AUTORITI ELEKTRIK NEGARA BRUNEI DARUSSALAM

KEMENTERIAN TENAGA

CODE OF PRACTICE FOR SMALL SCALE SOLAR PHOTOVOLTAIC SYSTEM CONNECTION TO LOW VOLTAGE NETWORK

Revision Record

Revision	Description	Reviewed by	Issued by the Authority	Date
00	First Issue	EO17 Task Force	[signature]	07/10/2020

FOREWORD

Code of Practice for Small Scale Solar Photovoltaic System connection to Low Voltage Network is an initiative by Autoriti Elektrik Negara Brunei Darussalam (AENBD) in regulating the generation, transmission and distribution of electricity; and safe use of electricity in accordance with the Electricity Order 2017 (EO17).

This Code of Practice is a technical document meant to facilitate or assist prospective Small Scale Solar (SSS) developers or owners who wishes to seek connection to the Low Voltage (LV) Network; and the relevant Distribution Service Providers (DSP) whose LV network is to be connected with the SSS PV systems. Small scale solar power generation capacity range applicable is below $0.9MW_{ac}$.

This Code of Practice does not contain a comprehensive details or information required in the designing of the SSS PV systems. It is solely the responsibility of the prospective SSS developers or owners for the interpretation of the information in this Code of Practice.

This Code of Practice is subject to periodical review to keep abreast with the development of technologies, standards, best practices to suit the changing needs of the electricity industry and its stakeholders. Any suggestion or recommendations are most welcomed and can be emailed to AENBD at aenbd@me.gov.bn for consideration.

ACKNOWLEDGEMENT

Autoriti Elektrik Negara Brunei Darussalam (AENBD) would like to thank and extend its sincere appreciation to the Electricity Order 17 Task Force (EO17TF) members, which comprises of officers from AENBD, Department of Electrical Services (DES) and invited special review panel from the Berakas Power Company Sdn. Bhd. (BPC) and Sustainable Energy Division (SED), Ministry of Energy, for their continuous support, contributions, time and effort which they have put into making this Code of Practice.

DES:

1. Dyg. Hjh Zuriayati binti Hj Zainal;
2. Awg. Lim Chee Kiat;

BPC:

3. Mr. Caius Yong;
4. Awg. Khairul Anwar b. Bakar;

SED:

5. Dyg. Nurul Hadinah binti Yahaya;

AENBD:

6. Pg. Hj. Shariful bin PSI Pg. Hj. Ismail;
7. Dyg. Hjh. Nuriryanty binti Hj. Muhd. Shah Al-Islam;
8. Awg. Shaikh Mohd Dzulamali bin Shaikh Hj Abdul Mutalib;
9. Dyg. Ayesha binti Abdullah Manggau.

ELECTRICITY ORDER 2017

CODE OF PRACTICE FOR SMALL SCALE SOLAR PHOTOVOLTAIC SYSTEM CONNECTION TO LOW VOLTAGE NETWORK

In exercise the power conferred by **Part 3 of the Electricity Order 2017**, the Authority issues the following Code of Practice:

Citation and Commencement

1. This Code of Practice may be cited as the **Code of Practice for Small Scale Solar Photovoltaic System Connection to Low Voltage Network**.

2. This Code of Practice shall come into effect on the issued date and will be revised as deemed necessary with a new revised issuance date.

Application of these Code of Practice

3. This Code of Practice is applicable to:

    i. any person or entity who are seeking connections to the low voltage electricity network (400V/230V – three and single phase);

    ii. Distribution Service Providers (DSP), whose network is to be connected with the Small Scale Solar Photovoltaic System (LV network)

Amendment and Variation

4. This Code of Practice at any time, may be updated, modified or revoked by the Authority as deemed necessary.

Table of Contents

Glossary of Terms

This section describes a list of terms used in this document.

Term	Definition
ac side	Part of a PV system from the Alternating Current (ac) terminals of the PV inverter up to the grid connection to the mains;
By-pass diode	A diode which is connected in parallel with a number of PV cells or the whole PV module;
Cable	A single cable core, or two or more cable cores laid up together, reinforced, or protective coverings;
Connection point	The point on the LV System, electrically closest to the SSS PV plant where solar generated energy is exported;
dc side	Part of a PV system from the PV cell to the Direct Current (dc) terminals of the PV inverter;
Demand	The demand of MW or MVAr of electricity (i.e. both Active Power and Reactive Power respectively) unless otherwise stated;
Distribution System	System of electric lines with voltage level of 11kV and below, within the Area of Supply operated by a Distribution Service Provider, for distribution of electricity from the Grid Supply Points or Generating Units to Customers or other Distributors and including any electrical plant and meters owned or operated by the Distribution Service Provider in connection with the distribution of electricity;
Distribution Service Provider	Means distribution system grid owner or operator who operate and maintains the distribution grid;
Harmonic	A sinusoidal component of a periodic wave or quantity having a frequency which is an integral multiple of the fundamental frequency;
Inverter	An electrical device or system which converts dc power to ac power;

Term	Definition
Islanding	A condition in which a portion of the Distribution Service Provider system that contains both load and distributed resources remains energised while isolated from the remainder of the Distribution Service Provider system;
Low Voltage	Voltage level or range of less than 1,000V;
Net-Metering	A mechanism where an eligible consumer installs a SSS PV system primarily for own use and the excess energy generated is exported to the grid for which credit is to be received that may be used to offset part of the electricity bill for energy provided by the Distribution Service Provider to the electricity consumer during the applicable billing period;
Nominal	The value or range of a parameter being within expected norms or being the normal operating level of that parameter;
Non-linear load	A load that draws a non-sinusoidal current wave when applied by a sinusoidal voltage source;
Plt n	Absolute long-term flicker severity;
Power Factor	The Power Factor λ is the ratio of the active power P (kW) to the apparent power S (kVA): $\lambda = \frac{P(kW)}{S(kVA)}$
Pst	Absolute short-term flicker severity;
PV ac Module	Integrated module or inverter assembly where the electrical interface terminals are ac only;
PV Array	Mechanically and electrically integrated assembly of PV modules and their associated components, to form a dc power supply unit. A PV array may consist of a single PV string or several parallel- connected strings or several parallel-connected PV sub-arrays and their associated components;
PV Array Cable	The output cable of a PV array which connects the PV array junction box to the inverter;
PV Array Junction Box	An enclosure where PV strings of any PV array is electrically connected and where protection devices can be located;

Term	Definition
PV Cell	Basic PV device which can generate electricity when exposed to light such as solar radiation;
PV dc Main Cable	Cable connecting the PV generator junction box to the dc terminals of the PV inverter;
PV Generator	Assembly of PV arrays;
PV Generator Junction Box	An enclosure where PV arrays are electrically connected and where devices can be located;
PV Module	An assembly of several PV cells electrically connected to form a larger photovoltaic conversion device, and which are encapsulated together to protect them from the environment. A PV module is the smallest ready-to-use photovoltaic conversion device;
PV String	A circuit in which PV modules are connected in series, in order for a PV array to generate the required output voltage;
PV String Cable	Cable connecting PV modules to form a PV string;
PV Sub-Array	A group of PV strings connected in parallel, that comprise a partial section of the PV array, where the output current of that group of strings is carried by a dedicated output cable before being connected in parallel with other sub-arrays;
PV Supply Cable	Cable connecting the ac terminals of the PV inverter to a distribution circuit of the electrical installation;
PV System	An electrically integrated assembly of PV array, inverter (or power conditioning unit) and other necessary components to form a power generation unit;
Renewable Energy (RE)	Sustainable energy from inexhaustible natural sources such as wind, solar, hydro etc.;

Term	Definition
Surge Protective Device (SPD)	A device which is intended to limit transient over-voltages and divert surge currents. It contains at least one non-linear component;
Total Harmonic Distortion (THD)	Harmonic distortion is the departure of a waveform from sinusoidal shape which is caused by the addition of one or more harmonics to the fundamental. THD 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.

1 Introduction

Solar energy is used in the generation of electricity as an alternative green energy to meet the world's rising demand for energy. Along with that was the creation of a worldwide market for photovoltaic panels and equipment to cater for renewable energy needs. Photovoltaic panels are available in many forms, notably monocrystalline, polycrystalline, and thin-film types. Solar PV systems can be classified based on the end-use application of the technology. There are two main types of small scale solar photovoltaic systems: grid-connected (or grid-tied) and off- grid (or stand-alone) solar PV systems. Typically, a solar energy system may generate energy for more than 20 years due to the durability of photovoltaic modules.

The main objectives of this Code of Practice are to facilitate and assist SSS developers and/ owners who seek connection to the low voltage network; and Distribution Service Provider (DSP) whose low voltage network is to be connected with the SSS PV systems; whilst stressing out the importance of complying with the technical requirements for Solar PV connection to a DSP grid. The technical interconnection requirements or standards is meant to ensure the safety requirement of the installations, the network and safety for the operation and maintenance personnel are met.

This Code of Practice refers to grid-connected Small Scale Solar PV systems (i.e. rooftop, floating, ground mounted etc.) which operates in parallel with the power grid supply. The power grid supply is considered the source, and the electrical installation with the solar PV system connected is considered as the load.

Installation of solar PV systems shall be carried out by registered electrical workers and all associated components of a PV system which includes PV panels, wiring, switches, mounting systems, inverters, LV protection, net-meters are to be procured from DSP's list of approved vendors or suppliers or as approved by the DSP.

