



# **Technical Expert to develop grid connection guidelines and standards for the Kingdom of Bahrain**

*Technical guidelines for Solar PV Systems to be connected in  
parallel with the distribution networks of the Kingdom of  
Bahrain*

Version 2.3

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## CONNECTION STANDARDS

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## CONNECTION STANDARDS

### 1 SCOPE

This document provides a common set of requirements for solar PV (Photovoltaic) generating plants which intend to operate in parallel with the LV & MV distribution networks of the Kingdom of Bahrain. These requirements shall be fulfilled irrespective of the presence of loads in the customer's network. Especially the document defines:

- Requirements for the equipment to be used for the interconnection of a solar PV generating plant with the distribution network,
- Requirements to support the frequency and voltage stability of the power system when it is subject to disturbances,
- Requirements for the start-up, the operation and the disconnection of the solar PV generating plants;
- Requirements to prevent the solar PV generating plants from causing disturbances and damages either to the distribution network and to the other customers connected to the same distribution network;
- Requirements to prevent the solar PV generating plants from operating in parallel with a portion of the distribution network which has been disconnected on purpose from the main power system.

The present document is not incompatible with additional requirements set out by other national & international standards, network codes or specific technical requirements of EWA, and which may apply for the connection of a solar PV generating plant; especially, the document "Regulations for Electrical Installations" [1] is "*applicable to all electrical installations in any premises fed by the Electricity distribution system of the Kingdom of Bahrain*" as set out in [1] itself, where superseding cannot be done to any of its clauses. Some especial requirements for solar PV systems however may request for further necessities than those in [1] for the same topic. Such document still represents the main technical document to refer to for the design of the electrical installation of a new customer or for the modification of the installation of an existing customer. The present standards shall apply only if the installation includes a solar PV generating plant and shall be intended as an extension of [1] only for what concerns the "active" part of the customer's network. For the "passive" part of the customer's network, reference shall be made to [1].

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

- define the process to be followed for the selection and evaluation of the point of connection;
- define the process to be followed for the assessment of the impact of the connecting solar PV generating plant to the power system;
- define the process to be followed for the assessment of a connection application and its compliance with the present standards;
- define technical rules for the islanding operation of isolated networks, 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 already been approved by EWA at the date of publication of the standards.

Finally, even if it is not directly within the scope of the document, the present document intends to stress the fundamental importance and necessity for solar PV generating plants to be built in a workmanlike

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manner, which means the use of products and their assembly in accordance with the international standards commonly used for the planning, design, installation, operation and maintenance of solar PV generating plants. Some of the most relevant documents are listed in **Error! Reference source not found..**

## 2 REFERENCE DOCUMENTS

- [1] Regulations for electrical installations, Ministry of Electricity and Water, Electricity Distribution Directorate, Second edition, 2004
- [2] IEC 62116:2014, Utility-interconnected photovoltaic inverters - Test procedure of islanding prevention measures
- [3] IEC 61000-3-2:2014 Electromagnetic compatibility (EMC) – Part 3-2: Limits – Limits for harmonic current emissions (equipment input current  $\leq 16$  A per phase)
- [4] 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  $\leq 75$  A per phase
- [5] Bahrain Grid Code, Electricity and Water Authority, Kingdom of Bahrain, November 2011
- [6] IEC/TR 61000-3-15: 2009, Assessment of low frequency electromagnetic immunity and emission requirements for dispersed generation systems in LV network

## 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 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.

**Delay time (of a protection relay)** – Indicates the minimum duration of a fault detected by the protection relay before the output of the protection relay is triggered.

**Distribution system / network** - Is the medium or low voltage electricity grid for supplying electricity to the end consumers; for the scope of the present document and in accordance with international standards:

- A Low Voltage (LV) network is a distribution network with nominal voltage lower than 1kV AC or 1.5 kV DC. The LV network nominal voltage of the Kingdom of Bahrain is 400/230V.
- A Medium Voltage (MV) network is a network with nominal voltage included in the range from 1kV AC (1.5 kV DC) up to 35 kV. The MV network nominal voltage of the Kingdom of Bahrain is 11kV.

**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.

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**Islanding** - Situation where a portion of the distribution network, containing generating plants, becomes physically disconnected from the rest of the distribution network and one or more generating plants maintain a supply of electrical energy to such isolated part of the distribution network.

**Loss Of Mains (LOM)** – Represents an operating conditions in which a distribution network, or part of it, is on purpose 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 the solar PV generating plant and which measures the total energy produced from the solar PV generating units.

