هيئة تنظيم الكهرباء - عمان
AUTHORITY FOR ELECTRICITY REGULATION, OMAN

Small Scale Grid-Connected Solar PV Systems

Technical Guidelines

May 2017

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1 SCOPE

This document defines a common set of requirements for solar PV generating plants, irrespective of the presence of loads in the customer's network, which intend to operate in parallel with the Oman distribution networks in low (LV) and medium (MV) voltage up to 36 kV; especially the document defines:

- Requirements for the minimum equipment to be used for interconnecting the generating plants with a distribution network;
- Requirements for the start-up, the operation and the disconnection of the generating plants;
- Requirements to prevent generating plants from causing disturbances and damages to the distribution network and to the other customers connected to the same distribution network;
- Requirements to prevent the generating plants from operating in a portion of the distribution network which has been disconnected from the main power system.

Furthermore other national & international standards, network codes, and other specific technical requirements of the DSOs may apply to solar PV generating plants and therefore shall be complied with, especially, the Sultanate of Oman's Distribution Code [12]. It represents the main document to refer to when a customer applies for a new connection or for a modification to its connection. The present standards shall apply only if the application includes the connection of a solar PV generating plant and shall be intended as an extension of the Distribution Code only for what concerns the connection of the solar PV generating units.

Moreover, it is not within the scope of the present document to:

- define a process for the selection and evaluation of the point of connection;
- define a process to assess the impact of the connecting generating plant to the power system;
- define a process to assess the connection application and the compliance with the present standards;
- define technical rules for the islanding operation of generating plants, both intentional and unintentional, where no part of the distribution network is involved;

Unless otherwise explicitly specified, the requirements set forth by these standards shall apply only to solar PV generating plants which don't have a technical design approval at the date of publication of the standards.

Finally, even if it is not directly within the scope of the document, these connection standards recognise the fundamental importance and necessity for solar PV generating plants to be built in a workmanlike manner, which means to be built according to the international standards listed in ANNEX A.

2 REFERENCE DOCUMENTS

[1] Omani Standard OES4 – Regulations for electrical installations, Second edition, May 1989
[2] Standard OES-11 – General specifications for electrical materials and equipment, Second edition, January 1995
[3] Standard OES-22A – Single phase kilowatthour meters for service connections, Second edition, January 1995
[4] Standard OES-22B – Three phase kilowatt-hour meters directly connected for service connections, Second edition, January 1995
[5] Standard OES-22C – Three phase kilowatt-hour meters with current transformer for service connections, Second edition, January 1995
[6] Standard OES-22D – Single phase kilowatt-hour digital meters directly connected for service connections, Second edition, May 2009
[7] Standard OES-22E – Three phase kilowatt-hour digital meters directly connected for service connections, Second edition, May 2009
[8] Standard OES-22F – Three phase kilowatt-hour digital meters, current transformer operated, connected for service connections, Second edition, May 2009
[9] IEC 62116:2014, Utility-interconnected photovoltaic inverters - Test procedure of islanding prevention measures
[10] IEC 61000-3-2:2014 Electromagnetic compatibility (EMC) – Part 3-2: Limits – Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)
[11] IEC 61000-3-12:2011 Electromagnetic compatibility (EMC) - Part 3-12: Limits - Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and ≤ 75 A per phase
[12] SULTANATE OF OMAN, The Distribution Code, Version 1.000, May 2005
[13] SULTANATE OF OMAN, The Grid Code, Version 2.0, April 2010, Document Nr OETC-GCRP-April-2010 (Version 2.0)

3 TERMS AND DEFINITIONS

Active Power - Active Power is the real component of the apparent power, expressed in watts or multiples thereof (e.g. kilowatts (kW) or megawatts (MW)). In the text this will be generically referred as P or Pn in case of rated active power of equipment.
Apparent Power - Is the product of voltage (in volts) and current (in amperes). It is usually expressed in kilovolt-amperes (kVA) or megavolt-amperes (MVA) and consists of a real component (Active Power) and an imaginary component (Reactive Power). In case of inverters, the rated apparent power corresponds to the maximum active power deliverable by the inverter at unity power factor. In the text this will be generically referred as S or Sn in case of rated apparent power of equipment.
Maximum Available Active Power Output – Is the Active Power Output determined by the primary resource (for example, sun irradiance) and by the maximum steady-state efficiency of the Generating Plant for this operating point.
Current - Unless stated otherwise, current refers to the root-mean-square value of phase current.
Distribution system / network - Is the medium or low voltage electricity grid for supplying electricity to the end consumers.
Distribution System Operator or Licensed Distributor (DSO) –Represents a legal entity responsible for operating, ensuring the maintenance of and developing the distribution system in a given area and, where applicable, its interconnections with other power systems, with the final scope to ensure the long term ability of the system to meet reasonable demands for electricity of its users.

Generating plant - Is an indivisible set of installations which can generate electrical energy into the distribution network and is composed of generating units, circuits and auxiliary services.
Interface Protection (IP) - The electrical protection required to ensure that either the generating plant and/or any generating unit is disconnected for any event that could impair the integrity or degrade the safety and reliability of the distribution network.
Islanded Network Operation (Islanding) - Situation where a section of the distribution network, containing generating plants, becomes physically disconnected from the rest of distribution network and one or more generating plants maintain a supply of electrical energy to the isolated section of the distribution network.
Loss Of Mains (LOM) – Represents an operating conditions in which a distribution network, or part of it, is separated from the main power system with the final scope of de-energization.
Main Electricity Meter - Is the device installed at the POC and which measures the amount of electric energy actually exchanged by the customer with the distribution network.
Network - Plant and apparatus connected together in order to transmit or distribute electrical power, and operated by the DSO.
PV electricity meter - Is the device installed at the common output point of all the solar PV generating plant and which measures the total energy produced.
Point of Connection or POC - Is the location at which a solar PV generating plant is connected to the distribution network and where the Main Electricity Meter is installed.
Power Factor - Is the ratio of Active Power to Apparent Power.
Reactive power capability - Describes the ability of a generating plant/unit to provide Reactive Power in the context of varying Active Power and at the rated voltage.
Reactive Power - Reactive Power is the imaginary component of the apparent power, usually expressed in kilovar (kVAr) or Megavar (MVAr).
ROCOF – Rate of change of frequency
Switch – Mechanical switching device capable of making, carrying and breaking currents in normal circuit conditions and, when specified, in given operating overload conditions. In addition, it is able to carry, for a specified time, currents under specified abnormal circuit conditions, such as short-circuit conditions.
Voltage - Unless stated otherwise, voltage refers to the root-mean-square value of phase-to-phase voltages.

4 GENERAL REQUIREMENTS FOR THE CONNECTION IN PARALLEL TO THE DISTRIBUTION NETWORKS

4.1 Point of Connection (POC)

Solar PV generating plants shall be connected to the network at an appropriate point, the POC. It is the responsibility of the DSO to design a connection assessment process which determines the appropriate POC and assesses the capacity of the network to host the connecting solar PV generating plant at that POC whilst maintaining safe and secure network operations under all operating conditions.

If the results of the connection assessment process performed by the DSO indicates that the connecting solar PV generating plant is likely to cause the network to operate outside of the DSOs statutory performance standards (or part of it), the DSO is obliged to propose modifications (in terms of POC and/or characteristics of the solar PV generating plant) or alternative solutions (in terms of network reinforcements) to enable the connection.

4.2 Interconnection system

A solar PV generating plant shall be in compliance with the connection requirements of the connecting DSO and especially shall meet the following requirements:

- the synchronization, operation and disconnection of the plant under normal network operating conditions, i.e. in the absence of faults or malfunctions, shall be done without consequences to the statutory power quality of the network;
- the protection schemes and settings needed for the solar PV generating plant and for the network shall be coordinated and agreed between the DSO and the generating plant owner with the following purposes:
    - faults and malfunctions within the generating plant shall not impair the normal operation of the distribution network,
    - the protection of the generating plant for different types of network faults shall operate in accordance with the requirements determined by the DSO,
    - the protection schemes of the generating plant shall be coordinated with those of the distribution network in order to operate properly in case of faults within the generating plant or within the distribution networks.

In order to satisfy the above requirements, the following equipment shall be at least installed for a safe and reliable interconnection of the solar PV generating plant:

- Main switch: switch installed as close as possible to the POC and commanded by a protection system against internal faults or for the disconnection of the producer's network from the distribution network;
- Interface switch: switch installed in the customer's network, for separating from the distribution network the part(s) of the customer's network containing at least one solar PV generating unit;
- Generating unit switch: switch installed electrically close to the terminals of each solar PV generating unit of the generating plant, for the protection and the disconnection of that generating unit.

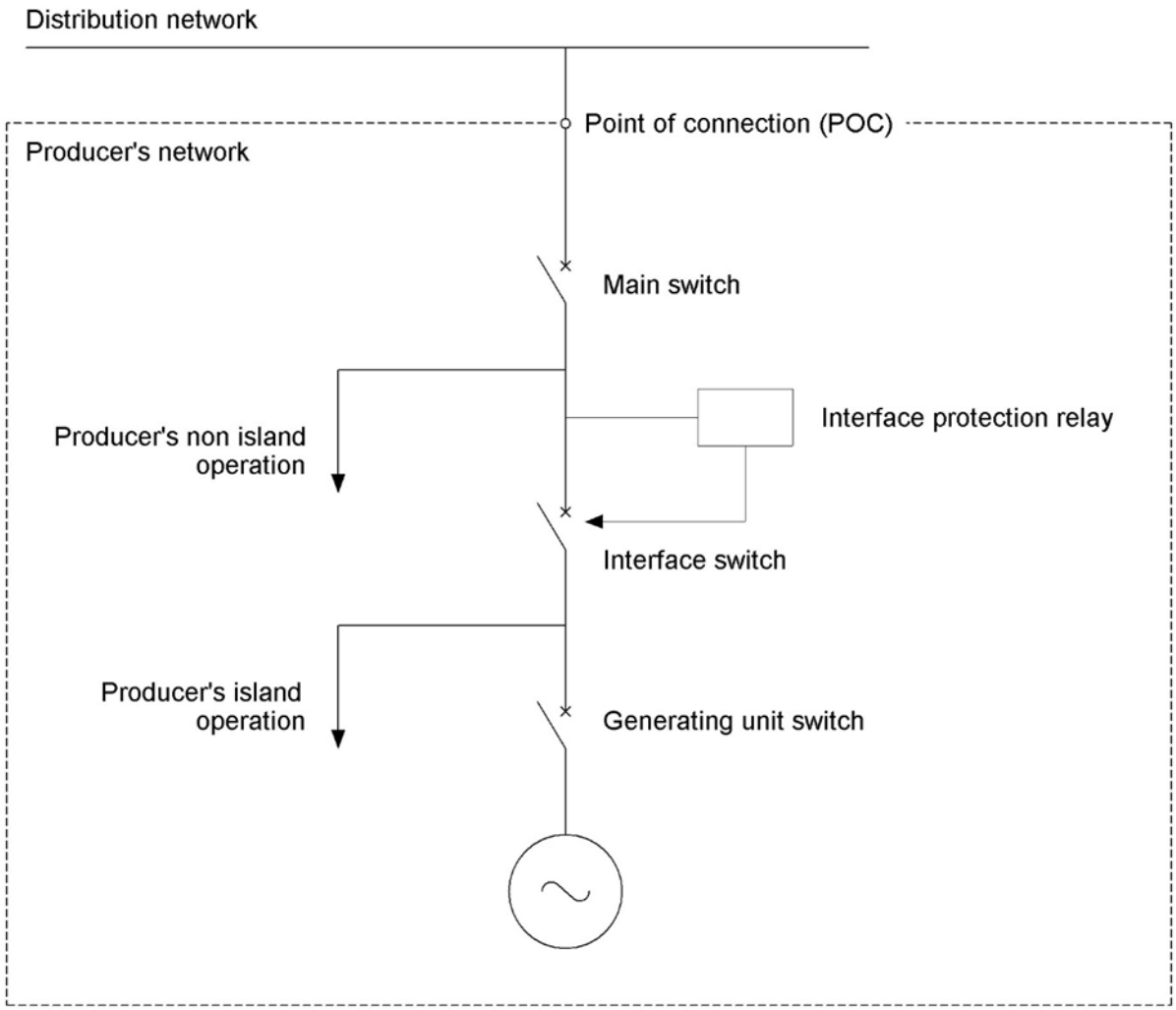

Figure 1: Schematic representation for the interconnection of a solar PV generating plant with the Omani distribution network

The switches shall be power relays, contactors or mechanical circuit breakers, each having a breaking and making capacity coordinated with the rated values of the producer's network (taking into consideration both the generating plant and the passive loads). Moreover, the short-time withstand current of the switching devices shall be coordinated with the maximum short circuit power at the POC. In case of loss of auxiliary supply power to the switchgear, a secure disconnection of the switch is required immediately.

For solar PV generating plants connected to the MV distribution network with the interface switch on the MV side of the plant (see §5.1), the interface switch shall consist of:

- three-polar withdrawable automatic circuit breaker operated by an undervoltage release, or
- three-polar automatic circuit breaker operated by an undervoltage release along with an isolator (either upstream or downstream the circuit breaker).

For solar PV generating plant connected to the MV distribution network with the interface switch on the LV side of the plant (see §5.1) or connected to the LV distribution network (see §6.1) the interface switch shall consist of:

- automatic circuit breaker or switch disconnector operated by an undervoltage release, or

- omnipolar AC_3 contactor.

The function of the interface switch might be combined with either the main switch or the generator switch in a single switching device. In case of a combination, the single switching device shall be compliant to the requirements of both, the interface switch and the combined switch (main switch or generator switch). As a consequence, at least two switches in series shall be always present between the solar PV generating units and the POC.

Except for configurations with more than one main switch, it is anyway recommended not to combine the interface switch with the main switch as it will lead to the disconnection of the overall customer's facility when the interface switch is opened, which means that the power supply will be removed also to the customer's loads.

4.3 Voltage and frequency operating ranges

Solar PV generating plants, when generating power, shall have the capability to operate stably and continuously in the operating ranges specified below, regardless the topology and the settings of the protection systems:

- when the frequency at the POC stays within the range of 47,5Hz to 52,5Hz.
- when the voltage at the POC stays within the range 85% to 110 % of the rated voltage.

4.4 Monitoring, remote control and information exchange

Adequate information concerning the customers connected to its distribution networks is a prerequisite for enabling a DSO to maintain the stability and security of its networks. DSOs need to have a continuous overview of the state of their networks, which may require, in some cases, updated information on the operating conditions of the generating plants as well as the possibility to communicate with them in order to direct operational instructions. Such requirements are usually needed in case of growing penetration of the solar PV generating plants in the distribution networks; they may also be introduced in the framework of initiatives dedicated to the optimization of the control performances of the network.