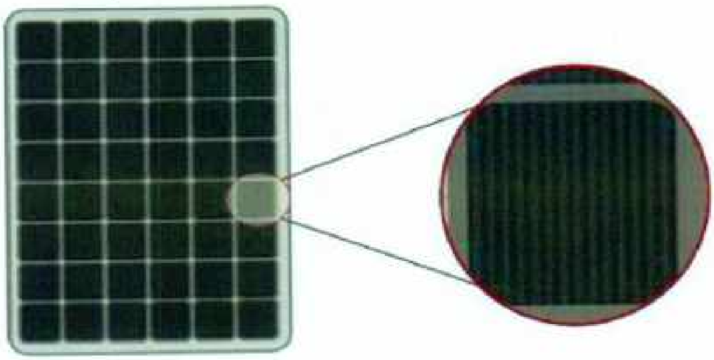
2 Types of PV Panels and Inverters

Solar panels are used to generate electricity; they are made up of solar cells, which are made from semiconducting material that convert light into electricity. The most common material used as a semiconductor is silicon. There are several types of solar panels available for selection in the market. The following describes some of the commonly used type of PV panels and inverters arrangement used or installed in a solar PV system.

2.1 Types of Solar Panel

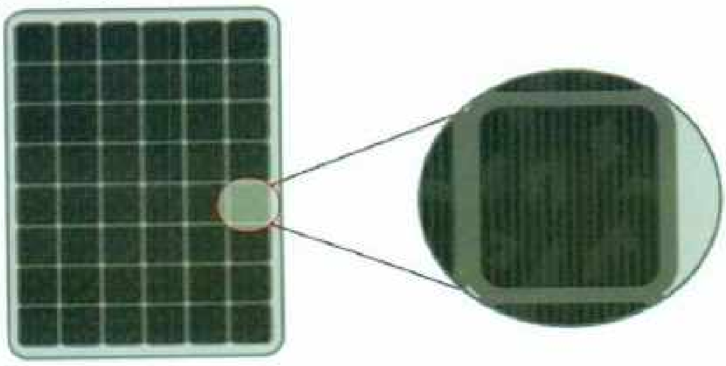
There are three (not limited to) major types of commonly used or installed solar panels:

a) Monocrystalline;



MONO

b) Polycrystalline; and



POLY

c) Thin-film.

Each type has its own unique advantages and disadvantages, and the solar panel best suited for your installation will depend on factors specific to your premise and desired system characteristics.

Solar Panels Type	Advantages	Disadvantages
Monocrystalline	• High efficiency • Aesthetics	• Higher cost
Polycrystalline	• Cheap	• Lower efficiency
Thin-Film	• Portable and flexible • Lightweight • Aesthetics	• Lowest efficiency

Monocrystalline typically have the highest efficiency and power capacity. Most monocrystalline solar panels often reach efficiency of more than 20%, while polycrystalline solar panels typically have efficiencies ranged between 15% to 17%.

Monocrystalline solar panels tend to generate more power than other types of panels not only because of their efficiency but because they come in higher wattage modules as well. Many monocrystalline solar panels come with more than 300 watts (W) of power capacity, some reaching more than 350W. Polycrystalline solar panels, on the other hand, have lower wattages. Both types of solar panels tend to come with 60 silicon cells each, with 72 or 96 cell variants (usually for large-scale installations). But even with the same number of cells, monocrystalline panels are capable of producing more electricity.

Thin-film solar panels tend to have lower efficiency and power capacity than monocrystalline or polycrystalline solar panels. Efficiency will vary based on the specific material used in the cells and typically closer to 11%.

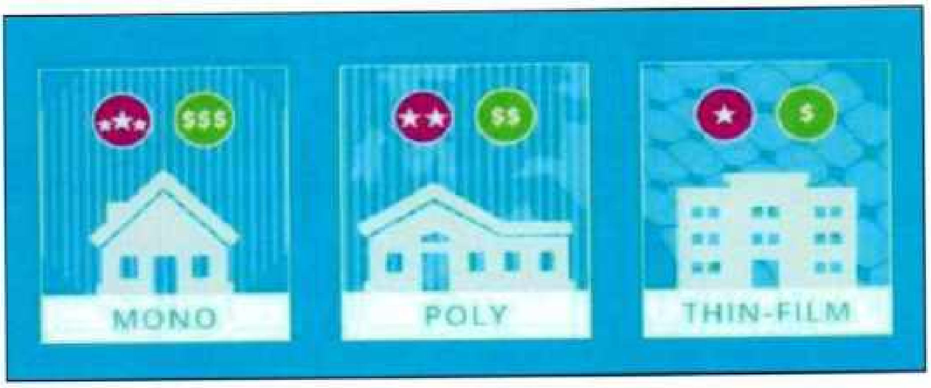
Unlike monocrystalline and polycrystalline solar panels that come in standardized 60, 72 and 96 cell variants, thin-film technology does not come in uniform sizes. As such, the power capacity from one thin-film panel to another will largely depend on its physical size.

2.1.1 Type of solar panel best for your installation

The type of panel you would choose for your system would depend on the specifics of your premise, the site condition and your power generation capacity target or your power requirement.

Premise owners with a lot of space for solar panels can save money upfront by installing lower efficiency, lower-cost polycrystalline panels. If you have limited space available and are looking to maximize your electric bill savings, you can do so by installing high-efficiency, monocrystalline solar panels.

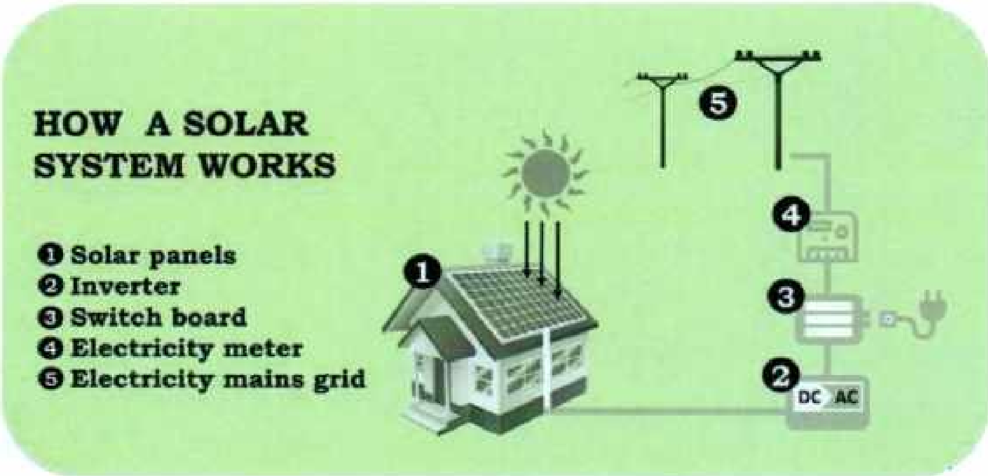
As for thin-film panels, it's most common to choose this type of solar panel if you're installing on a large, commercial roof that cannot handle the additional weight of traditional solar equipment.



2.2 Types of Inverters

Solar power inverters are also known as grid-tied inverters which play important role in a solar system; where they convert electricity generated by solar panels into a form that can be used by appliances, lighting and other electronics.

When the sun shines on the solar photovoltaic (PV) panels, electrons within the solar cells start to move around, which produces Direct Current (DC) energy. As DC electricity is not compatible with common household appliances nor shall be fed into the mains grid, it first needs to be converted to Alternating Current (AC) by the inverter.



Most premises use alternating current (AC) energy, not DC, so the energy produced by solar panels is not useful on its own. When the solar panels collect sunlight and turn it into energy, it gets sent to the inverter, which takes the DC energy and converts it into AC energy. At that point, solar electricity can power up appliances and electronics or, if the energy produced is more than being used up, it can be exported to the grid.

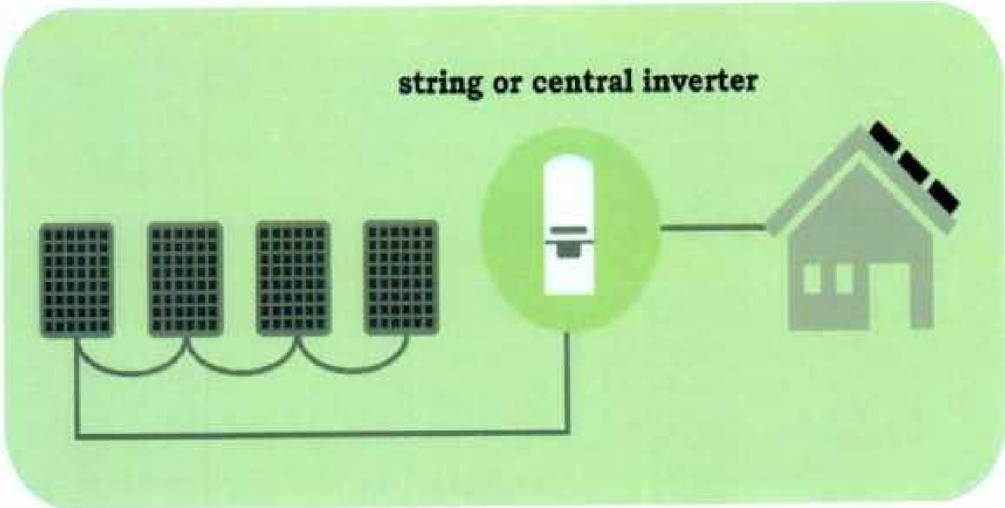
There are three (3) main types of inverters options, recommended for residential and commercial solar installations:

i. String (also known as Centralized) Inverters;
ii. Power optimizer system (also known as string inverters + power optimizers) and;
iii. Micro-inverters and power optimizers.

