIC OF TYPICAL INTERCONNECTION FEEDER at 33kV



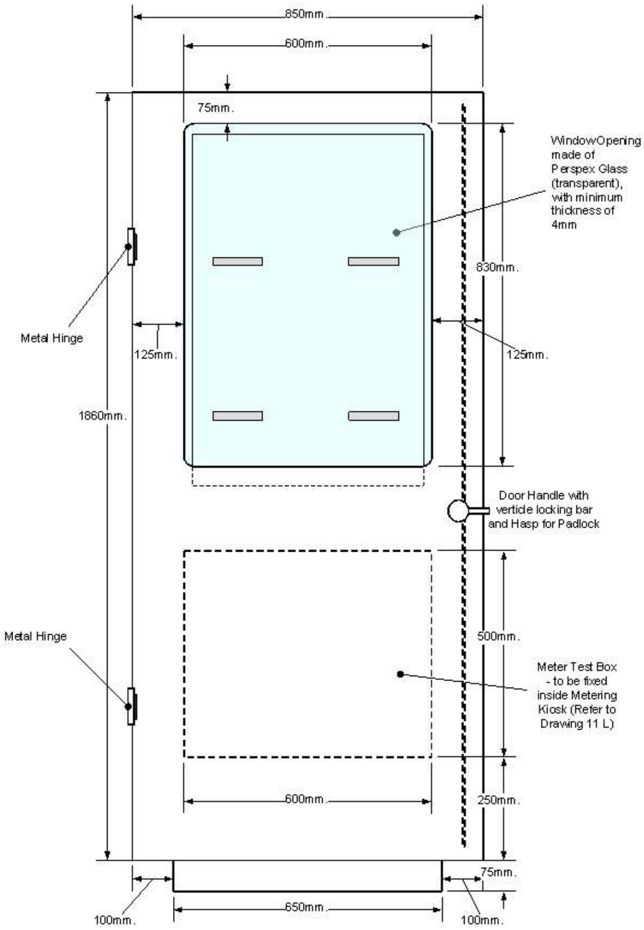
CT ratio of ?? is to be determined based on capacity of plant output.

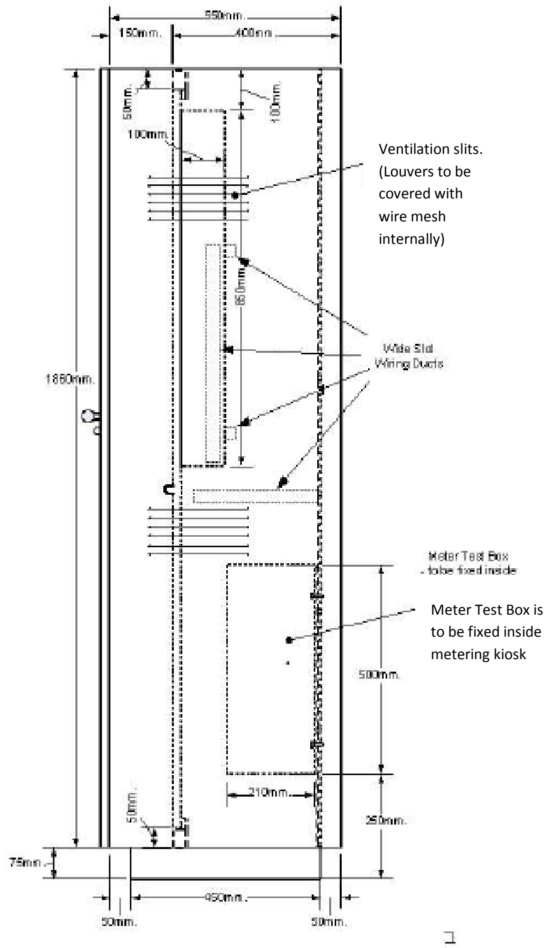
APPENDIX E – LAYOUT OF LV METERING PANEL



① Incoming cable from TNB
② Disconnect switch
③ Cut-out fuse
④ TNB energy meter
⑤ PV energy meter
⑥ Lockable door
⑦ Viewing pane (optional)
⑧ Safety label
⑨ Junction box

APPENDIX F – TYPICAL MV METERING KIOSK





Please refer to latest TNB Electricity Supply Application Handbook for full details of metering kiosk