In these cases and in accordance with a cost/benefit approach, the DSO shall have the right to specify additional requirements related to monitoring, remote control and information exchange for the solar PV generating plants, and especially:

- Data (and related sampling time) related to the operating conditions of the solar PV generating plant, which shall be periodically collected and sent to the DSO;
- Operational instruction sent by the DSO which shall be executed by the solar PV generating plant; such instructions shall be compliant with the requirements indicated in the present standards;
- Information on specific occurrences that are relevant for the DSO (status of the protection switches, feedback on the execution of given instructions such as switch-off and switch-on of the generating plant, etc.)
- Communications channels and protocols to be used for the above requirements.

4.5 Compliance

A customer shall ensure that its solar PV generating plant complies with the requirements defined in the present standards throughout the overall lifetime of the facility.

The customer shall notify to the connecting DSO any incident, failure or planned modification of its solar PV generating plant which may affect the compliance with the requirements defined in the present standards.

The customer shall provide to the DSO all the documents, simulations and measurements useful to demonstrate the compliance of the solar PV generating plant to the requirements defined in the present standards.

If deemed necessary and following the provisions set forth by the Distribution Code (DOC8) [12], the DSO may request that the customer carries out specific compliance simulations and tests not only during the connection process, but at any time throughout the lifetime of the solar PV generating plant, and more specifically after any failure, modification or replacement of any equipment that may have an impact on the compliance of the plant with these standards.

4.6 Metering

Dedicated metering systems are required for solar PV generating plants. They shall include a main electricity meter and a PV electricity meter.

The main electricity meter measures the net energy at POC and the PV electricity meter measures the energy produced by the PV generating plant connected to the POC.

The main characteristics of the components of these metering systems are described hereinafter. These apply for LV and MV connections.

The general service conditions and environmental conditions are detailed in OES 11 [2] and in the metering standards OES 22 [3].

4.6.1 Metering Requirements

4.6.1.1 Meters

The main electricity meter and PV electricity meter equipment shall maintain their levels of accuracy and functionality at all relevant times. The accuracy shall be according to the Standards: OES-22D, OES-22E, OES-22F [6][7][8].

All materials and equipment shall be designed in accordance with what specified in OES 11 [2] for use under the service condition prevailing at the site. The service conditions shall be considered as minimum design values.

Meters shall operate without loss of accuracy or life duration in the environmental conditions described in OES-11 [2].

Both the main electricity meter and the PV electricity meter shall measure the quantities defined below.

The main electricity meter and the PV electricity meter shall be installed, operated and maintained so as to comply at all relevant times with the standards indicated in Annex A.12.

Both electricity meters shall measure bi-directional flow of energy.

For each separate POC, a main electricity meter shall be installed, operated and maintained to measure the following parameters:

- Positive and Negative Active Energy
- Positive and Negative Reactive Energy

Conventionally the energy is considered "positive" when it enters in the meters towards the output connections of the meters itself; the energy is defined "negative" when it flows from the output of the meter towards the input of the meter itself.

The connecting DSO shall configure the main electricity meter and the PV electricity meter such that active energy is measured by a number of measuring elements equal to or one less than the number of primary system conductors. These include the neutral and/or earth conductor where system configurations enable the flow of energy in such conductors.

The main electricity meter and the PV electricity meter shall be labeled by the DSO and be readily identifiable.

The main electricity meter and the PV electricity meter shall meter the quantities on a continuous basis and the information shall be shown on a display and must be permanently stored in a non-volatile register of the meter. The meter registers shall not pass through zero to more than once within the normal meter reading cycle and their contents cannot be modified or altered by any means and by anyone, including even the meter manufacturer.

The main electricity meter and the PV electricity meter shall have two outputs for retrieving data related to each measured quantity. By means of these outputs the metering data related to the measured quantities shall be retrieved locally and, in the future, remotely, using the communication channels.

The main electricity meter and the PV electricity meter shall have test terminals to facilitate on-site tests. These terminals shall be in close proximity to the main electricity meter and to the PV electricity meter and shall be capable of providing suitable means for accessing current and voltage signals, injecting test quantities, connecting test Meters, and replacing the main electricity meter and the PV electricity meter without a circuit outage.

The test terminal must be protected by any tampering action and unauthorized use.

4.6.1.2 Current Transformers

Two sets of Current Transformers shall be provided according to the MDEC.5.2.1.2 [13]. The first set of current transformers will supply exclusively the main electricity meter. The second set of current transformers will supply exclusively the PV electricity meter.

The current transformer windings and the cables connecting such windings to the electricity meters shall be dedicated exclusively for such purposes; cables and connections shall be securely sealed.

No interconnections or sharing of connections among the two sets of current transformers are allowed.

The total burden on each current transformer shall not exceed the rated burden of such current transformer. No other burden shall be connected to these current transformers.

4.6.1.3 Voltage Transformers

Voltage Transformers shall be provided according to the MDEC.5.2.1.3 [13].

The voltage transformer winding supplying the main electricity meter shall be dedicated to that purpose and such windings and connections shall be securely sealed.

The voltage transformer winding supplying the PV electricity meter shall be dedicated to that purpose and such windings and connections shall be securely sealed.

No other burden shall be connected to these voltage transformer secondary windings.

Separately fused voltage transformer supplies shall be provided according to the MDEC.5.2.1.3 [13] for the main electricity meter and the PV electricity meter. The fuses shall be located as close to the voltage transformer as possible.

The connections of meters and measurement (Current and Voltage) transformers are illustrated in §5.1 and §6.1

4.6.1.4 Accuracy requirements

The accuracy of the various items of measuring equipment comprising the main electricity meter and the PV electricity meter shall comply with MDEC.5.2.2 [13] and the relevant IEC Standards listed in Annex A.12.

The Measurement Transformers must be chosen with an appropriate class of accuracy, in order to guarantee the final accuracy of the overall metering system.

No compensation shall be necessary; only the transformer ratio shall be set in the meters, in order to allow the use of different measurement transformers, in accordance with the power of the customer's facility and PV generating plant.

4.6.1.5 Meter approval and certification

Only meters from the DSO's list of approved meters shall be installed. The meters shall comply with MDEC.5.2.3 [13].

4.6.1.6 Operation and maintenance

The main electricity meter and the PV electricity meter shall be operated and maintained in accordance with [2] and according to manufacturer's recommendations.

4.6.2 Sealing – Intrusion Detection

Provision shall be made and seals shall be provided for the sealing of meter electronics housing and terminal cover. Active part of the meter shall be factory sealed. It shall not be possible to remove or open the meter without irreparable damage of the seals. Main cover and terminal cover shall be equipped with opening detectors (tamper switch).

4.6.3 Meter Communication and remote capability

4.6.3.1 Local communication

Meter configuration shall be able via optical head or the electrical output with software package to be supplied with the meters. Manufacturers shall inform about security provided to prevent and track unauthorized resetting and reconfiguration of the meter.

Basic data of the meter (year of manufacture, type, serial number, total kWh cumulative counter and total kVArh cumulative counter) shall not be changeable.

Optical head / terminal shall ensure connection with HHU (Hand Held Unit) or Laptop. In this regard, the meter optical head shall have a magnetic ring on the port so that optical head can stand on it without affecting the proper operation of the meter.

4.6.3.2 Remote communication

The meters installed on the field should be able to communicate at any time on a remote basis, all stored data and therefore have a reliable and recognized open communication protocol and appropriate port for connection of communication module.

4.6.3.3 Communication flexibility

In order to ensure flexibility for future communication such as wired and /or wireless system, modular communication architecture shall be adopted (for WAN/LAN and HAN infrastructures)

4.6.4 Meter and Data Security and Registration

The meter access and sealing shall be according to MDEC.5.4,1 [13], the metering records shall be according MDEC.5.4.2 [13] and the meter registration should comply with MDEC.5.4.3 [13].

5 SPECIFIC REQUIREMENTS FOR THE CONNECTION IN PARALLEL TO THE MV DISTRIBUTION NETWORK

5.1 Connection schemes

Unless required by and/or agreed with the connecting DSO, the connection schemes to be adopted for the connection of a solar PV generating plant to the Omani MV distribution networks are represented in the figures below.

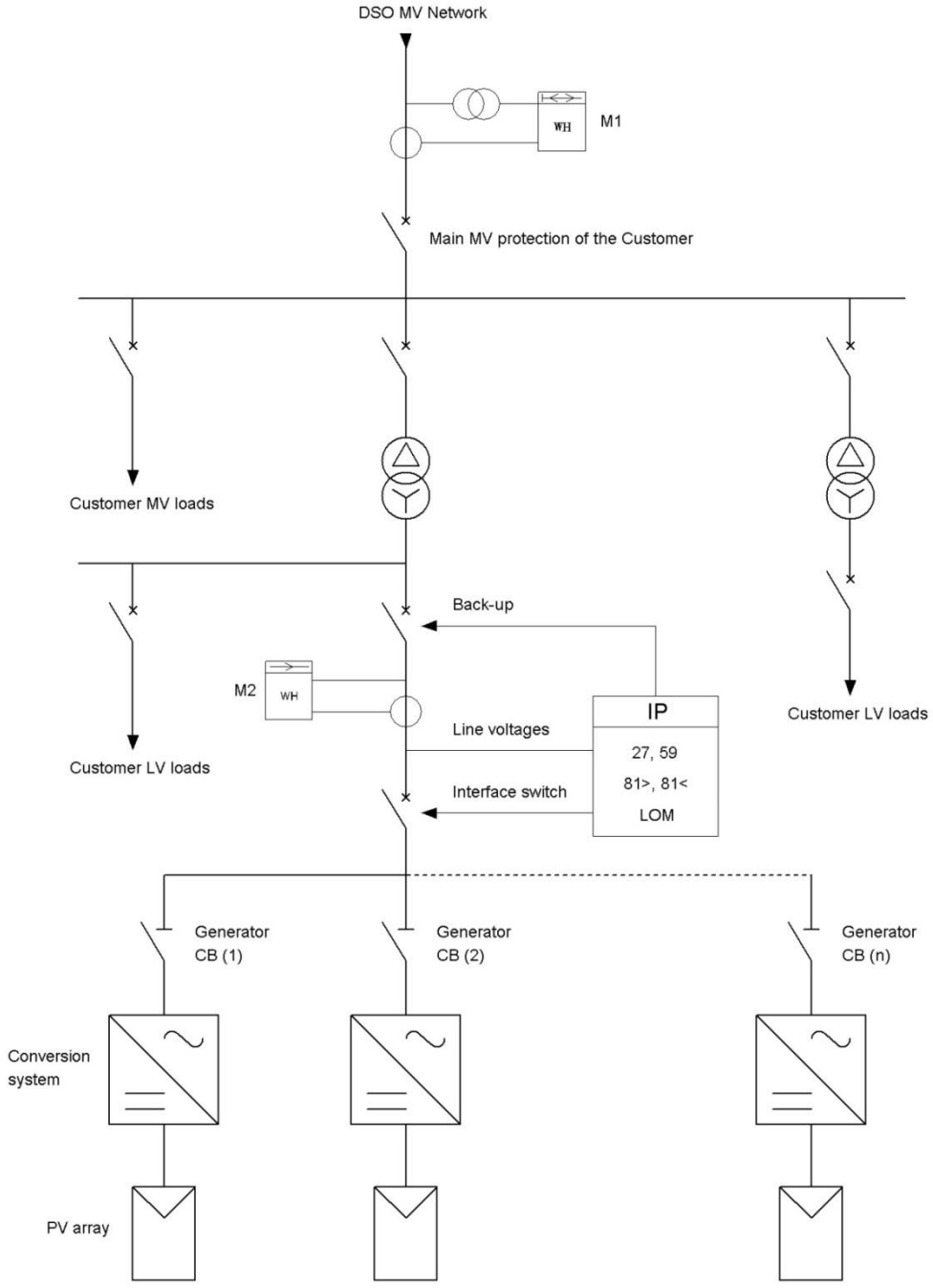

Figure 2: MV Connection Scheme – Interface Switch on LV side

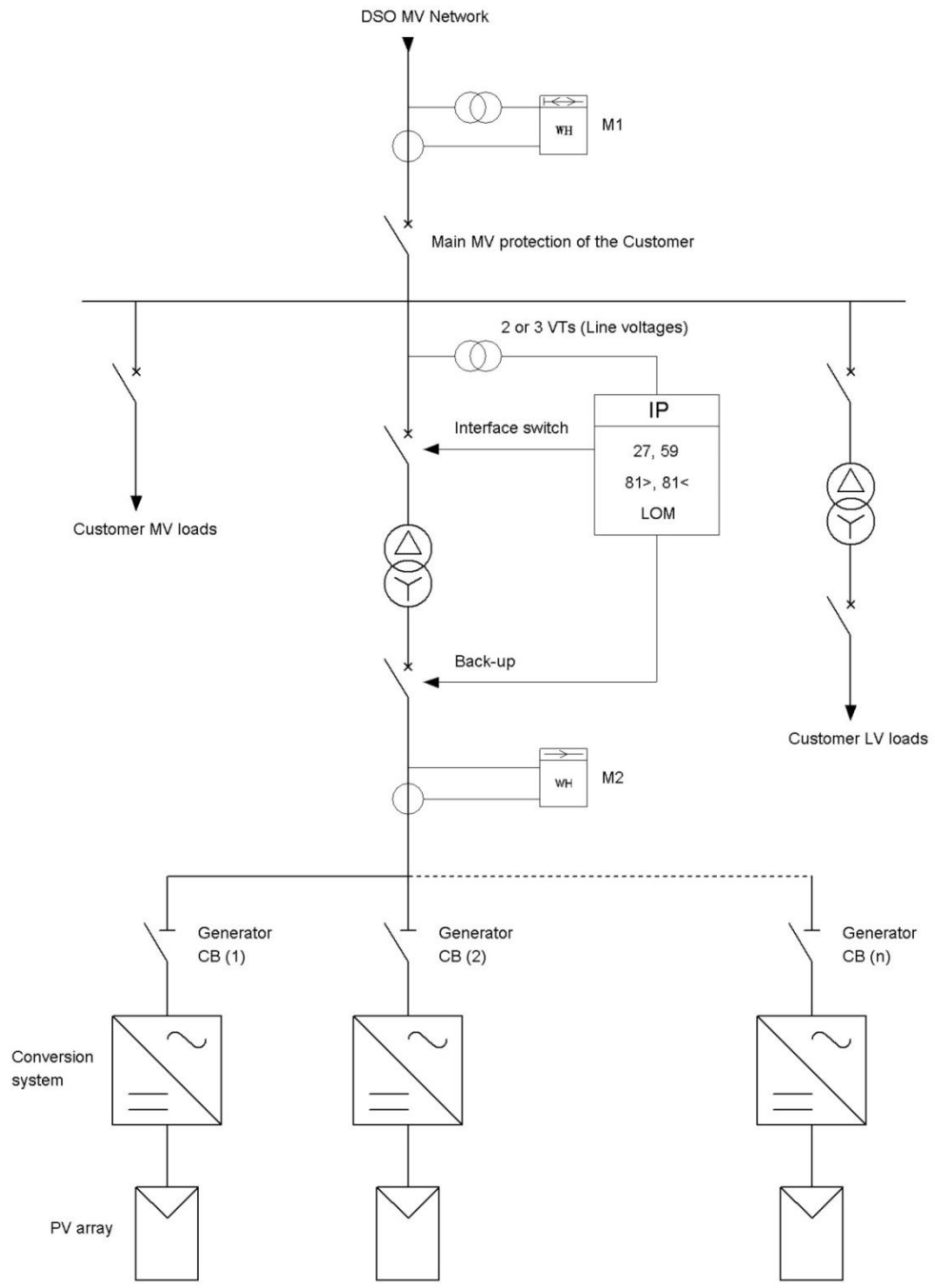

Figure 3: MV Connection Scheme – Interface Switch on MV side

5.2 Interface protection

The purpose of the interface protection is to:

- disconnect the solar PV generating plant from the distribution network in case of:
  - unintentional islanding of the MV distribution network it is connected to;
  - Voltage or frequency transients of the power system out of the operating ranges;

- prevent the solar PV generating plant, when generating power, to cause over-voltages in the MV distribution network it is connected to;

It is not the purpose of the interface protection to:

- disconnect the generating plant from the distribution network in case of faults within the customer's network; for such issues, the requirements for the connection of passive customers shall apply [1];
- prevent damages to the customer's equipment (generating units or loads) due to faults/incidents (e.g. short circuits) on the distribution network or on the customer's internal network; for such issues, the recommendations and requirements of the manufacturers of the equipment shall apply.