String Inverters are the most commonly deployed option for small scale solar system. While micro-inverters and power optimizers system are more expensive than string inverters, they are best for installations where one or more panels may be shaded, or where panels are facing different directions. Micro-inverters and power optimizers also allow owners to monitor the power production of each individual panel.

2.2.1 String (also known as Centralized) Inverters

If roof is not shaded at any point during the day and does not face multiple directions, string inverters is an option that can be considered.

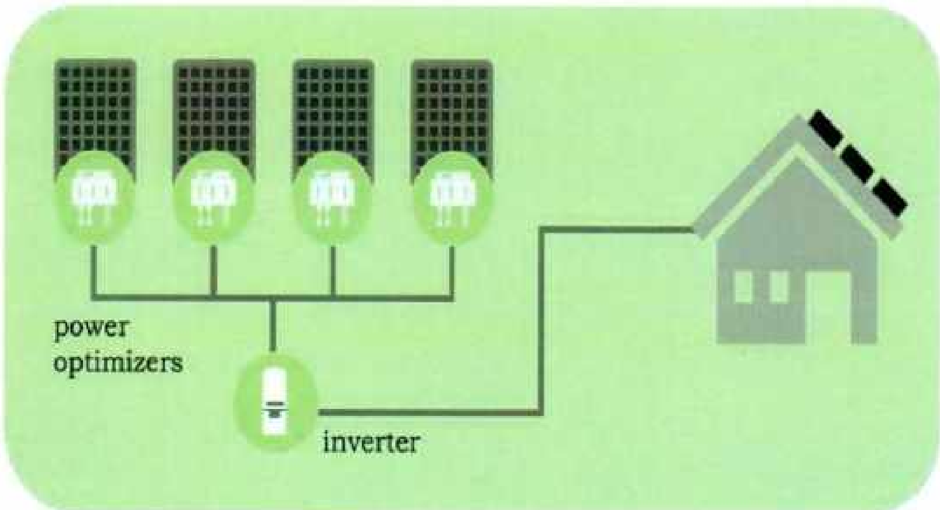


Most small scale solar energy systems use string inverters where each panel is wired together into strings and each string of panels is connected to a single inverter which converts DC electricity produced by the panels into AC electricity. String inverter are cost effective and easy to maintain, however, it will produce as much useful electricity as its least productive solar panel. Electricity production for a system with a string inverter may be reduced if just one or two panels are in the shade or does not operate properly.

2.2.2 Power optimizer system (string inverters + power optimizers)

Power optimizers offer many of the same benefits as micro-inverters but slightly cheaper. They are often considered a compromise between the more expensive micro-inverters and the standard string inverter. They are located at each panel, usually integrated into the panels themselves.

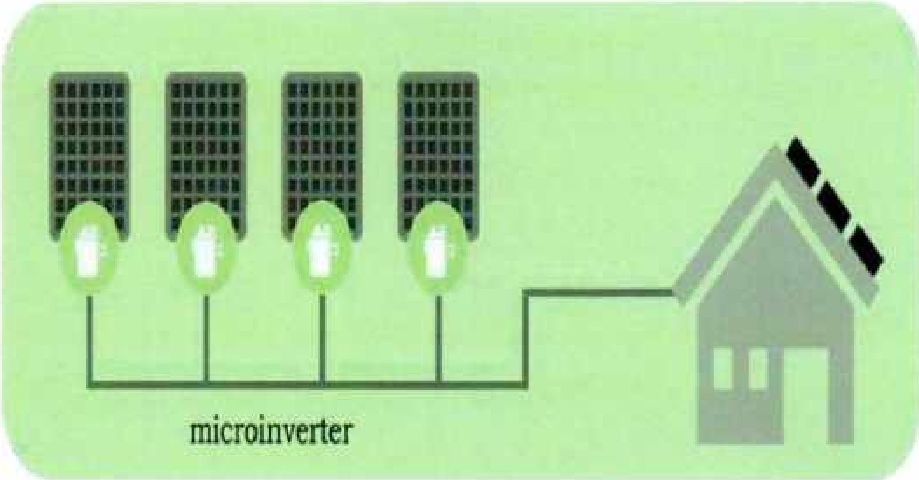
Power Optimizers do not convert DC electricity into AC electricity, they "condition" the DC electricity and send it to a string inverter. This approach results in higher system efficiency than a string inverter alone.



Small Scale Solar PV system paired with power optimizers is not only more efficient but also allows the monitoring of the performance of individual panels and can still produce significant energy even if one or two panels are underperforming. However, this type of system tends to be more expensive than a standard string inverters and is more difficult to maintain.

2.2.3 Micro-inverters and power optimizers

Micro Inverters are smaller devices connected to the back of each individual panel in a solar array. They are more expensive than a single central inverter however a micro inverter diminishes the effect of shading on a solar PV system's total energy output where any loss of efficiency in one panel does not diminish the output from the rest of the array. Rather than sending energy from every solar panel down to a single inverter, micro-inverters system convert DC solar energy to AC electricity right on the roof (with no need for a separate central inverter). It's a high performance inverter, more efficient than string inverters at converting energy and able to monitor the performance of specific panels.



However, micro-inverters and power optimizer systems are typically more expensive than standard string inverters. This type of small scale solar PV system is most suitable for installations where one or more panels may be shaded or where panels are facing different directions. This particular system allows system owners to monitor the power production or each individual panel performance.

3 Types of solar panels mounts

Solar panels work best when they receive shade free sunlight for certain maximum numbers of hours, mounted at a precise tilt angle. Mounting structure is an important element in a solar system, they secure panels onto the roof or the ground, preventing them from being damaged and position these panels at precise tilt angle to harness maximum sun's energy.

Solar panels or modules need to be mounted and tightened or secured on a very stable and durable structure, protecting the array against strong wind, rain or bad weather. The five basic types of mounting structures (not limited to) are:

i. Roof Mount Racks
ii. Ground Mount Racks
iii. Top of Poles Mount Racks
iv. Side of Poles Mount Racks
v. Tracking System Mount Racks

3.1 Roof Mount Racks

Typically keep the wire run distances between the solar array and the battery bank or inverter to a minimum, but require roof penetrations and run danger of causing roof leakages, thus the roof must be well sealed. Another disadvantage of roof mounted structures is, if the roof orientation and angle is not optimal, thus wasting lots of potential energy that the solar system could generate. Loading issues (weight of the panels) is another concern that need to be considered when designing SSS PV system.

3.1.1 Types of Roof Mounts

3.1.1.1 Flush Mounts

Flush Mounts system are suitable for most roof-mounted solar panel installations, inexpensive and simple. Flush mounts however are not adjustable, where they are designed to lay flush with the roof surface on which they are mounted, protects the roof as well as the panels. The solar panels are secured using metal clips that hold the panel in place, leaving about 2-4 inches of space between the roof and bottom of the panel. This allows for airflow along the underside of the panel, keeping the panel cool and operating at maximum efficiency while reducing wind load. If a panel overheats, its efficiency drops and shorten its lifespan. The flush mount reduces wind load on the solar panels and is ideal for reducing the dead load on the roof, suitable for high wind areas and offers flexibility in the panel slope and orientation.

However, depending on roof type, installing a flush mount may require roof penetration which may increase the risk of roof leakage.

3.1.1.2 Ballasted Mounts

Similar to flush mounts, but use weights to secure the solar panels onto the roof. This results in additional challenge of putting weights onto the roof, which can be substantial for larger systems. Ballasted mounts do not require roof penetrations and allow for panels tilt of up to 20 degrees for optimal solar exposure. However, this mount increases the load on the roof and is not suitable for high-wind areas. Other limitations include site conditions like roof slope and building height.

3.1.1.3 Hybrid Mounts

A combination of flush and ballasted mounts which makes use of structural element of both mounts to accommodate some roofs that cannot support either. Hybrid mount is recommended for use in areas with high wind loads, buildings of more than 60ft tall and island installations. Hybrid mounts require minimal roof penetration and allows for custom design optimization based on factors like load bearing and wind. This type of mounting is typically more expensive and take up more space on the roof leaving less room for the SSS PV system.

3.1.1.4 Roof-ground Mounts

Similar in design to normal ground mounts, but are able to "sit" on the roof. Depending on the type of roof, this may be better than a flush mount. Roof-ground mounts have the ability to come adjustable or fixed for maximum solar exposure throughout the year.

3.2 Ground Mount Racks

For roof which lacks space for a roof mount or is heavily shaded by trees, ground mounted racks is an alternative for mounting solar panels on the ground. These are usually adjustable to allow them to tilt for maximum solar absorption at various times throughout the day. The disadvantage is that ground mounted structures may be exposed to vandalism and thieving activities.

3.3 Top-of-pole Mount Racks

This type of mounting is used for anchoring solar panels to poles. There are two main types of pole mounts, "top-of-pole" and "side-of-pole". The former allows the solar panel to sit on top of a pole, elevated several feet off the ground. The latter anchors solar panels to the side of poles.

Top-of-pole mounted racks are structures where mounting poles are secured into the ground and tightened with concrete and the solar module is mounted on the top of the poles.

3.4 Side-of-pole Mount Racks

Side-of-pole Mount Racks are normally used for solar systems that comprises of a small number of modules. They are normally used for remote lighting systems, security cameras installations etc. that already came with a pole where they can be easily attached to.

3.5 Tracking System Mount Racks

Tracking System Mount Racks can be used for all kinds of solar tracking systems, allowing for maximum of sun radiation. The two types of mount structures for tracking systems are one-axis and two-axis. The one-axis trackers are designed to track the sun movement from the east to the west while the two-axis systems track the sun's daily and seasonal course. Solar trackers are an automated system that allows your panels to track the sun's path throughout the day for optimal solar exposure and collection. However, while solar trackers do increase efficiency and reduce manual upkeep of the panels, they are not commonly used due to the hefty increase in total cost and the addition of another moving part that potentially break down and cause problems for the array.

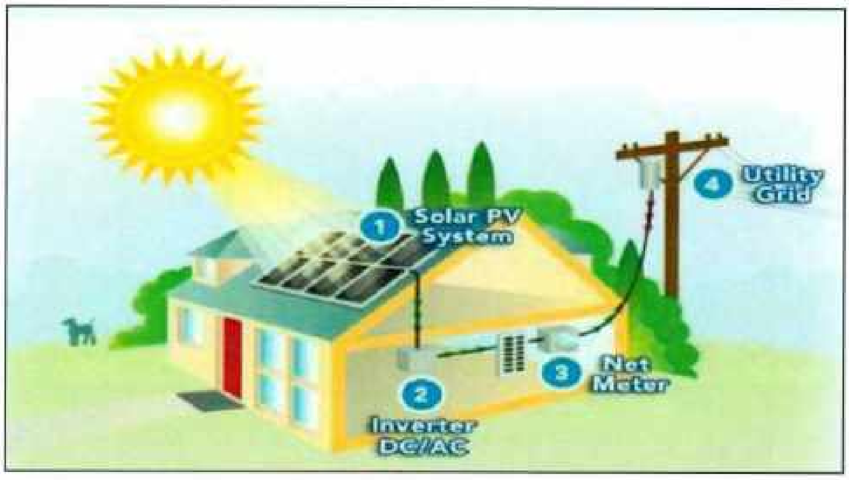
4 Grid connected and Off-Grid solar systems

4.1 Grid connected solar system

Grid connected solar system is one that is connected to the utility grid, which in this Code of Practice refers to the low voltage network. When solar panels generate more electricity than a premise requires, the surplus power is fed into the grid. In the event the premise requires more power than what the solar system is generating then the balance of electricity is supplied by the utility grid. This puts in a requirement of net-metering, where the solar energy exported to the grid is deducted from the energy imported from the grid subject to certain conditions. The consumer pays for the net-energy imported from the grid. So for example if the electrical loads in a premise were consuming 20 amps of power and the solar system was only generating 12 amps then the premise would be drawing 8 amps from the grid. Obviously at night all of its electricity needs are supplied by the grid because with a grid connected system it does not store power generated during the day.

4.1.1 Net-Metering

Net metering, also known as net energy metering or NEM, is a solar incentive scheme that allows you to store energy in the utility's grid. When solar panels generate more electricity than needed, the energy surplus is exported to the grid in exchange for credits. Then, at night or other times when the solar panels are under generating electricity, the premise will import or take in energy from the grid and use these credits to offset the costs of that energy. This "back-and-forth" between the solar system and the grid ensures that excess production will still be used and shortages will be met. With net metering, the excess electricity produced by solar PV system covers the times when it does not generate enough.



4.2 Off-Grid solar systems

Off-grid or stand-alone solar systems are not connected to the utility grid or network hence does not export excess electricity to the utility grid, therefore does not require net-metering to be installed in the small scale solar PV system. The solar panels are used to charge a bank of batteries that store the power produced by the solar panels and then the electrical loads from the premise draw their electricity from these batteries. Off- grid solar systems are mostly applicable for areas without power grid i.e. usually installed at isolated areas where the power grid is far away, rural areas, off-shore islands; or owners who choose not to be connected to the grid as it could be too costly to tap electricity from the power grid.

An off-grid solar PV system requires deep cycle rechargeable batteries such as lead-acid, nickel-cadmium or lithium-ion batteries to store electricity for use under conditions where there is little or no output from the solar PV system during the night.

5 Solar Photovoltaic System for Low Voltage (LV)

In this Code of Practice for Small Scale Solar PV System Connection to Low Voltage Network, only grid-connected solar system would be considered. This Code of Practice is to be read together with the

National Grid Code, Electrical Installation Requirements and relevant technical standards.

5.1 Background

A complete solar PV system makes up of different components that should be selected while taking into consideration individual's electricity requirement, site location, climate and expectations.

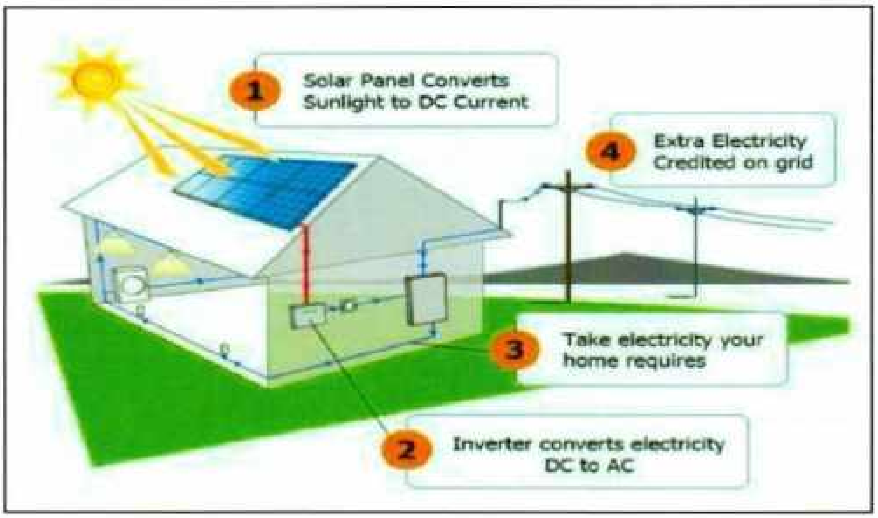


Fig. 1. A typical grid-connected solar rooftop photovoltaic system

Fig. 1 shows a typical solar rooftop connection to the low voltage side of the electricity network:

- When the sun shines on the installed solar PV panels, they generate Direct Current (DC) electricity.
- The DC electricity is fed into an inverter which converts it to 230V (single phase) or 400V (3 phase), 50Hz Alternating Current (AC) electricity.
- The building has two parallel power supplies, one from the solar PV system and the other from the power grid. The combined power supply feeds all the loads connected to the main AC distribution board.

- The ratio of solar PV supply to power grid supply varies, depending on the size of the solar PV system. Whenever the solar PV supply exceeds the building's demand, excess electricity will be exported to the grid. When there is no sunlight to generate electricity at night or if energy generated does not meet the energy demand, the power grid will supply all of the building's demand.
- Grid connected PV system requires net energy meter to be installed in its system.

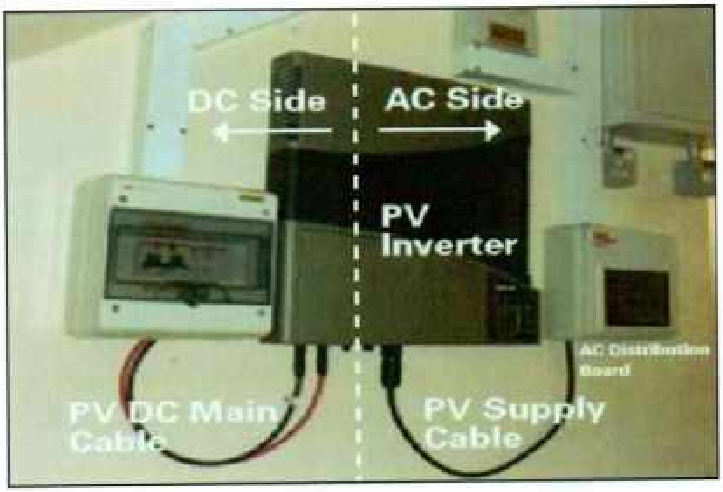


Fig. 2: Typical PV Inverter connected to a building's electrical installation

5.2 Voltage level for Grid and Off-Grid Connected Solar PV

The standard requirements for both grid and off-grid connected small scale solar PV systems interconnection to a DSP's network as in accordance to the Electricity Installation Requirements (EIR), nominal voltage level is defined:

- 400V, 50 Hz, 3-phase, 4-wire ac
- 230V, 50Hz, single-phase, 2-wire ac

5.3 Connection Requirements

Electricity energy produced by the solar PV system shall be capable to meet power quality requirement, as stipulated in this Code of Practice, relevant IEC standards on voltage, flicker, frequency, harmonics and power factor; and prudent utility practice. Deviations from these may cause out-of-bounds condition and may require the PV system to be disconnected from the DSP's LV network.

Power quality parameters must be measured at the DSP's interface or point of common coupling (PCC) prior to the commissioning of the SSS PV system and the report shall be submitted to the Authority and/ the DSP.

At the PCC, the power quality requirements must comply to the National Grid Code, Electrical Installations Requirements and this Code of Practice.

a) The power quality measurement is to be taken before and after energizing the SSS PV system and to be submitted to the Authority and/ DSP for approval;

b) All measurement at site shall be carried out by registered electrical workers, with the presence of a representative from DSP; and

c) Report for a) above is to be submitted to the DSP;

During abnormal system operating conditions such as faults, over-voltages or under-voltages and out-of-range frequencies occur, the SSS PV system is required to detect any possible abnormality occurs in the LV network and to completely disconnect from the LV network. At the DSP interface or PCC, unless stated otherwise, the values of voltage and harmonics (power quality parameters) must be measured and recorded before and after the energization of the SSS PV system.