In any case, the protection schemes and settings for electrical faults within the customer's network as well as those used for the protection of the customer's equipment must not jeopardise the performances of the requirements set out at §5.4 (immunity).

The interface protection shall be a dedicated device and shall not be integrated into the solar PV generating units. The interface protection shall command the interface switch; only one interface protection and one interface switch shall be used for a solar PV generating plant, unless explicitly agreed by the DSO.

The interface protection shall additionally command another switch (backup switch) with a proper delay in case the interface switch fails to open. The backup switch may consist of a dedicated switch or an already existing switch[1].

The loss of the auxiliary voltage of either the interface protection or the solar PV generating plant's control system shall trigger the interface switch without delay.

The protection functions required to be implemented in the interface protection device are the following:

- Undervoltage [27]
  - One threshold [27<] in the range [20%; 100%] of the POC nominal voltage (*default: 85%*), adjustable by steps of 5%, and delay time in the range [0,1s;100s] (*default: 1,5s*) adjustable in steps of 0,1s;
  - One threshold [27<<] in the range [5%; 100%] of the POC nominal voltage (*default: 30%*), adjustable by steps of 5%, and delay time in the range [0,1s;5s] (*default: 0,6s*) adjustable in steps of 0,05s.
- Overvoltage 10 min mean [59-Av]
  - One threshold in the range [100%; 115%] of the POC nominal voltage (*default: 110%*), adjustable by steps of 1%, and delay time lower than or equal to 3s;
- Overvoltage [59]
  - One threshold [59>] in the range [100%; 120%] of the POC nominal voltage (*default: excluded*), adjustable by steps of 1%, and delay time in the range [0,1s;100s] adjustable in steps of 0,1s;
  - One threshold [59>>] in the range [100%; 130%] of the POC nominal voltage (*default: 120%*), adjustable by steps of 1%, and delay time in the range [0,1s;5s] (*default: 0,6s*) adjustable in steps of 0,05s.
- Overfrequency [81>]

[1] It is anyway recommended not to use the main switch as back-up switch since it could lead to the disconnection of the overall customer's facility in the case the interface switch fails to open, with the consequence of the power supply also being removed to customer's loads.

  - One threshold [81>] in the range [50Hz; 53Hz] (*default: 52,5Hz*), adjustable by steps of 0,1Hz, and delay time in the range [0,1s;100s] (*default: 0,1s*) adjustable in steps of 0,1s;
  - One threshold [81>>] in the range [50Hz; 53Hz] (*default: excluded*), adjustable by steps of 0,1Hz, and delay time in the range [0,1s;5s] adjustable in steps of 0,05s;
- Underfequency [81<]
  - One threshold [81<] in the range [47Hz; 50Hz] (*default: 47,5Hz*), adjustable by steps of 0,1Hz, and delay time in the range [0,1s;100s] (*default: 4s*) adjustable in steps of 0,1s;
  - One threshold [81<<] in the range [47Hz; 50Hz] (*default: excluded*), adjustable by steps of 0,1Hz, and delay time in the range [0,1s;5s] adjustable in steps of 0,05s;
- Loss Of Mains:
  - for the LOM protection functions, a wide variety of approaches can be used: besides the passive observation of voltage and frequency, other active and passive methods are available and used to detect unintentional islanding situations, but only some of these methods rely on standards. The present standard doesn't intend to specify the method to be used to achieve the goal but rather its efficacy; for such a reason, the only requirement on LOM protection is that the protection function shall be tested in accordance with the standard IEC 62116 [9] which provides procedures to evaluate the performance of islanding prevention measures used with utility-interconnected PV systems.

[12] recognizes the possibility for a Licensed Distributor to "*decide dependent on local network conditions, if it is desirable for the Embedded Gensets to continue to Generate onto an islanded Distribution System*" during Emergency Conditions. The LOM protection function shall therefore have the possibility to be excluded or the LOM settings to be modified suitably.

The protection functions for undervoltage [27] and overvoltage [59] shall be fed by all the three line voltages, whereas the protection functions for underfrequency [81<] and overfrequency [81>] shall be fed by at least one line voltages.

The DSO is responsible to define the appropriate settings to be applied to the interface protection and which can ensure the correct tripping of the solar PV generating plant under specific conditions. The settings are chosen so that, in case a fault within the distribution network triggers the network protection systems which in turn disconnect a part of the network (the faulty feeder), there could not be any reclosure of the network switch before all the generating plants have been disconnected. The default settings above indicated for the different protection functions are therefore to be applied in the IP of a solar PV generating plant only when no other settings have been explicitly specified and communicated by the connecting DSO.

The interface protection shall have at least two configurable digital inputs which may be used in the future[2] by the connecting DSO for transfer trip, remote tripping or any other function that may be necessary to increase the distributed generation hosting capacity of the distribution networks while keeping an acceptable level of reliability.

[2] In a scenario of growing penetration level of generation on Omani distribution networks

5.3 Connection conditions

A solar PV generating plant is allowed to connect to the network and to start to generate electrical power due to normal operational start-up when the voltage and frequency are within the following range for at least the observation time:

- Frequency range 47,5 Hz ≤ f ≤ 50,05 Hz;
- Voltage range 90% Uc ≤ U ≤ 110% Uc;
- Minimum observation time180s.

Synchronizing a solar PV generating plant with the distribution network shall be fully automatic i.e. it shall not be possible to manually close the switch between the two systems to carry out synchronization.

The connection of a solar PV generating plant to the distribution network shall not create transient voltage variation at the POC of more than 3% of rated voltage.

After connection, a solar PV generating plant shall follow its target active power value with a variation rate not greater than 10% P_n/min.

The active power target shall be the maximum available active power output which is possible to generate from the solar PV generating plant, taking into account the environmental conditions (irradiation, temperature, …), except for the operating conditions when the power output shall follow changes due to the provision of some of the services specified in this document (see §5.5, 5.6 or 5.7).

5.4 Immunity to disturbances

5.4.1 Low Voltage Ride Through (LVRT) capability

Solar PV generating plants shall contribute to overall power system stability by providing also immunity towards dynamic voltage changes, especially those due to the faults on the higher voltage level networks. The requirements below apply to all kinds of disturbances (1ph, 2ph and 3ph) and are independent of the interface protection settings which overrule the technical capabilities.

A solar PV generating plant shall be capable to stay connected to the distribution network as long as the voltage at the POC remains above the voltage-time diagram of Figure 4. The voltage is relative to the nominal voltage at POC. The smallest phase to phase voltage shall be evaluated. The compliance to such LVRT requirement shall apply to all equipment within a solar PV generating plant that might cause its disconnection.

After the voltage returned to the voltage range, the pre-disturbance operating conditions (active & reactive power) shall be resumed as fast as possible and with a tolerance of ±10% of the generating pant rated power.

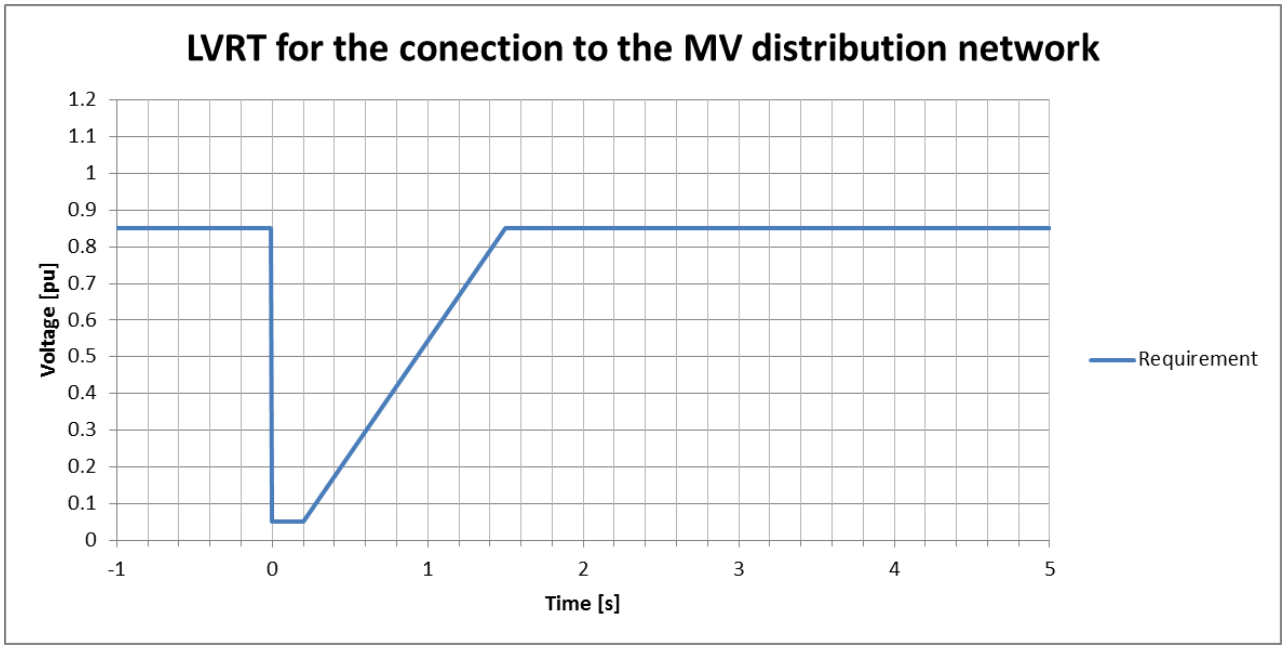

Figure 4: LVRT Characteristic for solar PV connected to MV distribution network

5.4.2 Rate of change of frequency (ROCOF) withstand capability

Solar PV generating plants when generating power shall be able to go through frequency transients within the frequency range and with rates of change of frequency up to 2 Hz/s.

5.5 Requirements for the frequency stability of the power system

5.5.1 Active power response to frequency variations

A solar PV generating plant shall be capable of activating the provision of active power response to over-frequency transients according to the curve of Figure 5[3], with frequency threshold and droop settings adjustable and to be specified by the relevant DSO;

- the frequency threshold shall be settable at least between 50 Hz and 52 Hz inclusive; if not explicitly specified by the DSO, the threshold shall be set to 50,3Hz
- the droop settings shall be between 2% and 12%; if not explicitly specified by the DSO, the droop shall be set to 4,4%.

The resolution of the frequency measurement shall be ±10mHz or less. The active power response shall be activated as fast as possible and shall be delivered with an accuracy of ±10% of the nominal power.

[3] In the figure, the power 1 p.u. refers to the actual output power at the time the frequency threshold is reached.

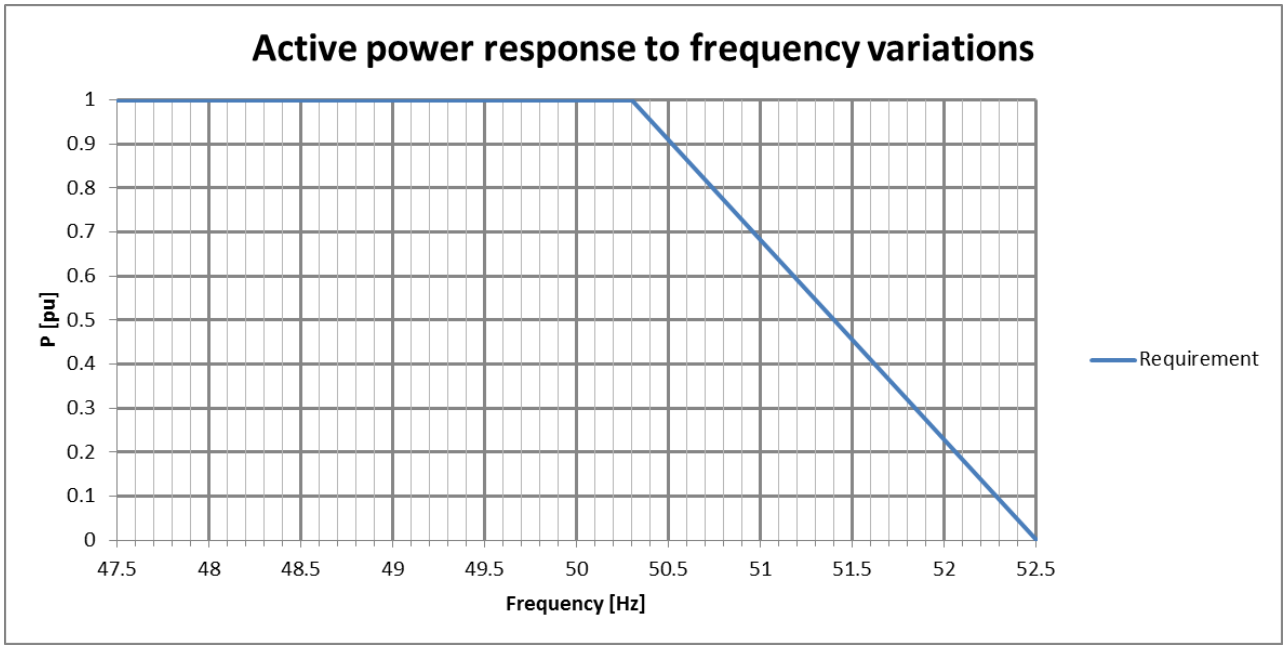

Figure 5: active power frequency response for solar PV connected to MV distribution network

5.5.2 Active power delivery at underfrequencies

A solar PV generating plant shall be resilient to reductions of frequency at the POC while reducing the maximum active power as little as possible.

The maximum admissible active power reduction due to under-frequency transient is illustrated in Figure 6 and is represented by a reduction rate of 10% of the rated active power at 50 Hz per 1 Hz frequency drop for frequency falling below 49 Hz.