5.3.1 Standard Voltage Operating Range

The SSS PV system should be able to operate within the voltage range shown in Table 1. The injection of current from the SSS PV system into the DSP's LV network shall not regulate voltage.

Table 1. Standard operating voltage at Point of Common Coupling

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

5.3.2 Voltage Fluctuation

Power generated by solar PV constantly varies due to the changing solar irradiation throughout the day. The varied power generation capacity injected into the DSP's LV network is bound to create voltage fluctuations at the interconnection point.

The maximum voltage fluctuation allowed for LV network due to fluctuating solar radiation is 6%. If the value is beyond this, there is a risk of DSP's and consumer equipment getting heated up that may subsequently cause damage.

For momentary voltage change, the requirement is as the following:

- 1% - Series voltage change which may lead to flickering problems
- 3% - Single voltage change due to switching ON or OFF of any loads

A distributed generator (DG) shall not regulate the voltage at PCC and it shall operate within a specified voltage range limit as specified in the National Grid Code, this Code of Practice, prudent utility practice and voltage standards.

5.3.3 Voltage Unbalance

In a three phase balanced power system, the line to neutral voltages are sinusoidal with equal magnitudes and phase angles. Unequal magnitudes or phase angles will result in an unbalanced supply. The voltage unbalance at the distribution networks may be caused by several factors:

i. Uneven distribution of single phase load across the three-phase network;
ii. Continuous changing of the instantaneous demand;
iii. Unbalanced or unstable utility supply.

Voltage unbalance is defined as the ratio of the negative sequence voltage or zero sequence voltage component to the positive sequence voltage component. When multiple single-phase PV units are installed, the negative phase sequence voltage should be 2% per 1-minute duration. It should be distributed evenly amongst the three phases of the power system.

The **Code of Practice on Large Scale Solar Photovoltaic Plant connection to Distribution Grid** states:

Negative Phase Sequence Voltage (%): 2% for 1minute duration.

The **National Grid Code** states:

Phase imbalance - planned outages for operation of installations shall not cause the maximum negative phase sequence component of the phase voltage to exceed 1.0 percent.

Where:

- The maximum negative phase sequence component of the phase voltage on distribution system shall remain below 1% unless abnormal conditions prevail.
- Infrequent short duration peaks with a maximum value of 2% are permitted for Voltage Unbalance.
- At the terminals of a user's installation, the unbalance voltage should not exceed 1% for 5 events within any 30 minutes' time interval.

5.3.4 Flicker

Flicker occurs due to rapidly varying loads which causes fluctuations in the customer's voltage (even a small change in voltage is noticeable). The operation of the PV system shall not cause voltage flicker in excess of values indicated in Table 2.

Table 2. Low voltage planning guideline (IEC 61000-3-3)

Voltage level at which the fluctuating load is connected	Absolute short-term flicker severity (Pst(10mins))	Absolute long-term flicker severity (Plt(2 hours))
Low Voltage System	1.0	0.65

5.3.5 Frequency

The DSP shall maintain the system frequency and the SSS PV System shall operate in synchronism with DSP's system frequency. The frequency shall be maintained in accordance to Section 2.5.5 of the National Grid Code.

Frequency is nominally maintained at 50 Hertz during normal operation. Grid frequency may temporarily deviate due to large changes in load, the tripping of a generator, or system faults. Limits for these various conditions are:

i. Normal Operating Conditions: 49.5 Hz to 50.5 Hz
ii. During System Stress: 49.0 Hz to 51.0 Hz
iii. Maximum deviation during faults: 48.75 Hz to 51.25 Hz
iv. Tripping values for generators 51.5 Hz or above and 47.5 Hz or below

5.3.6 Harmonic

Harmonic are currents or voltages with frequencies that are integer multiples of the fundamental power frequency. Harmonics can cause power quality problems because equipment and machinery can malfunction or fail in the presence of high harmonic voltage and/or current levels. In the presence non-linear loads such as computer power supplies and other appliances, alternating current (ac) can be distorted by the introduction of various harmonic frequencies.

Harmonics can be measured by fundamental frequency percentage or by calculating total harmonic distortion (THD). These harmonics are harmful to the electrical system and its loads when presence at high levels. In order to ensure that no adverse effects are caused to other equipment connected to the DSP's low voltage network, the SSS PV system output should have low-current distortion level.

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 3.

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

Table 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

Type tested inverters in compliance to Table 3 requirements does not require further testing.

5.3.7 Power Factor

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

National Grid Code Section 5.8.4 on power factor and reactive compensation requirements states that external systems shall have adequate reactive compensation to ensure minimum reactive power flowing through the interconnector and are required to ensure that their installations have satisfactory power factor correction. External party or parties connected to DSP's grid shall endeavors to maintain the average power factor between 0.85 and 0.9 lagging.

5.3.8 Direct Current Injection

SSS PV system shall not inject Direct Current (DC) greater than 1% of the rated inverter output current into the DSP's interface under any operating condition. DC currents can saturate transformers and other electric machines and generators.

5.3.9 Interconnection Method

For LV system, SSS PV interconnection is to be done through indirect connection method. The design must include an appropriate rating of low voltage circuit breaker (LVCB) for protection purposes near metering side mounted between meter and incoming feeder.

5.3.10 Short-Circuit Level

Table 4 below shows rated equipment to be used to withstand the maximum sub-transient three phase symmetrical short circuit fault levels.

Table 4. Typical equipment ratings

Nominal Voltage (kV)	Rated Voltage (kV)	Fault Current (kA)
0.4	1.0	31.5

6 Photovoltaic Penetration

6.1 Low Voltage Penetration Level

A large penetration of PV will increase current injection to the LV network. If the magnitude of PV current injection is greater than the load of the LV networks, overvoltage in the LV networks might occur.

Low Voltage PV penetration limits recommended are as the following:

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

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

iii. For PV connection capacity of more than 180kW, connection limit is to be determined by Power System Study (PSS) which is to be conducted by SSS PV system owner and/ developer at his own cost. However, 425kW limit for LV connection is applicable.

7 Protection Requirement

7.1 Background

In protection systems, voltage magnitude and frequency are the two (2) basic fundamental characteristics used to detect system failures in electrical systems. Unintended islanding is not permitted or allowed. In the case where power from the grid is cut-off, PV plant shall shut down. With no electricity supply, non-islanding inverters are incapable of providing the load. PV plant is not permitted to be energised during the outage of DSP's grid (loss of mains) for DSP's operation and maintenance personnel safety.

Re-synchronizing requirements are as follows:

i. Interlocking logics are satisfied
ii. Frequency difference = 0.05 Hz

iii. Voltage magnitude difference < 2%

iv. Voltage angle difference = 8 degrees

v. Pulse duration = 0.2s

7.2 Normal Inverter Operating Range

Voltage operating range for PV inverter shall be used:

i. as a protection function which responds to unusual DSP's grid conditions;

ii. not as a voltage regulation function.

7.3 Frequency

DSP shall maintain the system frequency in accordance to the National Grid Code Section 2.5.5 and the SSS PV system shall operate in synchronization with DSP's frequency.

7.4 Synchronization

The following required DG parameters to be synchronized with the DSP supply parameters:

iii. Frequency difference = 0.05 Hz

iv. Voltage magnitude difference < 2%

v. Voltage angle difference = 8 degrees

Synchronization devices are to be provided and maintained by SSS PV developer and/ owner. Synchronization is to be carried out on SSS PV side by matching DSP's grid parameters above.

7.5 Inverter

There are two (2) main categories of inverters:

i. grid-forming

ii. grid-following

For interconnection with DSP's network, grid-following inverter shall be employed for LV connections. Only grid-connected inverters are allowed to be connected to DSP grid.

7.5.1 Non-islanding / Anti-islanding Inverter

Non islanding inverters are unable to supply the load without DSP's supply. SSS PV plant is not allowed to be energized during DSP's LV network outage, for personnel safety. SSS PV developer and/ owner must ensure that their SSS PV system has anti-islanding capability that functions during pre-commissioning tests.

7.5.2 Inverter Interconnection

SSS PV system with inverter shall use irregular/abnormal voltage or frequency sensing for fault detection.

7.5.3 Inverter as UPS

For interconnection to DSP's LV network, PV inverter shall not be used as an Uninterrupted Power Supply (UPS). This is **strictly prohibited**.

7.5.4 PV Inverter Fault Current Contribution

Fault current contribution by the inverter will be restricted usually by the inverter control. Based on IEEE 1547 (IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces), the short circuit current typically ranges between 100% and 200% of the rated inverter current. DSP may request SSS PV developer or owner to carry out adjustment to lower the fault current contribution from the solar PV plant, if and when necessary.

7.6 Protection Schemes

The following are to be considered when designing PV protection scheme:

i. For any internal fault in the PV system, it must not cause problems to the DSP's system;

ii) For any distribution network fault outside the PV system, the PV system must be protected from any damaging effect.

PV system developer or owner is responsible for the protection scheme employed in their system and it must adhere to all requirement set by the DSP and/ the Authority. It is highly recommended to engage the DSP concerned on protection scheme and its settings so as to align with preset requirements.

Typical protection interfacing requirements are as follows (not limited to):

- Under-voltage
- Over-voltage
- Under-frequency
- Over-frequency
- PV active islanding detection (non-islanding inverter)
- Over-current and earth fault (OCEF) / Non Directional OCEF

7.7 PV Inverter Protection Requirement

The PV inverter shall cease to energise the DSP's grid for faults on the DSP grid where it is connected. A SSS PV system shall detect the DSP's grid conditions and cease to energise the network:

i. When the detected voltage and frequency lies outside the inverter operating range;

ii. During islanding conditions;

iii. When excess Direct Current injection is detected.

7.8 PV Inverter Tripping

In the event of inverter tripping or shutdown (ceases to energise DSP's grid), the inverter is required to comply with the following:

i. It does not entirely disconnect from the grid;

ii. It does not fully turn off;

iii. The inverter controls remain active;

iv. The connection to the DSP grid remains and is maintained for the inverter to continue detecting DSP power supply conditions.

The maintained connection and continued detection is necessary for a minimal period of time.

7.9 PV Reconnect Timing

No inverter shall reconnect after it trips, until the inverter senses the voltage and frequency to be within the normal range, the PV stabilization period starts.

7.10 Distance between PCC and Inverter

To minimise significant voltage drop and losses, the SSS PV system developer or owner is recommended to consider the distance of PCC to the inverter.

7.11 Failure of PV Protection or Control Equipment

The failure of SSS PV system equipment may include:

i. Failure of protection equipment;
ii. Failure of control equipment;
iii. Loss of control power.

In the event any of the above conditions occur, SSS PV system must be disconnected from the DSP's grid. The SSS PV system shall not be connected to the LV network during contingency periods when DSP is using generator sets to provide alternative supply.

7.12 Voltage and Frequency Disturbances

i) Voltage Disturbance

The inverter should be able to detect abnormal voltage and responds in accordance to conditions in Table 5.

Table 5: 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

The voltage values shall be in root mean square (rms) values measured at PCC. When the inverter sense the voltage lies out of its operating limits, the recommended action shall be as in Table 5.

ii) Frequency Disturbance

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

i. When the DSP's frequency is outside the nominal 50Hz value by ±1%;
ii. Trip time shall be within 0.20 sec;
iii. Applicable for LV interconnection.

7.13 Islanding Protection

During islanding detection, the SSS PV system shall cease to energise the DSP LV network through the PCC within 2 seconds of the formation of an island due to:

i. Safety;
ii. Power quality problem;
iii. Inverter technical limit.

7.14 Phase Measurement Requirements

SSS PV developer and owner shall ensure that over-voltage and under- voltage detection shall be made available for all 3 phases.

7.15 Fault Clearance Sequence for Inverter Based Distribution Generation

In the event of occurrence of abnormal conditions, the inverter shall disconnect immediately before or after the DSP's substation open depending on the voltage characteristics sensed; IEC 61727 states that a voltage of more than 135% nominal will be harmful to inverter.

Unwanted tripping is less serious for SSS PV system than other generation technologies because SSS PV system can restart as soon as fault is cleared and the voltage is back to normal.

7.16 DSP's Interface Disconnect Switch

SSS PV system interconnection shall incorporate DSP's interface disconnect switch to allow disconnection of SSS PV system output from the interconnection with DSP for safety reasons. The switch shall be manual, lockable, load break disconnect switch that:

i. Provide clear indication of switch position;
ii. Visible and accessible to maintenance and operational personnel;
iii. Offer visual verification of the switch contact position when the switch is in open position.

8 Connection Scheme

8.1 Background

The connection scheme proposed or employed shall take into account the following considerations:

i. Safety both to the grid, DSP personnel and end users;
ii. Compliance to regulatory requirements;
iii. Connection scheme with least alteration to existing network.

8.1.1 Connection Type

SSS PV system connections to DSP grid:

i. LV Single Phase - applicable for PV < 12kWp;
ii. LV Three Phase - is applicable for PV connection up to 425kWp; (subject to recommendation from the PSS). Connection confirmation check is required for 12<kWp<180;
iii. For PV generation above 425kWp, the SSS developer and/ owner shall engage a Professional Engineer to design and propose the SSS PV system for DSP's approval.

SSS PV developer and/ or owner is required to engage registered electrical worker; and to consult and engage a Professional Engineer on the connection scheme and all relevant technical requirements.

8.2 Low Voltage Network Interconnection Method

Interconnection or feeding method is as shown in Fig. 3.

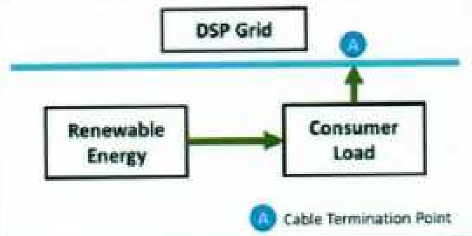
Feedings Method	Diagram
Indirect Feed – Connection point at customer (only applicable for LV)	

Fig.3. Feeding method

8.3 Renewable Energy Connections

Renewable energy connections options are shown in Table 6.

Table 6. Customer categories for various Renewable Energy connections

Renewable energy generation connection	Available connection point	
	LV 1-phase	LV 3-phase
LV single-phase	√	√
LV three-phase	√	√

8.3.1 LV Connection Main Type

For low voltage connection, this Code of Practice only considers indirect interconnection (Figure 4) however it is subject to any other additional requirements and/the approval from the DSP.

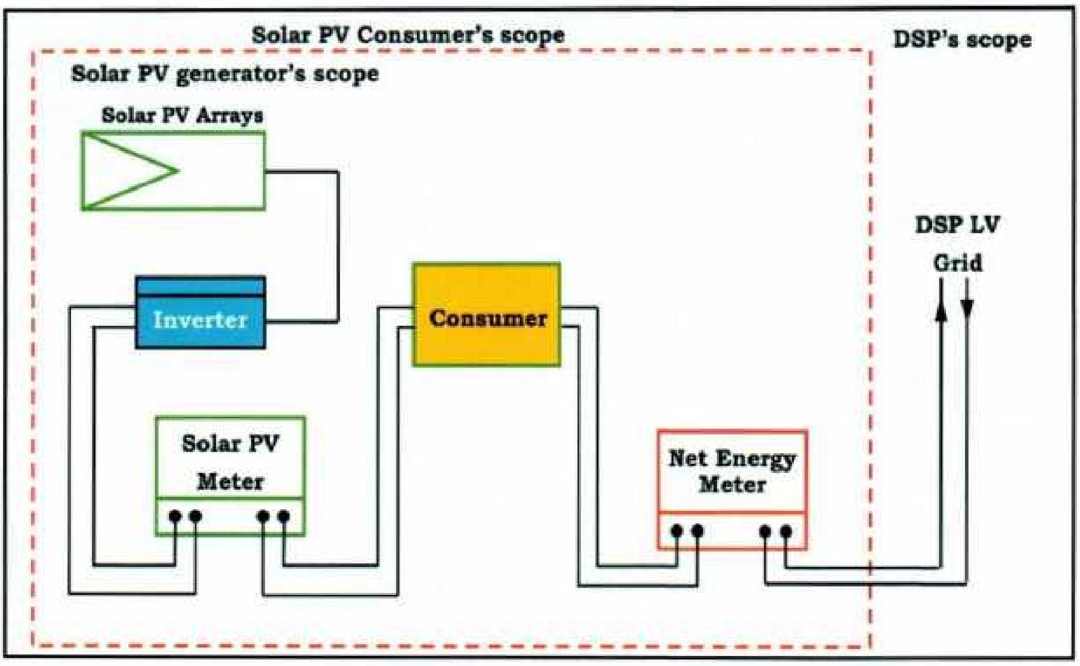


Fig 4. PV system indirect connection diagram for low voltage

8.4 Boundary of Ownership and Operation

The boundary of ownership and operation generally is located at the connection point to DSP's existing low voltage network. This is the point where energy is injected into DSP's grid. The interconnection cable belongs to the SSS PV developer and/ owner up to the cable termination point.

8.5 Equipment Specifications

Electrical equipment to be used or installed in the SSS PV system shall comply with DSP's technical specifications or requirements and/ approved by the DSP.

8.6 Approval Process

SSS PV system developers and/ or owners are responsible to do all the required adjustment at the connection point to facilitate connection of solar generated energy. All equipment to be used for means of interconnection to the DSP's network is subject to approval by the DSP.

Approval required including (but not limited to) the following:

- Design and Single line diagram approval;

- Shop drawing approval;
- Site Acceptance Test;
- Testing and Commissioning report.

The SSS PV plant must be tested prior to commissioning in order to ensure that the performance is up to the required standard and installations are according to the approved scheme, settings are done as approved, etc.

9 Metering

9.1 Background

All energy meters used for measuring the export of electricity shall comply with DSP's specifications. DSP shall determine the point at which every supply line shall terminate in any premise in view of ease of accessibility to DSP's personnel.

At any point in the premise at which supply line or lines terminate, the SSS PV system developer or owner shall provide the meter board according to DSP's specifications for the installation of meter and their accessories. DSP may change any meter and its accessories or their locations in any premise as deemed fit at any time for the purpose of maintenance and meter reading.

9.2 Metering for Low Voltage

For low voltage supply, bi-directional meters shall be employed for both Single-Phase and Three-Phase supply.

For low voltage connection requiring metering CT, SSS PV developer or owner shall provide low voltage CTs for the meter installation at their own cost. The CTs shall be of single ratio and single purpose type based on specifications that have been approved by the DSP and a metering panel (including accessories) must be provided.

10 Safety Requirements

10.1 Background

Grid connected SSS PV system operation is aligned with the power grid supply. The power grid supply is considered the source, whereas the load would be the electrical installation with the SSS PV system.