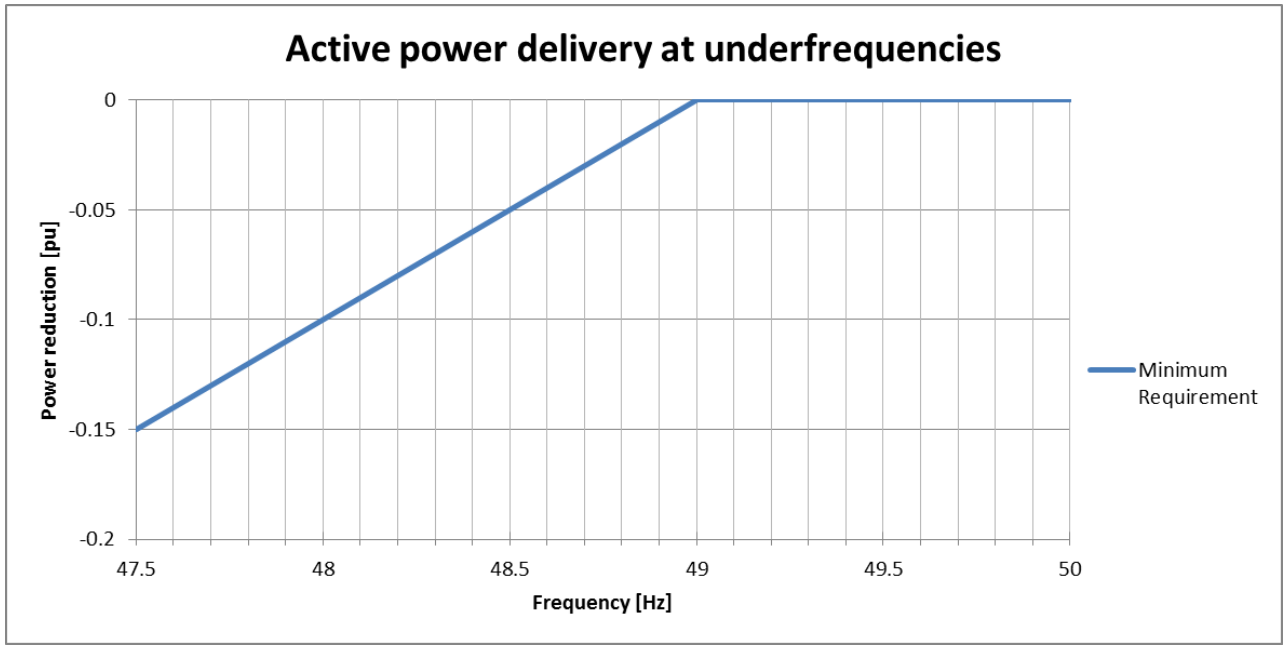

Figure 6: maximum active power reduction for under-frequency transients

5.5.3 Remote limitation of active power

A solar PV generating plant shall be equipped with an interface (input port) in order to be able to reduce its active power output following an instruction received at the interface.

In accordance with the provisions set forth in §4.4, the DSO shall have the right to specify further requirements in terms of equipment, communication protocol, information to be exchanged and/or time of execution, which allow to integrate such feature into the control systems of its distribution network and which allow to remotely limit the active power output of the solar PV generating units connected to its network.

5.6 Requirements for the voltage stability of the power system

5.6.1 Reactive power capability

When voltage and frequency at POC are within their normal operating ranges, the solar PV generating plants shall be able to provide reactive power in any operating point according to the boundaries of the reactive power capability defined in Figure 7[4].

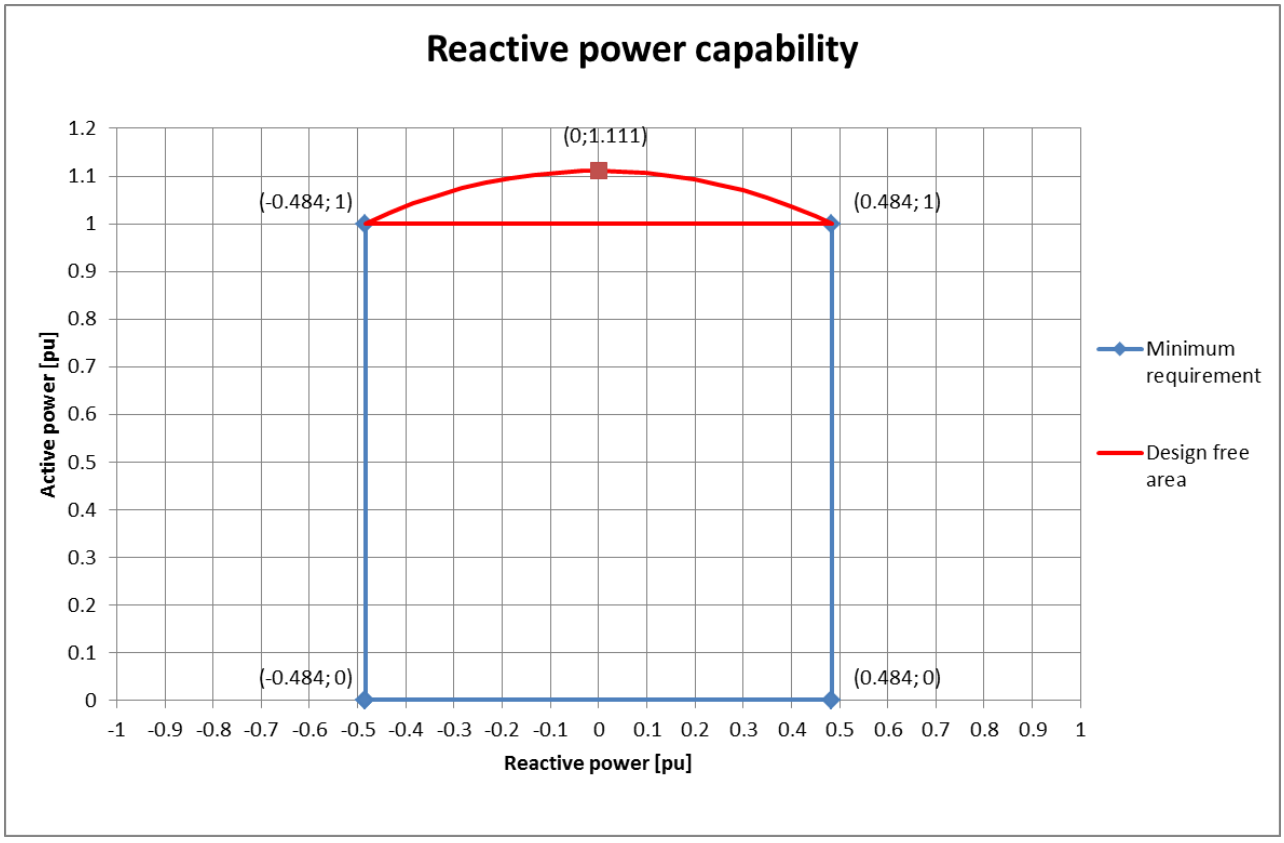

Figure 7: Reactive power capability for MV connection

[4] In the figure, the active power 1 p.u. shall refer to the rated active power value of the rooftop solar PV generating plant: at 1 p.u. of active power, the reactive power capability of a rooftop solar PV generating plant corresponds to a power factor varying between 0,9 leading to 0.9 lagging.

With reference to Figure 7, when the solar PV generating plant operates in the design free area (i.e. above its rated active power because of favorable environmental conditions), it is allowed to reduce the reactive power capability according to the widest possible technical capability of the generating units.

When the solar PV generating plant is operating above a threshold of 10 % of its nominal apparent power Sn, the required reactive power shall be provided with an accuracy of ± 2% Sn. Below the threshold of 10 % of Sn, deviations above 2% of accuracy are permissible; nevertheless the accuracy shall always be as good as technically feasible and shall not exceed 10% of Sn.

5.6.2 Reactive power control modes

A solar PV generating plant shall be capable of operating in the control modes stated below within the limits of its reactive power capability:

- Q fix : the reactive power is controlled in order to have a fix value ;
- Cos φ fix : the reactive power is controlled in order to have a fix power factor;
- Cos φ (P) : the reactive power is controlled in order to have a power factor function of the actual active power delivery;

The above control modes are exclusive; only one mode shall be active at a time. The activation, deactivation and configuration of the control modes shall be field adjustable.

5.6.2.1 Fix control modes

Q fix mode and cos φ fix mode control the reactive power and the cos φ of the output respectively, according to a set point set in the control of the solar PV generating plant or received from a remote control center.

The control modes Q fix and cos φ fix shall be settable by remote control according to the requirements of §4.4.

5.6.2.2 Power related Control mode

The power related control mode cos φ (P) controls the cos φ of the output as a function of the active power output. A characteristic with a minimum and maximum value and three connected lines according to Figure 8 shall be configurable within the control systems of the solar PV generating plant; a change in active power output results in a new cos φ set point according to the characteristic.

The parameters A, B and C shall be field adjustable and their settings are the responsibility of the DSO. If not explicitly specified by the DSO, these parameters shall be set as indicated below:

- A P = 0 Pn cos φ = 1
- B P = 0,5 Pn cos φ = 1
- C P = Pn cos φ = 0.9 (with the solar PV generating plant absorbing reactive power)

The response to a new cos φ set point value shall be as fast as technically feasible and at the latest within 10 s after the new value of the active power is reached. The accuracy of the control to each set point shall be according to §5.6.1.

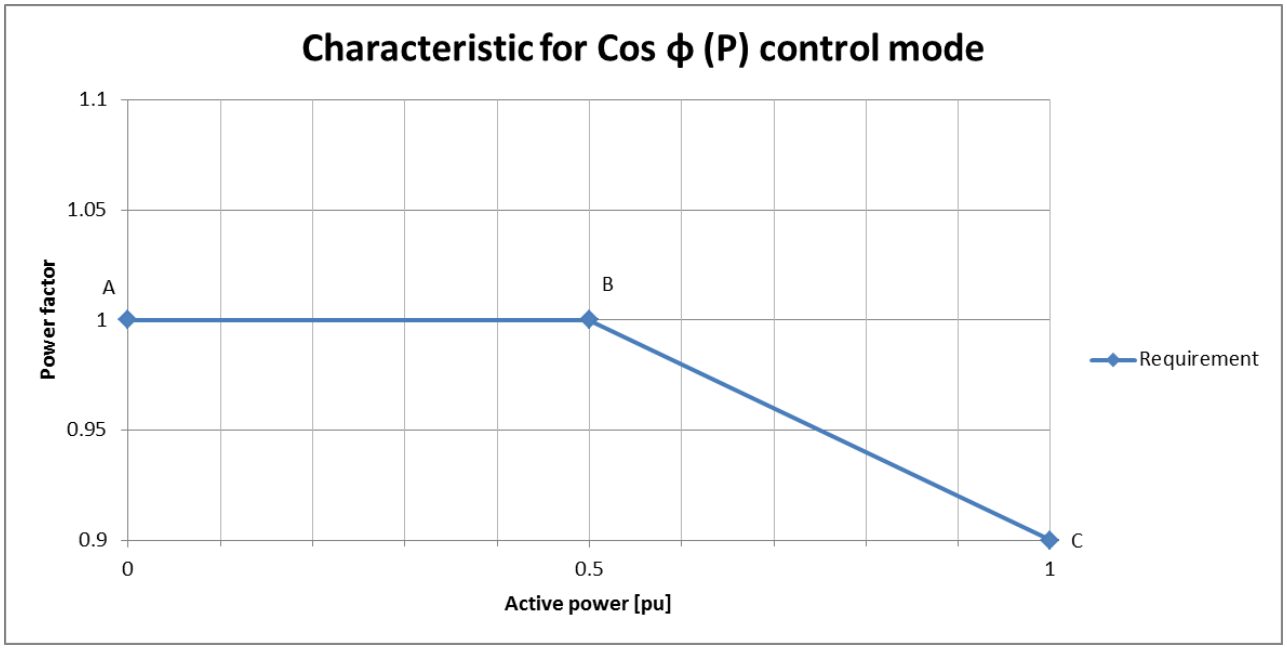

Figure 8: Characteristic for Cos φ (P) control mode

The implementation of lock-in and lock-out voltage levels shall be configurable, each separately in the range of 90% to 110% of the nominal voltage at POC: the contribution shall be activated when the voltage at POC exceeds the lock-in voltage and deactivated when the voltage at POC drops below the lock-out voltage. When the contribution is deactivated, the solar PV generating plant shall be controlled with a unit power factor.

5.6.3 Active power reduction at increasing voltage

In order to avoid the disconnection due to overvoltage protection, a solar PV generating plant is allowed to reduce its power output (active and/or reactive) as a function of the rising voltage. The implemented logic can be chosen by the manufacturer. Nevertheless, the implemented logic shall not cause steps or oscillations in the power output.

5.6.4 Reactive current injection during a fault

The provision of reactive current during a fault is currently not required for solar PV generating plants. Such feature might be introduced in the future in a scenario of a growing penetration level of distributed generation and a decreasing short circuit power of the Omani power system.

5.7 Participation to defence & restoration of the power system

5.7.1 Remote switch on/off

A solar PV generating plant shall be equipped with a logic interface (input port) in order to disconnect from the network following an instruction received at the interface.

In accordance with the provisions set forth in §4.4, the DSO shall have the right to specify further requirements in terms of equipment, time of execution, communication protocol and/or data to be exchanged, to integrate such feature into the control systems of its distribution network and to allow the remote disconnection of the solar PV generating plants connected to its MV networks.

5.7.2 Automatic reconnection after tripping

After the trip of the interface protection, a solar PV generating plant is allowed to reconnect to the network only if the voltage and frequency are within the following range for at least the observation time:

- Frequency range 47,5 Hz ≤ f ≤ 50,05 Hz;
- Voltage range 90% Uc ≤ U ≤ 110% Uc;
- Minimum observation time 180s.

After reconnection, the solar PV generating plant shall return to its target active power value with a variation rate not greater than 10% P_n/min.

5.8 Power quality

5.8.1 Voltage deviation

Under normal operating conditions, the connection and operation of a solar PV generating plant shall not cause the voltage at POC and at the POC of any other customer connected to the same distribution network varying from the system rated voltage by more than ±6% (Please refer also to [12] – DCC.4.1).

5.8.2 Rapid voltage changes

Connection and disconnection of the solar PV generating plant from the MV distribution networks should not give rise to voltage variations at the POC exceeding 3% of the system rated voltage (Please refer also to [12] – DCC.4.4).

5.8.3 Harmonics and inter-harmonics

Voltage harmonics and inter-harmonics at POC caused by the solar PV generating plant shall not exceed the limits specified in EN 50160.

5.8.4 DC injection

The DC component which solar PV generating plants inject into the network shall not exceed 0,5% of the rated AC current value of the plant.

5.8.5 Clusters of single-phase generating units

A solar PV generating plant connected to the MV distribution network shall not be composed of clusters of single-phase generating units unless explicitly agreed with the DSO.