The installation of grid-connected solar PV systems shall comply with the requirements of IEC 60364-7-712 (low voltage electrical installations - Part 7-712: Requirements for special installations or locations – Solar photovoltaic (PV) power supply systems) or any other relevant IEC standards with respect to solar PV system installation recommended by the DSP and/or the Authority.

10.2 Structural Safety

There are procedures which need to be complied with when installing SSS PV system onto rooftop to ensure safety. The structural design of new building must take into consideration the loading of solar panels or its complete system installation onto the rooftop.

For existing buildings, inspections of the buildings' roof structure are to be carried out by Professional Engineers to determine whether it is structurally safe to install the PV system onto the buildings' roof. Also the calculation on the structural loading is required to be submitted to the Authority of Building and Construction Industry (ABCi), Ministry of Development (MOD) for review and approval. If the roof is unable to endure the loading of the solar PV system, structural plans is required to be submitted to the ABCi for approval before solar PV system installation works can commence.

10.3 By-pass Diode

By-pass diode shall be used in the solar PV modules. If by-pass diode is not embedded in the solar PV module encapsulation, the following requirements shall be satisfied and complied with:

i. Voltage rating of at least **2 ×** $V_{OC\ STC\ ARRAY}$ of the protected module ($V_{OC\ STC\ ARRAY}$ – Open Circuit Voltage at Standard Test Condition for a PV Array);

ii. Current rating of at least **1.4 ×** $I_{SC\ STC\ MOD}$ ($I_{SC\ STC\ MOD}$ – Short Circuit Current of the Solar PV String at Standard Test Condition);

iii. To be installed in accordance to the module manufacturer's recommendations;

iv. Ensuring no live parts are exposed;

v. Protected from degradation due to environmental factors.

10.4 Over-current Protection

10.4.1 Discrimination

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

10.4.2 PV Strings

In cases where it applies, 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 as per IEC 60364-7-712:

$$1.5 \times I_{SC\ STC\ MOD} < I_{TRIP} < 2.4 \times I_{SC\ STC\ MOD}$$

10.4.3 PV Array and PV Sub-Arrays

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

10.4.4 Disconnecting Means

Disconnecting means shall be provided in PV arrays according to the 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:

- Only device with DC rating which is able to extinguish electrical arc shall be used;
- Suitably rated circuit breakers used for over-current protection may also provide load breaking disconnecting facilities.

For PV strings and PV sub-arrays:

- No separate disconnection device is required if suitably rated circuit breakers are used for the over-current protection which also provide load breaking disconnecting facilities.

For PV array:

- 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 locked in the off position.

For inverter:

- Suitably AC rated and readily available load-breaking disconnection device, which interrupts both positive and negative conductors, shall be installed in the cable connected to the inverter AC terminal. This device shall be locked 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 in IEC 60364 and/ IEC 60364-7-712:2017 or any other relevant standards recommended by the DSP and/ the Authority. 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 IEC 60364-7-712:2017 or any other relevant standards recommended by the DSP and/ the Authority.

10.7 Lightning Protection

Solar PV systems are exposed to lightning strikes. Precautions must be taken in ensuring proper lightning protection is employed for the SSS PV system and the entire structure as lightning can cause damage to the PV modules and inverters. On both DC and AC side, the inverters should be protected by appropriately rated surge arresters. Structures and PV module frames must be properly grounded.

- Lightning protection measures may be required in some PV installations. The requirement for lightning protection shall be assessed in accordance with IEC 62305-1 (Protection against lightning) or any other standards recommended by the DSP and/ the Authority.
- For ground mounted or freestanding PV arrays, the requirement for a lightning protection system shall be assessed in accordance with IEC 62305-1 or any other standards recommended by the DSP and/ the Authority.
- 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 for a lightning protection system to be assessed in accordance to IEC 62305-1 or any other standards recommended by the DSP and/ the Authority.

- When a PV array is protected by 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 IEC 62305-1 (or any other standards recommended by the DSP and/ the Authority) can be achieved.

10.8 Over-voltage Protection

Basically over-voltage protection measures include:

i. Equipotential bonding;
ii. Avoidance of wiring loops;
iii. Installation of surge protective devices (SPDs);
iv. 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):

i. SPDs are a very common method of protecting electrical systems and equipment against over-voltages. When these devices are used, the recommendations of IEC 61643-12 (Low-voltage surge protective devices-Part 12: Surge protective devices connected to low-voltage power distribution systems) shall be observed in the selection of PDs or any other standards recommended by the DSP and/ the Authority.
ii. 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.

iii. The selection of SPDs shall be in accordance to IEC 61643-12 or any other standards recommended by the DSP and the Authority. The SPDs on the DC side shall be installed closest possible to the inverter.

iv. Recommended 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}) (8/20 µs) with I_{max} > 40 (or at least 20 kA)
  - Have a nominal discharge current (I_n) (8/20 µs) with I_{max} > 20 (or at least 10 kA)
  - Have voltage protection level (U_P) with 1.3 x $V_{OC\ STC\ GEN} < U_P <$ 1.1 kV
  - Have a voltage protection level at I_N (U_P) with (L-PE) < 2.5 kV

- SPDs specifications to protect inverter (AC terminal):
  - The specifications for SPDs to protect inverter (AC terminal) shall be suitably rated for AC use and in accordance to IEC 61643-12 and in conjunction with IEC 61643-1 (Low-voltage surge protective devices) or any other standards recommended by the DSP and/ the Authority.

- Shielding:
  - 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 armor 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 Devices

All switching devices shall comply with all the following requirements:

i. Rated for AC side as AC and rated for DC side as DC use and able to extinguish electrical arcs.
ii. Voltage rating greater than $V_{OC\ STC\ ARRAY}$
iii. No exposed metallic live parts in connected or disconnected state
iv. 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:

i. Shall not be polarity sensitive (as fault current in a PV array may flow in the opposite direction of normal operating current)
ii. To 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;
iii. When over-current protection is incorporated, the trip-current shall be rated according to over current protection systems.
iv. Plugs, sockets and couplers to comply with the following requirements:
    - Rated for AC side for AC use and Rated for DC side for DC use;
    - Have a voltage rating greater than $V_{OC\ STC\ ARRAY}$;
    - Protected from contact with live parts in both the connected and disconnected state;
    - Current rating equal to or greater than the cable to which they are fitted;
    - Require a deliberate force to disconnect;

- Temperature rating suitable for their installation location;
- If multipolar, be polarized;
- Comply with Class 11; and
- If exposed to the environment, rated for outdoor use, UV resistant and at least of IP 56 compliant.

10.11 Fuses

Fuses used in PV arrays shall comply with the following requirements:

i. To be for AC for AC use and to be rated for DC for DC use;
ii. Voltage rating equal to, or greater than $V_{OC\ STC\ ARRAY}$;
iii. To 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
iv. Current rating of ≥ 1.5 and ≤ 2 time $I_{SC\ STC\ STRING}$.

Fuse holders shall comply with all the following requirements:

i. Voltage rating equal to, or greater than $V_{OC\ STC\ ARRAY}$;
ii. Current rating equal to, or greater than, the corresponding fuse and;
iii. Degree of protection not less than IP 2X.

10.12 Earthing

The SSS PV system and interface equipment shall be earthed in accordance with the Electrical Installation Requirements 2011 – First Edition. Earthing for means of protection are required due to the following:

i. Equipotential bonding to avoid uneven potentials across and installation;
ii. Protective earthing to provide a path for fault currents to flow and;
iii. 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.

10.12.1 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 based on recommended size in the Electrical Installation Requirements 2011 – First Edition or a suitably sized earthing approved by the DSP.

10.12.2 Earthing Conductors

All PV array earthing conductors shall comply with the material, type, insulation, identification, and installation and connection requirements as specified in the Electrical Installation Requirements 2011 – First Edition and/or the IEC 60364 or IEC 60364-7-712.

10.12.3 Earthing Arrangement

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.

10.13 Operation

DSP and SSS PV system and/ owner must establish proper coordination and maintain the required isolation and earthing when works and/or tests are to be carried out at the interface or connection point. This is to ensure the safety of operation and maintenance staff.

Safety coordination applies to when work and/or tests that are to be carried out involving the interface between the low voltage network and the SSS PV system where compliance to Safety Rules, the National Grid Code and Electrical Installation Requirements are mandatory.

10.14 Operation and Safety Requirements

The following requirements are prerequisites required for safety coordination between DSP and SSS PV system developer and/ owner:

i. At each point of interface/connection between the distribution or low voltage network and the SSS PV Plant, the boundary of ownership shall be clearly defined;
ii. The DSP and the SSS PV system developer or owner shall provide each other with the as-built diagrams of their respective side of the point of interface or connection;
iii. The DSP and the SSS PV system developer or owner shall exchange information on DSP safety rules and/ or instructions as practiced in their respective system.

The above information shall be included in the Connection Operation Manual.

All switching operations shall be carried out according to the procedures as defined in the DSP Safety Rules or System Operating Regulation, which include but not limited to the following:

i. Coordination;
ii. Isolation or Islanding
iii. Earthing;
iv. Recording;
v. Testing;
vi. Commissioning; and
vii. Re-energizing.

11 Testing and Commissioning

11.1 Testing

SSS PV systems shall be tested to ensure compliance to this Code of Practice, the National Grid Code and Electrical Installations Requirements. There are two (2) types of testing required:

i) inverter compliance tests

SSS PV system developer and/ owner shall ensure that the inverter unit(s) in compliance to the requirements in Section 5, 7 and 10 of this Code of Practice. Certified tests results shall be submitted to the DSP.

ii) interconnection compliance tests

Prior to the commissioning of the SSS PV plant, tests ensuring system performance has satisfactorily meet the set standards, settings and scheme; also ensuring the connection of the SSS PV plant shall not have detrimental impact to the operation of the DSP's grid.