6 SPECIFIC REQUIREMENTS FOR THE CONNECTION IN PARALLEL TO THE LV DISTRIBUTION NETWORK

6.1 Connection schemes

Unless required by and/or agreed with the connecting DSO, the connection schemes to be adopted for the connection of a solar PV generating plant to the Omani LV distribution networks are represented in one of the figures below.

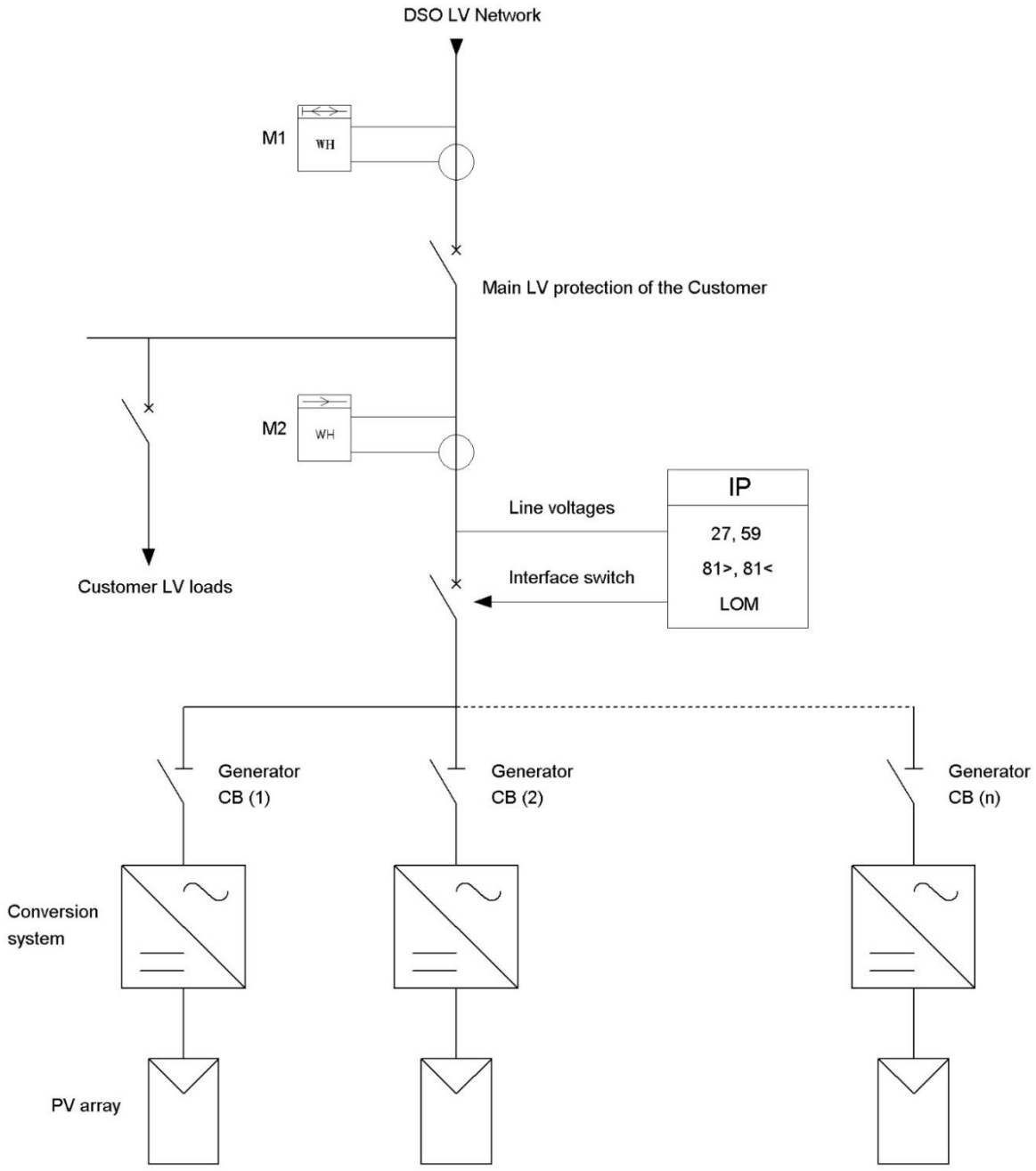

Figure 9: LV Connection Scheme

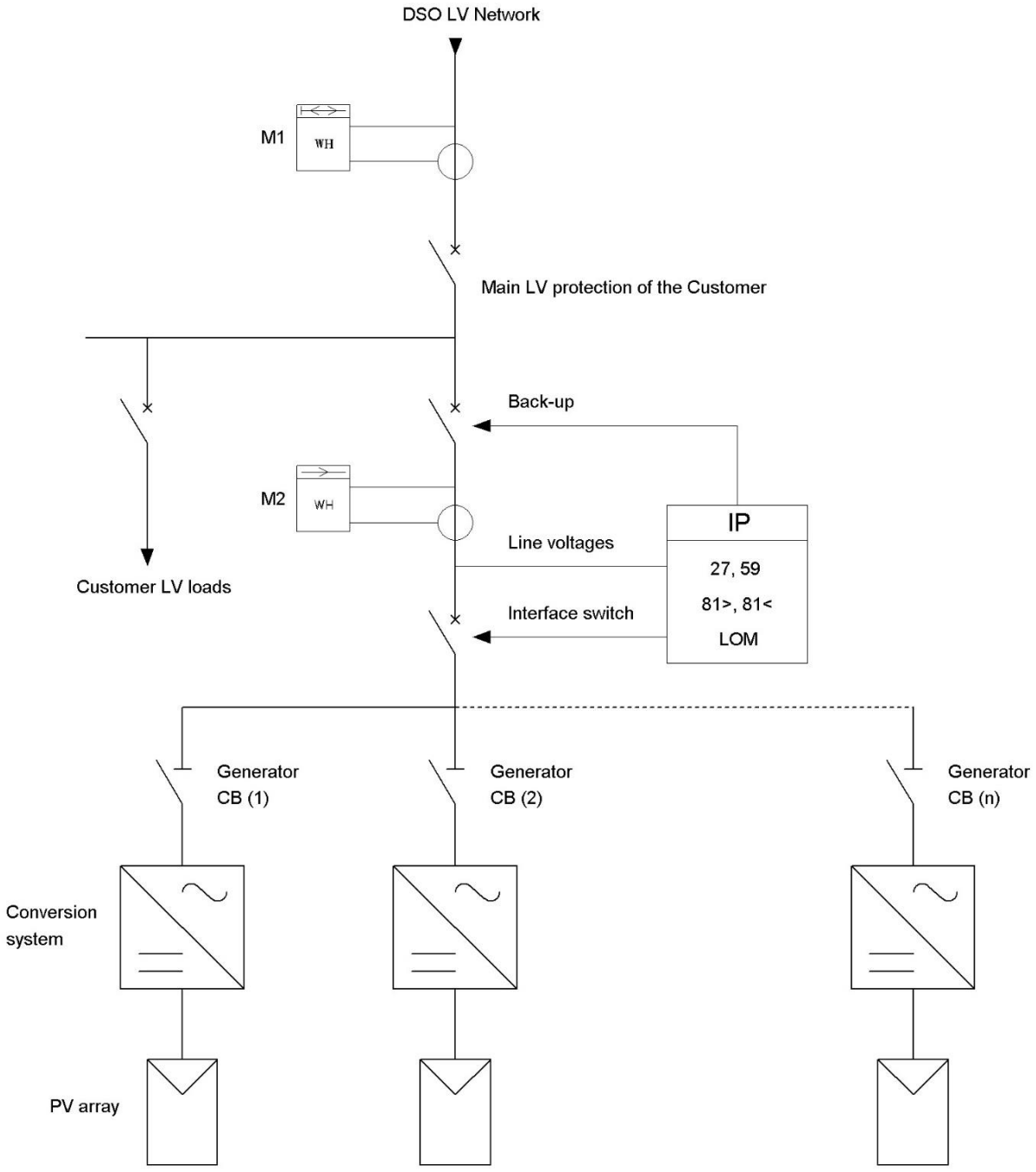

Figure 10: LV Connection Scheme with back-up

6.2 Interface Protection

The purpose of the interface protection is to:

- disconnect the solar PV generating plant from the distribution network in case of
  - unintentional islanding of the LV distribution network it is connected to;
  - Voltage or frequency transients of the power system out of the operating ranges.

- prevent the solar PV generating plant, when generating power, to cause overvoltages in the LV distribution network it is connected to;

It is not the purpose of the interface protection to:

- disconnect the generating plant from the distribution network in case of faults within the customer's network; for such issues, the requirements for the connection of passive customers shall apply [1];
- prevent damages to the customer's equipment (generating units or loads) due to faults/incidents (e.g. short circuits) on the distribution network or on the customer's internal network; for such issues, the recommendations and requirements of the manufacturers of the equipment shall apply.

In any case, the protection schemes and settings for electrical faults within the customer's network as well as those used for the protection of the customer's equipment must not jeopardise the performances of the requirements set out at §6.4 (immunity).

The interface protection shall be a dedicated device which acts on the interface switch. For a solar PV generating plant with a rated active power lower than 11,09kW[5], it is permitted to integrate the interface protection into the solar PV generating units.

For a solar PV generating plant with a rated active power greater than 20kW, the interface protection shall additionally act on another switch (backup switch) with a proper delay in case the interface switch fails to operate. The backup switch may consist of a dedicated switch or an already existing switch[6].

The loss of the auxiliary voltage of either the interface protection or the solar PV generating plant's control system shall trigger the interface switch without delay.

The protection functions required in the Interface Protection are the following:

- Undervoltage [27]
  - One threshold [27<] in the range [20%; 100%] of the POC nominal voltage (*default: 85%*), adjustable by steps of 5%, and delay time in the range [0,1s;100s] (*default: 0,4s*) adjustable in steps of 0,1s;
  - One threshold [27<<] in the range [5%; 100%] of the POC nominal voltage (*default: 40%*), adjustable by steps of 5%, and delay time in the range [0,1s;5s] (*default: 0,2s*) adjustable in steps of 0,05s.
- Overvoltage 10 min mean [59-Av]
  - One threshold in the range [100%; 115%] of the POC nominal voltage (*default: 110%*), adjustable by steps of 1%, and delay time lower than or equal to 3s;
- Overvoltage [59]
  - One threshold [59>] in the range [100%; 120%] of the POC nominal voltage (*default: excluded*), adjustable by steps of 1%, and delay time in the range [0,1s;100s] adjustable in steps of 0,1s;
  - One threshold [59>>] in the range [100%; 130%] of the POC nominal voltage (*default: 115%*), adjustable by steps of 1%, and delay time in the range [0,1s;5s] (*default: 0,2s*) adjustable in steps of 0,05s.
- Overfrequency [81>]

[5] three-phase solar rooftop PV generating plant with 16A per phase

[6] It is anyway recommended not to use the main switch as back-up switch since it could lead to the disconnection of the overall customer's facility in the case the interface switch fails to open, with the consequence of the power supply also being removed to customer's loads.

  - One threshold [81>] in the range [50Hz; 53Hz] (*default: 52,5Hz*), adjustable by steps of 0,1Hz, and delay time in the range [0,1s;100s] (*default: 0,1s*) adjustable in steps of 0,1s;
  - One threshold [81>>] in the range [50Hz; 53Hz] (*default: excluded*), adjustable by steps of 0,1Hz, and delay time in the range [0,1s;5s] adjustable in steps of 0,05s;
- Underfequency [81<]
  - One threshold [81<] in the range [47Hz; 50Hz] (*default: 47,5Hz*), adjustable by steps of 0,1Hz, and delay time in the range [0,1s;100s] (*default: 4s*) adjustable in steps of 0,1s;
  - One threshold [81<<] in the range [47Hz; 50Hz] (*default: excluded*), adjustable by steps of 0,1Hz, and delay time in the range [0,1s;5s] adjustable in steps of 0,05s;
- Loss Of Mains:

  for the LOM protection functions, a wide variety of approaches can be used: besides the passive observation of voltage and frequency, other active and passive methods are available and used to detect unintentional islanding situations but only some of these methods rely on standards. The present standard doesn't intend to specify the method to be used to achieve the goal but rather its efficacy; for such a reason, the only requirement on LOM protection is that the protection function shall be tested in accordance with the standard IEC 62116 [9] which provides procedures to evaluate the performance of islanding prevention measures used with utility-interconnected PV systems.

The Distribution Code [12] recognizes the possibility for a Licensed Distributor to "*decide dependent on local network conditions, if it is desirable for the Embedded Gensets to continue to Generate onto an islanded Distribution System*" during Emergency Conditions. The LOM protection function shall therefore have the possibility to be excluded or the LOM settings to be modified suitably.

The protection functions for undervoltage [27] and overvoltage [59] shall be fed by all the line voltages with generating units whereas the protection functions for underfrequency [81<] and overfrequency [81>] shall be fed by at least one line voltages.

The DSO is responsible to define the appropriate settings to be applied to the interface protection and which can ensure the correct tripping of the solar PV generating plant under specific conditions. The settings are chosen so that, in case a fault within the distribution network triggers the network protection systems which in turn disconnect a part of the network (the faulty feeder), there could not be any reclosure of the network switch before all the generating plants have been disconnected. The default settings above indicated for the different protection functions are therefore to be applied in the IP of a solar PV generating plant only when no other settings have been explicitly specified and communicated by the connecting DSO.

The interface protection shall have at least two configurable digital inputs which may be used in the future[7] by the connecting DSO for transfer trip, remote tripping or any other function that may be necessary to increase the distributed generation hosting capacity of the distribution networks while keeping an acceptable level of reliability.

6.3 Connection conditions

A solar PV generating plant is allowed to connect to the network and to start to generate electrical power due to normal operational start-up when the voltage and frequency are within the following range for at least the observation time:

[7] In a scenario of growing penetration level of generation on Omani distribution networks

- Frequency range 47,5 Hz ≤ f ≤ 50,05 Hz;
- Voltage range 85% Uc ≤ U ≤ 110% Uc;
- Minimum observation time180s.

Synchronizing a solar PV generating plant with the distribution network shall be fully automatic i.e. it shall not be possible to manually close the switch between the two systems to carry out synchronization.

The connection of a solar PV generating plant to the distribution network shall not create transient voltage variation at the POC of more than 3% of rated voltage.

After connection, a solar PV generating plant shall follow its target active power value with a variation rate not greater than 10% P_n/min.

The active power target shall be the maximum available active power output which is possible to generate from the solar PV generating plant, taking into account the environmental conditions (irradiation, temperature, …), except for the operating conditions when the power output shall follow changes due to the provision of some of the services specified in this document (see §6.5, 6.6 or §6.7).

6.4 Immunity to disturbances

6.4.1 Low Voltage Ride Through (LVRT) capability

Solar PV generating plants with a rated active power greater than or equal to 11,08kW, shall contribute to overall power system stability by providing also immunity towards dynamic voltage changes, especially those due to the faults on the higher voltage level networks. The requirements below apply to all kinds of disturbances (1ph, 2ph and 3ph) and are independent of the interface protection settings which overrule the technical capabilities.

A solar PV generating plant with a rated active power greater than 11,08kW shall be capable to stay connected to the distribution network as long as the voltage at the POC remains above the voltage-time diagram of Figure 11. The voltage is relative to the nominal voltage at POC. The smallest phase to phase voltage shall be evaluated. The compliance to such LVRT requirement shall apply to all equipment within a solar PV generating plant that might cause its disconnection.

After the voltage returned to the voltage range, the pre-disturbance operating conditions (active & reactive power) shall be resumed as fast as possible and with a tolerance of ±10% of the generating pant rated power.

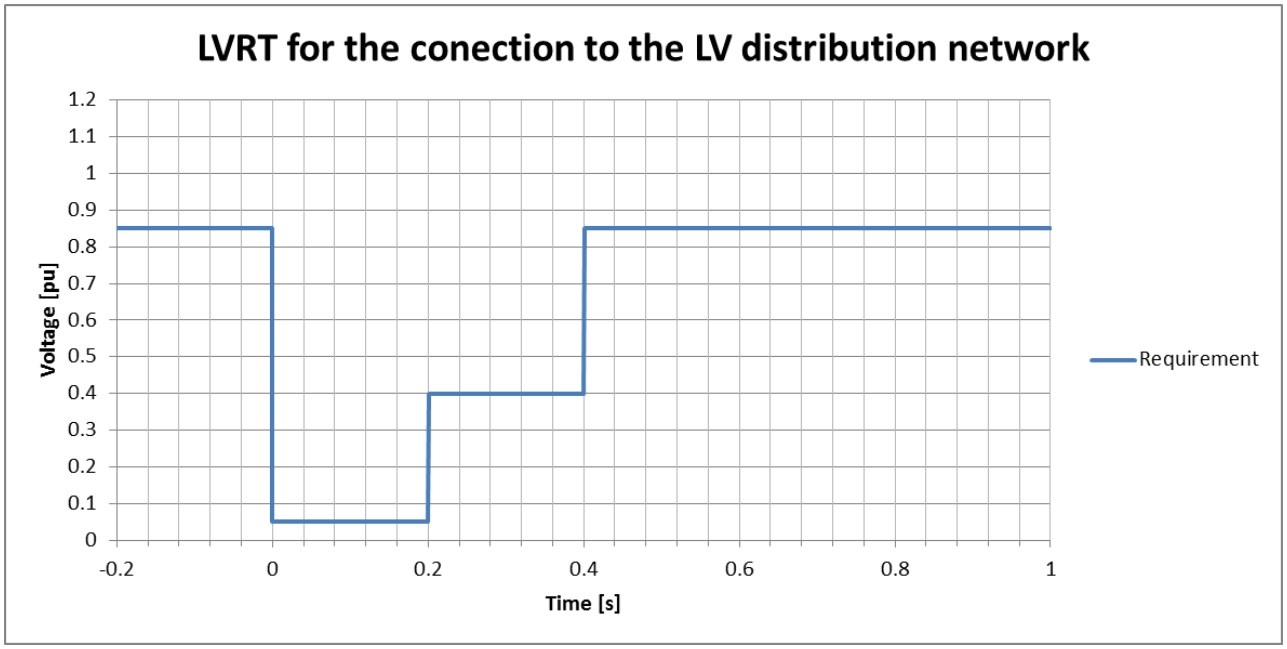

Figure 11: LVRT Characteristic for solar PV connected to LV distribution network

6.4.2 Rate of change of frequency (ROCOF) withstand capability

Solar PV generating plants when generating power shall be able to go through frequency transients within the frequency range and with rates of change of frequency up to 2 Hz/s.

6.5 Requirements for the frequency stability of the power system

6.5.1 Active power response to frequency variations

A solar PV generating plant shall be capable of activating the provision of active power response to over-frequency transients according to the curve of Figure 5, with frequency threshold and droop settings specified by the relevant DSO;

- the frequency threshold shall be settable at least between 50 Hz and 52 Hz inclusive; if not explicitly specified by the DSO, the threshold shall be set to 50,3Hz
- the droop settings shall be between 2% and 12%; if not explicitly specified by the DSO, the droop shall be set to 4,4%.

The resolution of the frequency measurement shall be ±10mHz or less. The active power response shall be activated as fast as possible and shall be delivered with an accuracy of ±10% of the nominal power.

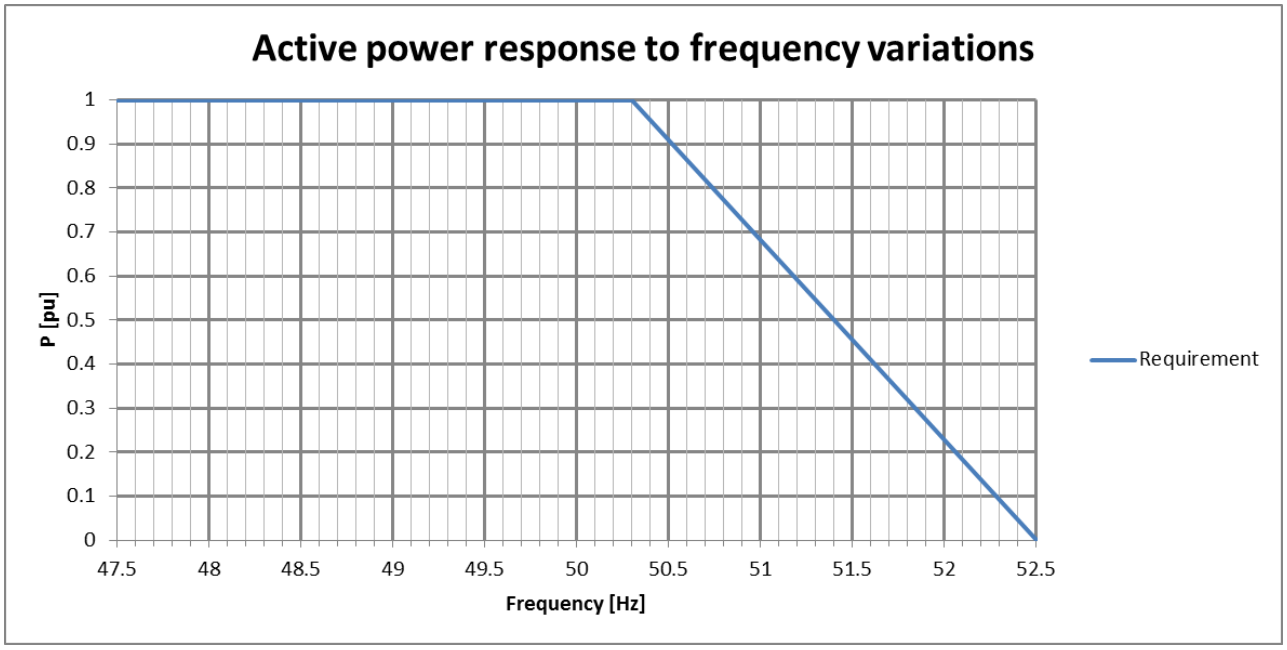

Figure 12: active power frequency response for solar PV connected to LV distribution network

6.5.2 Active power delivery at underfrequencies

A solar PV generating plant shall be resilient to reductions of frequency at the POC while reducing the maximum active power as little as possible.

The maximum admissible active power reduction due to under-frequency transient is illustrated in Figure 6 and is represented by a reduction rate of 10% of the rated active power at 50 Hz per 1 Hz frequency drop for frequency falling below 49Hz.

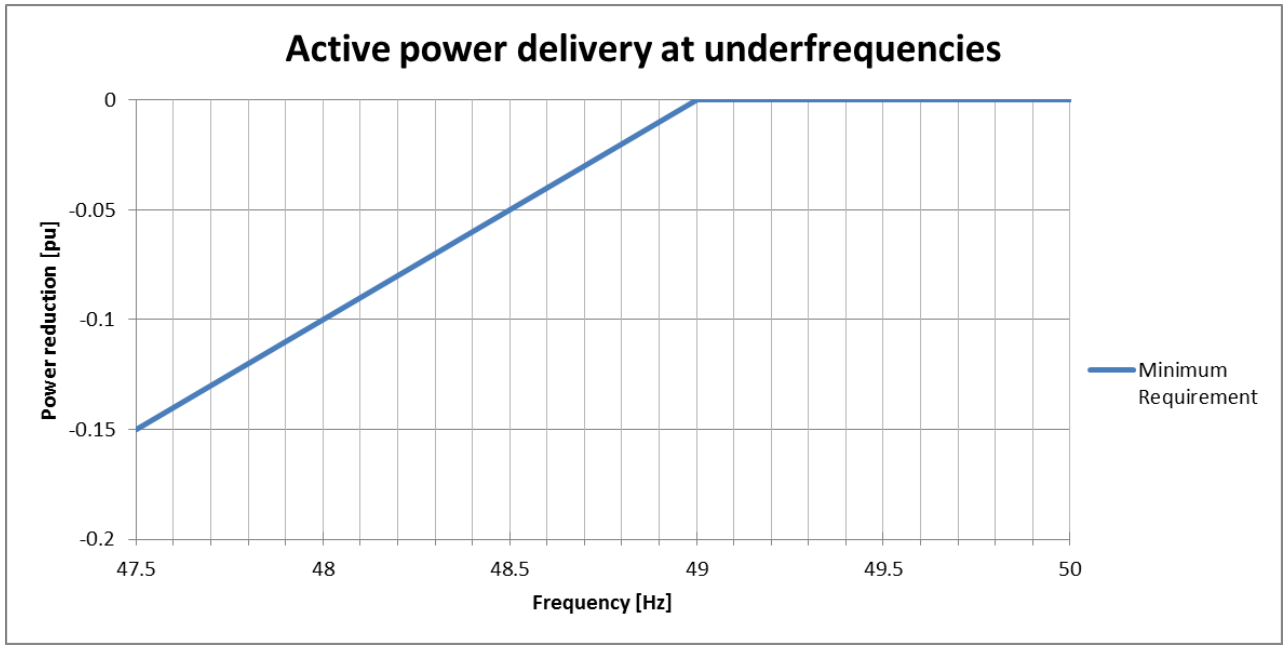

Figure 13: maximum active power reduction for under-frequency transients

6.5.3 Remote limitation of active power

A solar PV generating plant, with a rated active power greater than or equal to 11,08kW, shall be equipped with an interface (input port) in order to be able to reduce its active power output following an instruction received at the interface.

In accordance with the provisions set forth in §4.4, the DSO shall have the right to specify further requirements in terms of equipment, communication protocol, information to be exchanged and/or time of execution, which allow to integrate such feature into the control systems of its distribution network and which allow to remotely limit the active power output of the solar PV generating units connected to its network.

6.6 Requirements for the voltage stability of the power system

6.6.1 Reactive power capability

When voltage and frequency at POC are within their normal operating ranges, the solar PV generating plants shall be able to provide reactive power in any operating point within the boundaries of the reactive power capability defined in Figure 14.

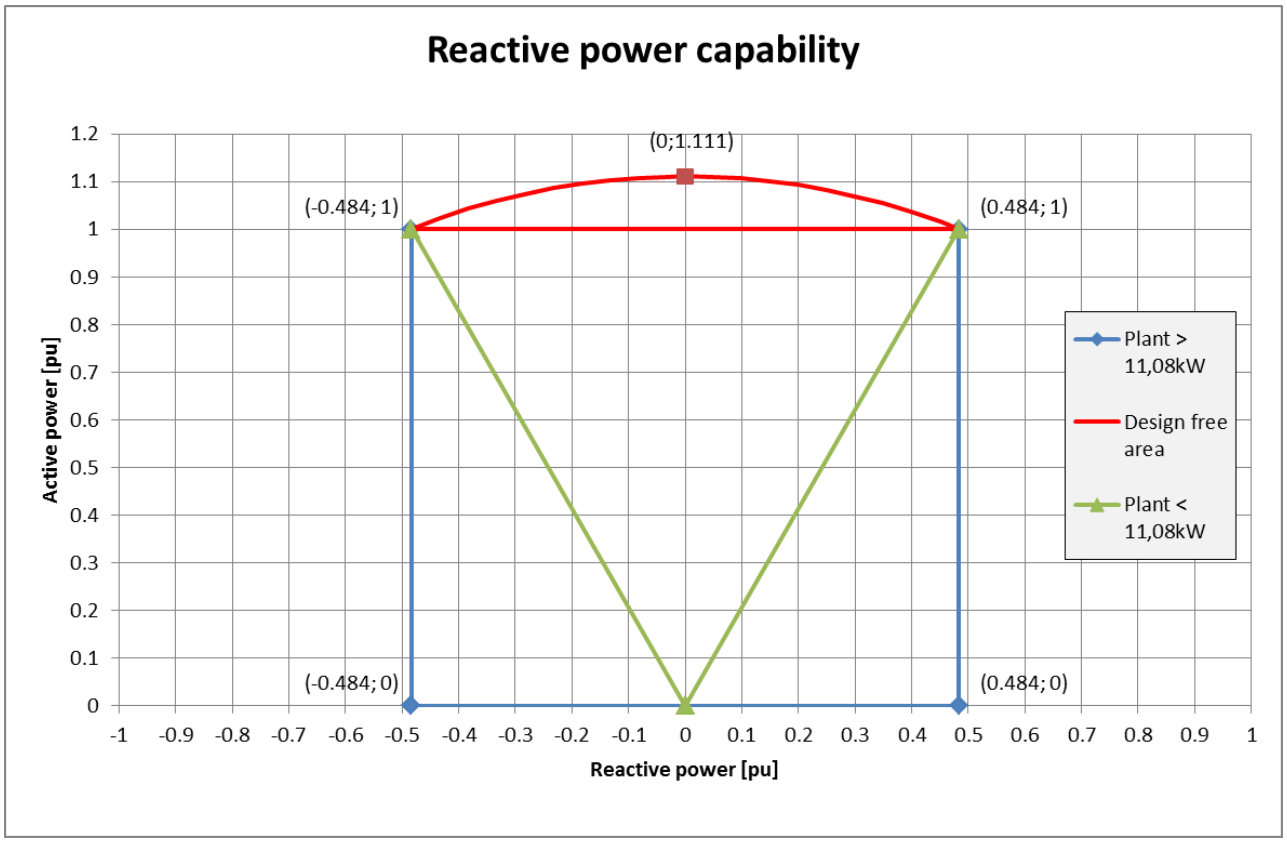

Figure 14: Reactive power capability for LV connection

With reference to Figure 14, when the solar PV generating plant operates in the design free area (i.e. above its rated active power because of favorable environmental conditions), it is allowed to reduce the reactive power capability according to the widest possible technical capability of the generating units.

When the solar PV generating plant is operating above a threshold of 10 % of its nominal apparent power Sn, the required reactive power shall be provided with an accuracy of ±2% Sn. Below the threshold of 10% of Sn, deviations above 2% of accuracy are permissible; nevertheless the accuracy shall always be as good as technically feasible and shall not exceed 10% of Sn.