The following tests shall be carried out in the commissioning process:

i. Anti-islanding on loss of mains;
ii. Interlocking scheme;
iii. Equipment functional tests;
iv. Power Quality measurement.

11.2 Power Quality Measurement

Power quality measurement shall be carried out at the connection point to ensure the existing power quality before commissioning.

i. voltage regulation profile;
ii. THD voltage;
iii. Unbalanced voltage;
iv. Flicker voltage.

Tests for the above shall also be carried out after commissioning to monitor the power quality due to connection of the SSS PV plant.

11.3 Commissioning Tests

The SSS PV developer and/ owner is required to submit all the documents (not limited to) to the DSP as the following:

i. A practicing certificate (PC) from a Professional Engineer (PE) with a valid practicing certificate (PC) issued by the Board of Architects Professional Engineers, Quantity Surveyors (BAPEQS) Brunei stating that the SSS PV system have been designed and constructed in accordance with the current local regulations, Code of Practice, guidelines and best practices;

ii. Copies of approved as-built drawing;

iii. Test results of the connection point;

11.4 Anti-islanding Test

Anti-islanding test reports performed by the manufacturer in the laboratory is to be as reference for the following tests.

i. Anti-islanding test – as per recommendation from the inverter manufacturer;

ii. Cease to energize functionality test – to check inverter operation when interface cable is shut off

   a. interface cable shut off – expected outcome: no inverter reconnection before time delay lapse;

   b. interface cable to switch back on – expected outcome: inverter shall only start to generate again after 5 minutes

iii. Revised setting – SSS PV developer is required to re-test any parameter that initially set at factory but has been change at site

   – expected outcome: inverter operate normally with the new settings.

All test results shall be certified by the Professional Engineer and to be submitted to the DSP for approval.

12 Design and Installation Guideline-Checklist

The following is some guideline-checklist (non-exhaustive) for the installation of a SSS PV system both for grid connected (grid-tied) and off-grid (stand-alone).

Table 7. Design Installation guideline-checklist

No	Design and Installation Guide
1	Allocate budget and determine location/ site.
2	Determine energy requirement and/ desired SSS PV system size.
3	Perform site survey (space) for panels installation and identify access for maintenance and operation works.
4	Engage registered electrical worker(s) if the proposed SSS PV system: i. is to be connected to the electrical installation within the premises of the building; and /or ii. is to be connected and operated in parallel to the power grid. The appointed registered electrical worker is responsible for the design, installation and connection of the SSS PV system to the electrical installation and/or to DSP's low voltage network.
5	Select PV module and mounting types.
6	Select inverter to match PV array: i. Number of inverters needed; ii. Select inverter type; and iii. Location of inverters (accessible for inspection and maintenance).
7	Ensure the structure for mounting is safe:

	i. Additional loading by SSS PV system is required to be taken into account; ii. Wind loading is considered; and Ensure roof waterproofing is not compromised during installation.
8	Ensure solar access: i. Ensure location to be mounted will get maximum exposure to sunlight; ii. Ensure all PV modules connected to the same inverter face the same direction. iii. Ensure PV modules are mounted at an incline for self-cleaning.
9	Ensure sufficient ventilation space behind the PV array for cooling purposes.
10	Ensure: i. Cabling used meet sufficient current-carrying capacity and are suitably rated for usage in the environment; ii. DC cables are single-core and double-insulated; and iii. Cable insulation on outdoor cables must withstand high temperature and UV exposure for an estimated period of more than 20 years.
11	Determine whether Lightning Protection System is required.
12	Ensure the PV module frame is earthed.
13	Finalise the Inverter and AC wiring system.
14	SSS PV system shall be installed by registered electrical workers, where: i. Safety rules must be observed at all time; ii. Installations comply with EIR; iii. workers must wear PPE; and

	Only proper safety equipment shall be used e.g. scaffolding, stepladders, etc.
15	Cables must be properly connected, secured, and routed.
16	Ensure continuity and insulation tests are done.
17	All testing of the SSS PV system must be completed prior to SSS PV system commissioning.
18	Prepare and keep documentation on the SSS PV system (including as-built single line diagram) and its operation manual.

13 Operations and Maintenance

13.1 Operation of Solar PV Systems

Remote monitoring and data logging software are supplied by most inverter manufactures can be used as the performance indicator or monitor of the SSS PV systems.

The data logging software records daily, monthly and annual output for comparisons of the actual system performance against the expected system performance.

SSS PV systems require minor maintenance, as they do not usually have moving parts. However, routine maintenance is required to ensure the SSS PV system will continue to perform properly.

It is a good practice for SSS PV systems developer to provide an operation and maintenance (O&M) manual for the client. The manual should include basic system data, test and commissioning data, O&M data, etc.

13.2 Recommended Preventive Maintenance Works

Preventive inspection and maintenance works are recommended to be carried out every six or twelve months. The PV modules require routine visual inspection for signs of damage, dirt built-up or shade encroachment. SSS PV system fixtures must be checked for corrosion. This is to ensure that the solar PV system is secured properly.

Whereas the inverter's functionality can be remotely verified, only on-site inspection can validate the state of lightning surge arresters, cable connections, and circuit breakers.

Table 8 shows some recommendations on the preventive maintenance works on the components and equipment, and the corresponding remedial actions to be carried out by REW.

Table 8. Recommended Preventive Maintenance Works

No	Equipment	Description	Action
1	PV modules	• Check for dust/debris on surface of PV module. • Check for physical damage to any PV module. • Check for loose cable terminations between PV modules, PV arrays, etc. • Check for cable conditions.	• Wipe clean. Do not use any solvents other than water. • Recommend replacement if found damaged. • Retighten connection. • Replace cable if necessary.

No	Equipment	Description	Action
2	PV inverter	• Check ventilation condition. • Check for loose cable terminations. • Check for abnormal operating temperature.	• Clear dust and dirt in ventilation system. • Tighten connection. • Recommend replacement.
3	Cabling	• Check for cable conditions, i.e. wear and tear. • Check cable terminals for burnt marks, hot spots or loose connections.	• Replace cable if necessary. • Tighten connections or recommend replacement.
4	Junctio n boxes	• Check cable terminals e.g. wear and tear or loose connections. • Check for warning notices. • Check for physical damage.	• Tighten or recommend replacement. • Replace warning notice if necessary • Recommend replacement.
5	Means of isolation	• Check functionality.	• Recommend replacement if tests fail.

No	Equipment	Description	Action
6	Earthing of solar PV system	• Check earthing cable conditions. • Check the physical earthing connections. • Check continuity of the cable to electrical earth	• Recommend placement if necessary. • Retighten connection if loose. • Troubleshoot or recommend replacement
7	Bonding of the exposed metallic structure of solar PV system to lightning earth	• Check bonding cable conditions • Check physical bonding connection • Check continuity of the bonding to lightning earth	• Recommend replacement if necessary • Tighten connection • Troubleshoot or recommend replacement

14 Glossary

AC	Alternating Current
DC	Direct Current
DSP	Distribution Service Provider
DG	Distributed Generator
EIR	Electrical Installation Requirements
I_T	Rated trip current
LV	Low Voltage
MV	Medium Voltage
O&M	Operation & Maintenance
OCEF	Over Current and Earth Fault
PCC	Point of common coupling
PF	Power Factor
Plt	Absolute long-term flicker severity
PSS	Power System Study
Pst	Absolute short-term flicker severity

PV	Photovoltaic
RE	Renewable Energy
REW	Registered electrical worker
Rms	Root-mean-square
RTU	Remote Terminal Unit
SPD	Surge protective device
S_{TC}	Standard Test Conditions
THD	Total Harmonic Distortion
U_C	Maximum continuous operating voltage
U_P	Voltage protection level
UPS	Uninterrupted Power Supply

Disclaimer:

This Code of Practice for Small Scale Solar Photovoltaic System Connection to Low Voltage Network specifies the technical requirements for grid-connected SSS PV system. It does not contain a comprehensive information needed in designing SSS PV system. Whilst all reasonable care has been considered in the preparation of this Code of Practice, the Authority does not make any representation, warranty or undertaking, expressed or implied, in or in relation to the completeness and or accuracy of information contained in this Code of Practice. To this end, the Authority disclaims all or any responsibility whatsoever to anyone for information contained in this Code of Practice or for any representation or statement herein, whether expressed or implied, or for any responses given in response to any queries on or in relation to the Code of Practice. All such persons expressly disclaims any obligation or duty (whether in contract or otherwise) to any prospective small scale solar PV developer or owner and disclaims any and all liability based on or relating to any such information or representations or warranties (expressed or implied) contained in, or errors or omissions from, the Code of Practice or based on or relating to the use of the Code of Practice or any other written or oral communication transmitted to or information provided to or otherwise acquired by a prospective small scale solar PV developer or owner.

A prospective small scale solar PV developer or owner shall be solely responsible for the interpretation of the information provided to or otherwise acquired by the prospective small scale solar PV developer or owner. The prospective small scale solar PV developer or owner certifies that it understands, accepts and agrees to the disclaimer on this page. Nothing contained in any other provision of this Code of Practice, nor any statement made orally or in writing by any person or party have the effect of negating or superseding any of the disclaimers on this page.