6.6.2 Reactive power control modes

A solar PV generating plant shall be capable of operating in the control modes stated below within the limits of its reactive power capability:

- Q fix : the reactive power is controlled in order to have a fix value ;
- Cos φ fix : the reactive power is controlled in order to have a fix power factor;
- Cos φ (P) : the reactive power is controlled in order to have a power factor function of the actual active power delivery;

The above control modes are exclusive; only one mode may be active at a time. The activation, deactivation and configuration of the control modes shall be field adjustable.

6.6.2.1 Fix control modes

Q fix mode and cos φ fix mode control the reactive power and the cos φ of the output respectively, according to a set point set in the control of the solar PV generating plant or received from a remote control center.

For a solar PV generating plant with a rated active power greater than or equal to 11,08kW, the control modes Q fix and cos φ fix shall be settable by remote control according to the requirements of §4.4.

6.6.2.2 Power related Control mode

The power related control mode cos φ (P) controls the cos φ of the output as a function of the active power output. A characteristic with a minimum and maximum value and three connected lines according to Figure 8 shall be configurable within the control systems of the solar PV generating plant; a change in active power output results in a new cos φ set point according to the characteristic.

The parameters A, B and C shall be field adjustable and their settings are the responsibility of the DSO. If not explicitly specified by the DSO, these parameters shall be set as indicated below:

- A P = 0 Pn cos φ = 1
- B P = 0,5 Pn cos φ = 1
- C P = Pn cos φ = 0.9 (with the solar PV generating plant absorbing reactive power)

The response to a new cos φ set point value shall be as fast as technically feasible after the new value of the active power is reached. The accuracy of the control to each set point shall be according to §5.6.1.

The implementation of a lock-in and lock-out voltage level shall be configurable each separately in the range of 90% to 110% of the nominal voltage at POC: the contribution is activated when the voltage at POC exceeds the lock-in voltage and is deactivated when the voltage at POC drops below the lock-out voltage. When the contribution is deactivated, the solar PV generating plant shall be controlled with a unit power factor.

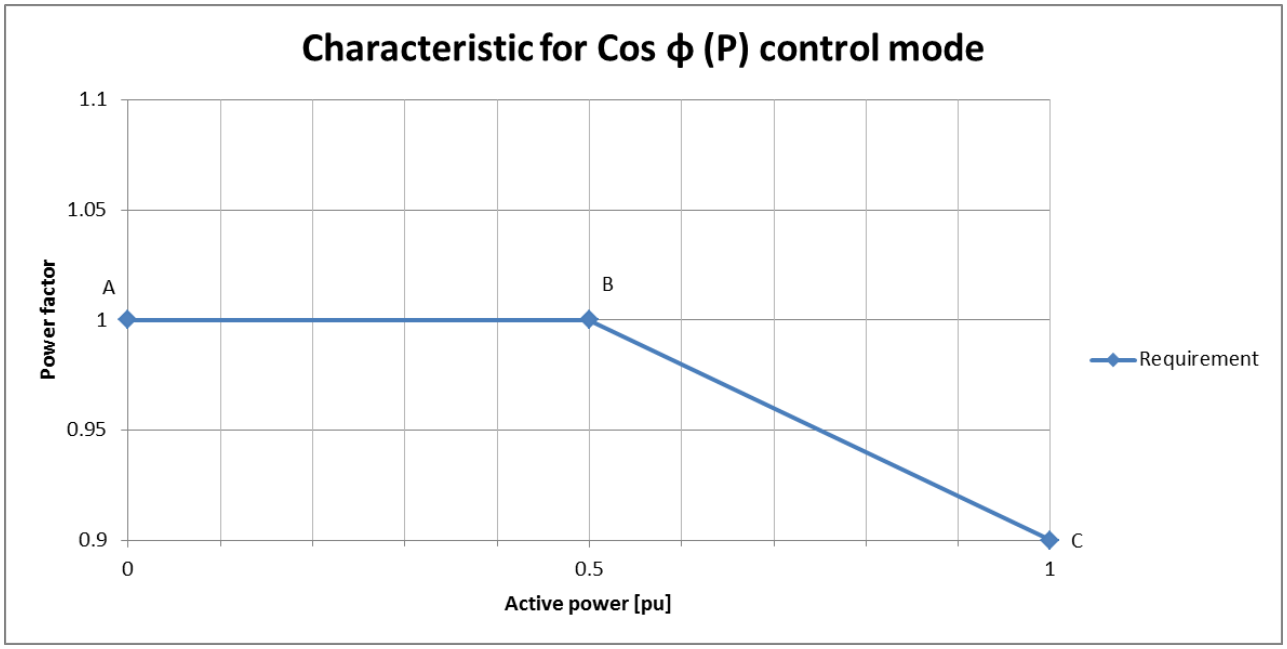

Figure 15: Characteristic for Cos φ (P) control mode

6.6.3 Active power reduction at increasing voltage

In order to avoid the disconnection due to overvoltage protection, a solar PV generating plant is allowed to reduce its power output (active and/or reactive) as a function of the rising voltage. The implemented logic can be chosen by the manufacturer. Nevertheless, the implemented logic shall not cause steps or oscillations in the power output.

6.7 Participation to defence & restoration of the power system

6.7.1 Remote switch on/off

A solar PV generating plant, with a rated active power greater than or equal to 10kW, shall be equipped with a logic interface (input port) in order to disconnect from the network following an instruction received at the interface.

In accordance with the provisions set forth in §4.4, the DSO shall have the right to specify further requirements in terms of equipment, time of execution, communication protocol and/or data to be exchanged, to integrate such feature into the control systems of its distribution network and to allow the remote disconnection of the solar PV generating plants connected to its LV networks.

6.7.2 Automatic reconnection after tripping

After the trip of the interface protection, a solar PV generating plant is allowed to reconnect to the network only if the voltage and frequency are within the following range for at least the observation time:

- Frequency range 47,5 Hz ≤ f ≤ 50,05 Hz;
- Voltage range 90% Uc ≤ U ≤ 110% Uc;
- Minimum observation time180s.

After reconnection, the solar PV generating plant shall return to its target active power value with a variation rate not greater than 10% P_n/min.

6.8 Power quality

6.8.1 Voltage deviation

Under normal operating conditions, the connection and operation of a solar PV generating plant shall ensure that the voltage at POC and at the POC of any other customer connected to the same distribution network shall not vary from the system rated voltage by more than ±6% (Please refer also to [12] – DCC.4.1).

6.8.2 Rapid voltage changes

Connection and disconnection of the solar PV generating plant from the MV distribution networks should not give rise to voltage variations at the POC exceeding 3% of the system rated voltage (Please refer also to [12] – DCC.4.4).

6.8.3 Harmonics and inter-harmonics

Voltage harmonics and inter-harmonics at POC caused by the solar PV generating plant shall not exceed the limits specified in EN 50160. It is usually recognised that such goal can be achieved when the harmonic current emissions of a solar PV generating plant do not exceed the following limits:

- for generating plants with a rated power below 600W, the limits defined in the standard IEC 61000-3-2 [10], Class C (lighting) equipment, shall apply;
- for power plant with a rated power greater than 600W, the limits defined in the standard IEC 61000-3-12 [11], Table 2, R_{sce} = 33,.shall apply.

6.8.4 DC injection

The DC component which solar PV generating plants inject into the network shall not exceed 0,5% of the rated AC current value of the plant.

6.8.5 Clusters of single-phase generating units

For LV connections, the use of three-phase equipment is required. It is anyway allowed for a solar PV generating plant connected to the LV distribution network to be composed of clusters of single-phase generating units only if the sum of the currents of all the solar PV generating units connected to one phase doesn't exceed 16A.

ANNEX A. LIST OF APPLICABLE STANDARDS FOR EQUIPMENT

The main standards to be used as a reference in the development of a solar PV application are summarized hereinafter. For each standard a short comment and its importance from a 3-level scale are added.
The meaning of the "stars" is the following:

☆ Useful document
☆☆ Important document
☆☆☆ Fundamental document

A.1. PV modules

Reference	Title	Importance	Application
IEC 61215-1	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1: Test requirements	☆☆☆	**All PV modules, type tests**
IEC 61215-1-1	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-1: Special requirements for testing of crystalline silicon photovoltaic (PV) modules	☆☆☆	**All crystalline PV modules, special requirements**
IEC 61215-1-2	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-2: Special requirements for testing of thin-film Cadmium Telluride (CdTe) based photovoltaic (PV) modules	☆☆☆	**All CdTe PV modules, special requirements**
IEC 61215-1-3	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-3: Special requirements for testing of thin-film amorphous silicon based photovoltaic (PV) modules	☆☆☆	**All amorphous silicon PV modules, special requirements**
IEC 61215-1-4	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-4: Special requirements for testing of thin-film Cu(In,GA)(S,Se)2 based photovoltaic (PV) modules	☆☆☆	**All Cu(In,GA)(S,Se)2 PV modules, special requirements**
IEC 61215-2	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 2: Test procedures	☆☆☆	**All PV modules, type tests**
IEC 61215	Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval	☆☆☆	**Temporarily still valid for existing certificates**
IEC 61646	Thin-film terrestrial photovoltaic (PV) modules - Design qualification and type approval	☆☆☆	**Temporarily still valid for existing certificates**
IEC 61730-1	Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction	☆☆☆	**All PV modules, especially those installed on buildings, construction**
IEC 61730-2 RLV	Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing	☆☆☆	**All PV modules, especially those installed on buildings, testing**
IEC 61701	Salt mist corrosion testing of photovoltaic (PV) modules	☆☆☆	**PV modules installed in a marine environment**

Reference	Title	Importance	Application
IEC 62716	Photovoltaic (PV) modules - Ammonia corrosion testing	☆☆	**Tests on PV modules used in environments with a high degree of ammonia**
IEC TS 62782	Photovoltaic (PV) modules – Cyclic (dynamic) mechanical load testing	☆☆	**Tests on PV modules used in environments with a high mechanical stress**
IEC TS 62804-1	Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation - Part 1: Crystalline silicon	☆☆	**Tests on all PV modules to prevent the occurrence of PID**
IEC TS 62941	Terrestrial photovoltaic (PV) modules - Guideline for increased confidence in PV module design qualification and type approval	☆☆	**Performance and reliability of certified PV modules**
IEC 62759-1	Photovoltaic (PV) modules - Transportation testing - Part 1: Transportation and shipping of module package units	☆☆	**Tests on all PV modules to assess the mechanical stress during transportation**
IEC TS 62804-1	Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation - Part 1: Crystalline silicon	☆☆	**Tests on all PV modules to prevent the occurrence of PID**
IEC 61853-1	Photovoltaic (PV) module performance testing and energy rating - Part 1: Irradiance and temperature performance measurements and power rating	☆	**Measurement of the outdoor performance of PV modules**
IEC 61853-2	Photovoltaic (PV) module performance testing and energy rating - Part 2: Spectral responsivity, incidence angle and module operating temperature measurements	☆	**Measurement of the outdoor performance of PV modules**
EN 50380	Datasheet and nameplate information for photovoltaic modules	☆☆	**Documentation for PV modules**
IEC 62790	Junction boxes for photovoltaic modules – Safety requirements and tests	☆☆	**Tests on the junction boxes of all PV modules**
IEC 60068-2-68	Environmental testing - Part 2-68: Tests - Test L: Dust and sand	☆☆☆	**Environmental test applied to PV modules installed in desert climates**

A.2. Inverters

Reference	Title	Importance	Application
IEC 62109-1	Safety of power converters for use in photovoltaic power systems - Part 1: General requirements	☆☆☆	**Safety requirements for inverters, international standards**
IEC 62109-2	Safety of power converters for use in photovoltaic power systems - Part 2: Particular requirements for inverters	☆☆☆	
IEC TS 62910	Utility-interconnected photovoltaic inverters - Test procedure for low voltage ride- through measurements	☆☆☆	**Test methods for assessing the LVRT capacity of inverters**
EN 50530	Overall efficiency of grid connected photovoltaic inverters	☆☆	**Test methods for measuring static and dynamic efficiency**

Reference	Title	Importance	Application
			of PV inverters
EN 50524	Data sheet and name plate for photovoltaic inverters This European Standard describes data sheet and name plate information for photovoltaic inverters in grid parallel operation	☆	**Documentation for inverters**
IEC 62116	Utility-interconnected photovoltaic inverters - Test procedure of islanding prevention measures	☆☆☆	**Test methods for assessing the capacity of an inverter and its protection to avoid islanding**

A.3. EMC (Electro Magnetic Compatibility)

Reference	Title	Importance	Application
IEC 61000-3-2	Electromagnetic compatibility (EMC) - Part 3-2: Limits - Limits for harmonic current emissions (equipment input current ≤16 A per phase)	☆☆☆	**Maximum output harmonic content for small inverters**
IEC 61000-3-12	Electromagnetic compatibility (EMC) - Part 3-12: Limits - Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and ≤ 75 A per phase	☆☆☆	**Maximum output harmonic content for medium size inverters**
IEC 61000-2-2	Electromagnetic compatibility (EMC) - Part 2-2: Environment - Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems	☆	**Maximum level of voltage disturbances on a LV public grid**
IEC 61000-3-3	Electromagnetic compatibility (EMC) - Part 3-3: Limits - Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤16 A per phase and not subject to conditional connection	☆☆	**Non harmonic voltage disturbances on a LV grid and test systems. Valid for I ≤ 16 A per phase**
IEC 61000-3-11	Electromagnetic compatibility (EMC) - Part 3-11: Limits - Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems - Equipment with rated current ≤ 75 A and subject to conditional connection	☆☆	**Non harmonic voltage disturbances on a LV grid and test systems. Valid for 16 > I ≤ 75 A per phase**
IEC 61000-6-1	Electromagnetic compatibility (EMC) - Part 6-1: Generic standards - Immunity for residential, commercial and light-industrial environments	☆	**Immunity requirements and test for LV equipment installed in residential, commercial and light-industrial environments**
IEC 61000-6-2	Electromagnetic compatibility (EMC) - Part 6-2: Generic standards - Immunity for industrial environments	☆☆	**Immunity requirements and test for LV equipment installed in industrial environments**
IEC 61000-6-3	Electromagnetic compatibility (EMC) - Part 6-3: Generic standards - Emission standard for residential, commercial and light-industrial environments	☆☆	**Immunity requirements and test for LV equipment installed in residential, commercial and light-industrial environments**

Reference	Title	Importance	Application
IEC 61000-6-4	Electromagnetic compatibility (EMC) - Part 6-4: Generic standards - Emission standard for - industrial environments	☆	**Immunity requirements and test for LV equipment installed in industrial environments**
IEC/TR 61000-3-14	Electromagnetic compatibility (EMC) - Part 3-14: Assessment of emission limits for harmonics, interharmonics, voltage fluctuations and unbalance for the connection of disturbing installations to LV power systems	☆☆	**Guide to LV IEC 61000 series standards with examples of application**
IEC/TR 61000-3-6	Electromagnetic compatibility (EMC) - Part 3-6: Limits - Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems	☆	**Harmonic current in MV and HV RRGU**
IEC/TR 61000-3-7	Electromagnetic compatibility (EMC) - Part 3-7: Limits - Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems	☆	**Flicker effects and other rapid voltage changes in MV and HV RRGU**
IEC/TR 61000-3-13	Electromagnetic compatibility (EMC) - Part 3-13: Limits - Assessment of emission limits for the connection of unbalanced installations to MV, HV and EHV power systems	☆	**Effects of unbalances in MV and HV RRGU**

A.4. Cables and connectors

Reference	Title	Importance	Application
EN 50618	Electric cables for photovoltaic systems	☆☆☆	**Standard on cables for DC arrays**
EN 50521	Connectors for photovoltaic systems - Safety requirements and tests	☆☆☆	**Widely used European standard for PV connectors**
UL 6703	Outline of Investigation for Connectors for Use in Photovoltaic Systems	☆☆	**Widely used US outlines/standards for PV connectors**

A.5. Combiner boxes

Reference	Title	Importance	Application
IEC 62093	Balance-of-system components for photovoltaic systems – Design qualification natural environments	☆	**Test sequence is to determine the performance characteristics of BOS components**
EN 50178	Electronic equipment for use in power installations	☆☆☆	**Electronic equipment in power installations with respect to safety and reliability**
IEC 62447-1	Safety requirements for power electronic converter systems and equipment Part 1: General	☆☆	**Equipment for power conversion and electronic**

Reference	Title	Importance	Application
			power switching

A.6. LV switchgears and controlgear

Reference	Title	Importance	Application
IEC/TR 61439-0	Low-voltage switchgear and controlgear assemblies - Part 0: Guidance to specifying assemblies	☆	**A guide with the explanation of main characteristics**
IEC 61439-1	Low-voltage switchgear and controlgear assemblies - Part 1: General rules	☆☆☆	**The main standard for the design and construction of LV switchgears and controlgear assemblies**
IEC 61439-2	Low-voltage switchgear and controlgear assemblies - Part 2: Power switchgear and controlgear assemblies	☆☆☆	
IEC 61439-3	Low-voltage switchgear and controlgear assemblies - Part 3: Distribution boards intended to be operated by ordinary persons (DBO)	☆☆	**LV switchgears and controlgear for specific applications**
IEC 61439-5	Low-voltage switchgear and controlgear assemblies - Part 5: Assemblies for power distribution in public networks	☆☆	
IEC 61439-6	Low-voltage switchgear and controlgear assemblies - Part 6: Busbar trunking systems (busways)	☆☆	
IEC 61439-7	Low-voltage switchgear and controlgear assemblies - Part 7: Assemblies for specific applications such as marinas, camping sites, market squares, electric vehicles charging stations	☆☆	
IEC 60947-3	Low-voltage switchgear and controlgear - Part 3: Switches, disconnectors, switch-disconnectors and fuse-combination units	☆☆☆	**Characteristics of LV circuit-breakers and protection devices**
IEC 62626-1	Low-voltage switchgear and controlgear enclosed equipment - Part 1: Enclosed switch-disconnectors outside the scope of IEC 60947-3 to provide isolation during repair and maintenance work	☆☆☆	**Characteristics of LV circuit-breakers and protection devices**

A.7. HV switchgears and controlgear

Reference	Title	Importance	Application
IEC 62271-1	High-voltage switchgear and controlgear - Part 1: Common specifications	☆☆	**All the PV plants connected to the MV grid**
IEC 62271-100	High-voltage switchgear and controlgear - Part 100: Alternating current circuit-breakers	☆☆	

Reference	Title	Importance	Application
IEC 62271-103	High-voltage switchgear and controlgear - Part 103: Switches for rated voltages above 1 kV up to and including 52 kV	☆☆	
IEC 62271-200	High-voltage switchgear and controlgear - Part 200: AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV	☆☆	
IEC 62271-202	High-voltage switchgear and controlgear - Part 202: High-voltage/low-voltage prefabricated substation	☆☆	

A.8. Transformers

Reference	Title	Importance	Application
IEC 60076-8	Power transformers - Part 8: Application guide	☆☆	
IEC 60076-11	Power transformers - Part 11: Dry-type transformers	☆☆	
IEC 60076-13	Power transformers - Part 13: Self-protected liquid-filled transformers	☆☆	**MV/LV dry-type and liquid-filled transformers**
EN 50588-1	Medium power transformers 50 Hz, with highest voltage for equipment not exceeding 36 kV. Part 1: General requirements	☆☆☆	
IEC 61558-1	Safety of power transformers, power supplies, reactors and similar products - Part 1: General requirements and tests	☆☆	**LV transformers**

A.9. Electrical installation

Reference	Title	Importance	Application
IEC 60364-1	Low-voltage electrical installations - Part 1: Fundamental principles, assessment of general characteristics, definitions	☆☆	
IEC 60364-4-41	Low-voltage electrical installations - Part 4-41: Protection for safety - Protection against electric shock	☆☆	**Main standards for electric safety**
IEC 60364-4-42	Low-voltage electrical installations - Part 4-42: Protection for safety - Protection against thermal effects	☆☆	
IEC 60364-4-43	Low-voltage electrical installations - Part 4-43: Protection for safety - Protection against overcurrent	☆☆	

Reference	Title	Importance	Application
IEC 60364-4-44	Low-voltage electrical installations - Part 4-44: Protection for safety - Protection against voltage disturbances and electromagnetic disturbances	☆☆	
IEC 60364-5-52	Low-voltage electrical installations - Part 5-52: Selection and erection of electrical equipment - Wiring systems	☆☆	
IEC 60364-5-53	Electrical installations of buildings - Part 5-53: Selection and erection of electrical equipment - Isolation, switching and control	☆☆	
IEC 60364-5-54	Low-voltage electrical installations - Part 5-54: Selection and erection of electrical equipment - Earthing arrangements and protective conductors	☆☆	
IEC 60364-6	Low-voltage electrical installations - Part 6: Verification	☆☆	
IEC 60364-7-712	Electrical installations of buildings - Part 7-712: Requirements for special installations or locations - Solar photovoltaic (PV) power supply systems	☆☆	**Standard for electric safety of PV plants**
IEC 62548	Photovoltaic (PV) arrays - Design requirements	☆☆☆	**Fundamental for the design of DC sections of PV plants**
IEC 62446-1	Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 1: Grid connected systems - Documentation, commissioning tests and inspection	☆☆☆	**Important for the start-up and verification of PV plants**
IEC 61724-1	Photovoltaic system performance - Part 1: Monitoring	☆☆	**Monitoring of PV system, power capacity and energy evaluation**
IEC 61724-2	Photovoltaic system performance - Part 2: Capacity evaluation method	☆☆	
IEC 61724-3	Photovoltaic system performance - Part 3: Energy evaluation method	☆☆	
IEC 61829	Crystalline silicon photovoltaic (PV) array - On-site measurement of I-V characteristics	☆☆	**Measurement of PV arrays on field**
IEC 62305-1	Protection against lightning - Part 1: General principles	☆☆	**Main standards on lightning effects**
IEC 62305-2	Protection against lightning - Part 2: Risk management	☆☆	
IEC 62305-3	Protection against lightning - Part 3: Physical damage to structures and life hazard	☆☆	
IEC 62305-4	Protection against lightning - Part 4: Electrical and electronic systems within structures	☆☆	

A.10. PV mounting system

Reference	Title	Importance	Application
EN 50583-1	Photovoltaics in buildings. Part 1: BIPV modules	☆☆	**Building Integrated PV**
EN 50583-2	Photovoltaics in buildings. Part 2: BIPV systems	☆☆	**Building Integrated PV**
UL 2703	Outline of Investigation for Mounting Systems, Mounting Devices, Clamping/Retention Devices, and Ground Lugs for Use with Flat-Plate Photovoltaic Modules and Panels	☆☆	**Important document especially for Building Integrated PV**

A.11. Grid connection

Reference	Title	Importance	Application
EN 50160	Voltage characteristics of electricity supplied by public electricity networks	☆☆	**Minimum requirements for a grid supply**
EN 50438	Requirements for the connection of micro-generators in parallel with public low-voltage distribution networks	☆	**Different requirements for connection in Europe**
EN 61727	Photovoltaic (PV) systems - Characteristics of the utility interface	☆	**General requirements for grid connection**
CLC/TS 50549-1	Requirements for generating plants to be connected in parallel with distribution networks – Part 1: Connection to a LV distribution network above 16 A	☆☆	**Technical specifications for the LV grid connection**
CLC/TS 50549-2	Requirements for generating plants to be connected in parallel with distribution networks – Part 2: Connection to a MV distribution network	☆☆	**Technical specifications for the LV grid connection**

A.12. Electricity Metering System

Reference	Title	Importance	Application
OES 22D	SINGLE PHASE KILOWATT-HOUR DIGITAL METERS DIRECTLY CONNECTED FOR SERVICE CONNECTIONS	☆☆☆	**Single Phase connections**
OES 22E	THREE PHASE KILOWATT-HOUR DIGITAL METERS DIRECTLY CONNECTED FOR SERVICE CONNECTIONS	☆☆☆	**Three-phase connections**
OES 22F	THREE PHASE KILOWATT-HOUR DIGITAL METERS, CURRENT TRANSFORMER OPERATED, CONNECTED FOR SERVICE CONNECTIONS	☆☆☆	**Three-phase connections (indirect measurement)**
IEC 62052-11	Electricity metering equipment (a.c.) – General	☆☆	**Type tests for electricity**

Reference	Title	Importance	Application
	requirements, tests and test conditions – Part 11: Metering equipment		**metering equipment**
IEC 62053-11	Electricity metering equipment (a.c.) – Particular requirements - Part 11: Electromechanical meters for active energy (classes 0,5, 1 and 2)	☆	**Type tests for electromechanical watt-hour meters of accuracy classes 0,5, 1 and 2**
IEC 62053-21	Electricity metering equipment (a.c.) - Particular requirements - Part 21: Static meters for active energy (classes 1 and 2)	☆☆	**Type tests for static watt-hour meters of accuracy classes 1 and 2**
IEC 62053-22	Electricity metering equipment (a.c.) – Particular requirements – Part 22: Static meters for active energy (classes 0,2 S and 0,5 S)	☆☆	**Type tests for static watt-hour meters of accuracy classes 0.2 and 0.5**
IEC 62053-23	Electricity metering equipment (a.c.) – Particular requirements - Part 23: Static meters for reactive energy (classes 2 and 3)	☆☆	**Type tests for static var-hour meters of accuracy classes 2 and 3**
IEC 62054-11	Electricity metering (a.c.) - Tariff and load control - Part 11: Particular requirements for electronic ripple control receivers	☆	**type test of electronic ripple control receivers for the reception and interpretation of pulses**
IEC 62054-21	Electricity metering (a.c.) - Tariff and load control - Part 21: Particular requirements for time switches	☆	**Hardware and protocol specifications for local meter data exchange**
IEC 62056-41	Electricity metering - Data exchange for meter reading, tariff and load control - Part 41: Data exchange using wide area networks: Public switched telephone network (PSTN) with LINK+ protocol	☆	**Data exchange architecture used for communication with large industrial and commercial customer's metering equipment**
IEC 62056-42	Electricity metering - Data exchange for meter reading, tariff and load control - Part 42: Physical layer services and procedures for connection-oriented asynchronous data exchange	☆	**Physical layer services and protocols within the Companion Specification for Energy Metering (COSEM) three-layer connection**
IEC 62056-46	Electricity metering - Data exchange for meter reading, tariff and load control - Part 46: Data link layer using HDLC protocol	☆	**Data link layer for connection-oriented, HDLC-based, asynchronous communication profile**
IEC TS 62056-51	Electricity metering - Data exchange for meter reading, tariff and load control - Part 51: Application layer protocols	☆	**Architectured application layer used for communication with metering equipment**
IEC TS 62056-52	Electricity metering - Data exchange for meter reading, tariff and load control - Part 52: Communication protocols management distribution line message specification (DLMS) serve	☆	**Information specific to the management DLMS server of the protocols described in IEC 62056-31, 62056-41 and 62056-51**
IEC 62058-11	Electricity metering equipment (AC) - Acceptance inspection - Part 11: General acceptance inspection methods	☆	**general acceptance inspection methods which apply to electricity meters**
IEC 62058-21	Electricity metering equipment (AC) - Acceptance inspection - Part 21: Particular	☆	**Particular requirements for acceptance inspection of**

Reference	Title	Importance	Application
	requirements for electromechanical meters for active energy (classes 0,5, 1 and 2)		**electromechanical meters for active energy (classes 0,5, 1 and 2)**
IEC 62058-31	Electricity metering equipment (AC) - Acceptance inspection - Part 31: Particular requirements for static meters for active energy (classes 0,2 S, 0,5 S, 1 and 2)	☆☆	**particular requirements for acceptance inspection of static meters for active energy (classes 0,2 S, 0,5 S, 1 and 2)**
IEC 62068	Electrical insulating materials and systems - General method of evaluation of electrical endurance under repetitive voltage impulses	☆	**Test procedure to evaluate insulation endurance under conditions of repetitive impulses**
IEC TR 61361	Electricity metering - Local and remote data exchange - Applications and performance	☆	**examples of performance requirements for exchange of data between utilities and their customers**
IEC 60410	Sampling plans and procedures for inspection by attributes	☆	**Sampling plans and procedures for inspection by attributes**
IEC 60529	Degree of protection provided by enclosures (IP Code)	☆	**Classification of degrees of protection provided by enclosures for electrical equipment**
IEC TR 62059-11	Electricity metering equipment - Dependability - Part 11: General concepts	☆	**dependability of static metering equipment for measurement and load control**
IEC 62059-41	Electricity metering equipment - Dependability - Part 41: Reliability prediction	☆	**Tool for prediction the failure rate of electricity metering equipment**
IEC 61869-1	Instrument transformers - Part 1: General requirements	☆	**It is applicable to instrument transformers with analogue or digital output**
IEC 61869-2	Instrument transformers - Part 2: Additional requirements for current transformers	☆	**Inductive current transformers for use with electrical measuring instruments and/or electrical protective devices**
IEC 61869-3	Instrument transformers - Part 3: Additional requirements for inductive voltage transformers	☆	**inductive voltage transformers for use with electrical measuring instruments and electrical protective devices**
IEC 61869-4	Instrument transformers - Part 4: Additional requirements for combined transformers	☆	**Combined transformers for use with electrical measuring instruments and electrical protective devices**
IEC 60044-7	Instrument transformers - Part 7: Electronic voltage transformers	☆	**Electronic voltage transformers, for use with electrical measuring**

Reference	Title	Importance	Application
			instruments and electrical protective devices
IEC 60044-8	Instrument transformers - Part 8: Electronic current transformers	☆	**electronic current transformers, for use with electrical measuring instruments and electrical protective devices**