**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.

**Rated active power** – Represents the sum of the nominal active power of all the generating units which compose the generating plant; it is generally referred as  $P_n$ .

**Reactive power capability** – Defines the reserves of inductive/capacitive reactive power which can be provided by a generating plant/unit. The reactive power capability usually varies with the active power and the voltage of the generating plant/unit.

**Reactive Power** - Represents the imaginary component of the apparent power, usually expressed in kilovar (kVAr) or Megavar (MVAR).

**ROCOF** – Rate of change of frequency usually expressed in Hz/s.

**Switch** – Mechanical 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.

**THD** – with reference to an alternating quantity, it represents the ratio of the r.m.s. value of the harmonic content to the r.m.s. value of the fundamental component or the reference fundamental component.

**Voltage** - Unless stated otherwise, voltage refers to the root-mean-square value of phase-to-phase voltages.

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### 4 TECHNICAL REQUIREMENTS FOR THE CONNECTION IN PARALLEL TO THE DISTRIBUTION NETWORKS

#### 4.1 General requirements

A solar PV generating plants shall be connected to the network at an appropriate point, called the POC. It is the responsibility of EWA to design a suitable 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 a safe and secure operation of the network for all operating conditions.

If the results of such process put in evidence that the connecting solar PV generating plant is likely to cause the network to possibly operate outside of EWA statutory performance standards, EWA has the right to turn down the connection application or to propose modifications (for example in terms of POC and/or characteristics of the solar PV generating plant) or alternative solutions (for example in terms of network reinforcements) to enable the connection.

With reference to the requirements defined in the present document and the possibility that different requirements may interfere with each other, the protection and control devices of a solar PV generating plant shall be organized in accordance with the following priority ranking (from highest to lowest):

1. Protection of the generating units;
2. Protection of the network (interface protection and protection against faults within the customer's network);
3. Remote disconnection;
4. Active power response to frequency variations;
5. Remote limitation of active power;
6. Remote reactive power control modes;
7. Local reactive power control modes.

#### 4.2 Connection scheme

A solar PV generating plant shall be in compliance with the connection requirements of EWA; 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 shall be coordinated with the network protection schemes and settings; they shall therefore be agreed between EWA and the solar PV generating plant owner with the following scope:
  - faults and malfunctions within the solar PV generating plant shall not impair the normal operation of the distribution network,
  - the protection schemes and settings for internal electrical faults must not jeopardize the performances of the solar PV generating plant;
  - the protection schemes of the solar PV 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.

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In order to satisfy the above requirements, Figure 1 presents the typical equipment which shall be at least installed for a safe and reliable interconnection of the solar PV generating plant with the distribution network:

- The main switch shall be installed as close as possible to the POC and shall be commanded by a protection system against internal faults<sup>1</sup>; the main switch is also used for the disconnection of the customer's network from the distribution network; it is possible to install up to two main switches in order, for example, to have two separate circuits, one dedicated to the customer's loads and one dedicated to the solar PV generating plant.
- The interface switch shall be installed in the customer's network to separate from the distribution network the part(s) of the customer's network containing at least one solar PV generating unit; for a solar PV generating plant with a rated active power greater than 11kW, unless explicitly agreed by EWA, only one interface switch shall be used (see also §4.7.4).
- The unit switch shall be installed as electrically close as possible to the terminals of each solar PV generating unit of the generating plant, for the protection and the disconnection of that generating unit.

ANNEX A presents typical connection schemes which can be adopted for the connection of a solar PV generating plant to EWA distribution networks. Different arrangements may be used if previously agreed with EWA.

For each of the above mentioned equipment, the choice of the type of switch to be installed (power relays, contactors or mechanical circuit breakers, ...) shall be based on:

- the functions the switch shall carry out,
- the characteristics of the customer's network.

Especially, the following criteria shall be adopted:

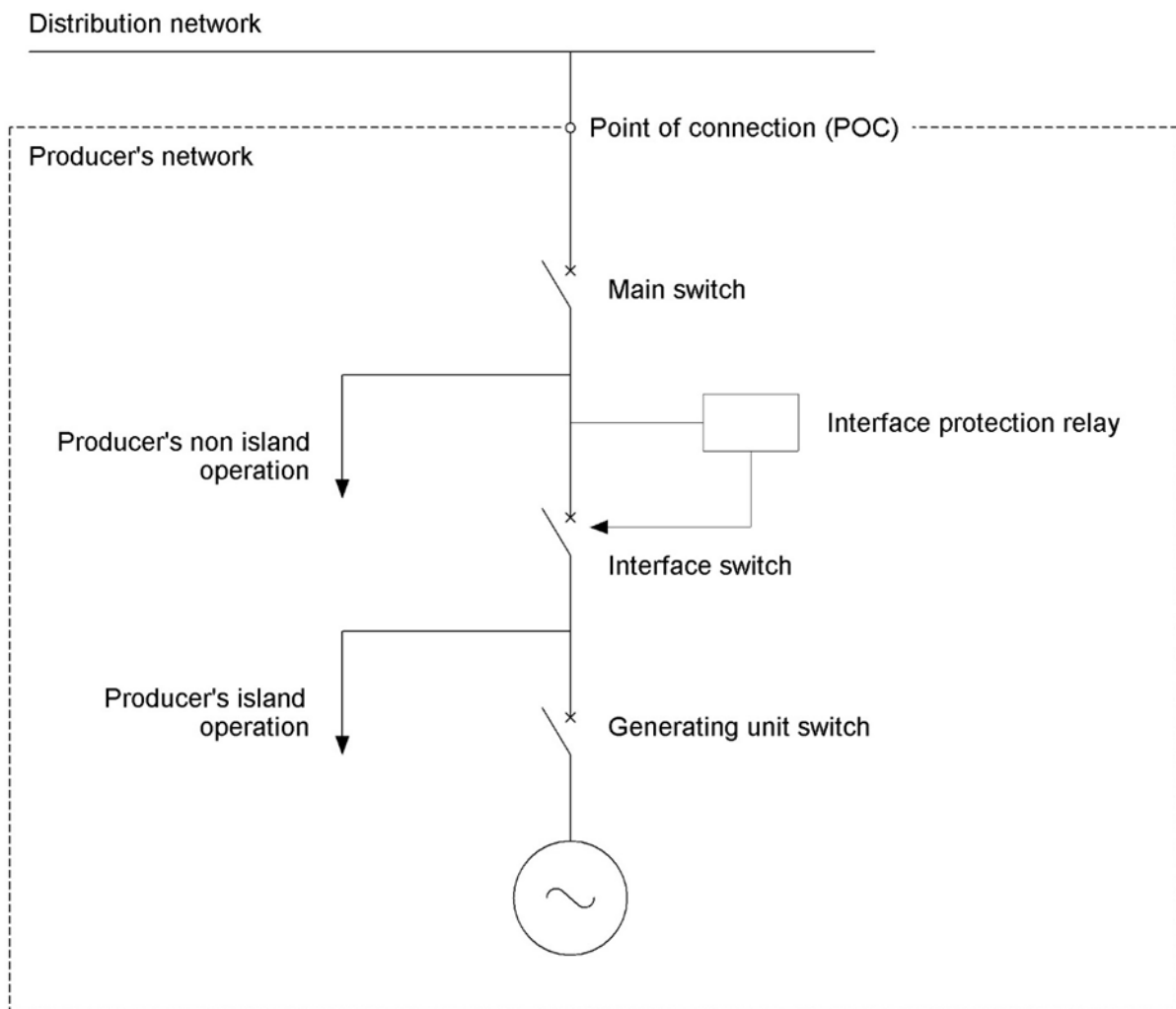
- the main switch shall be compliant with the requirements of [1]<sup>2</sup>,
- the switch(es) of the generating unit(s) shall be compliant with the manufacturer's requirements,
- Electronic switches shall not be used for protective functions.
- For solar PV generating plants connected to the MV distribution network and with the interface switch on the MV side of the plant (Figure 8), 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 plants connected to the MV distribution network and with the interface switch on the LV side of the plant or for solar PV generating plants connected to the LV distribution network, the interface switch shall consist of:
  - automatic circuit breaker or switch disconnecter operated by an undervoltage release, or
  - omnipolar AC<sub>3</sub> contactor.

<sup>1</sup> For the definition of the requirements of the protection system against faults within the customers' network, please refer to [1]

<sup>2</sup> With particular reference to section 5 "EXCESS CURRENT PROTECTION"

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- any switch shall have a breaking and making capacity coordinated with the rated values of the customer's network, taking into consideration both the generating plant and the passive loads.
- the short-time withstand current of the switching devices shall be coordinated with the maximum short circuit power at the POC<sup>3</sup>.
- In case of loss of auxiliary supply power to the switchgear, a secure disconnection of the switch is required immediately.



**Figure 1: Schematic representation of the interconnection of a solar PV generating plant with the distribution network of the Kingdom of Bahrain**

<sup>3</sup> Information about the maximum prospective short-circuit level of the Bahraini distribution networks are reported in the regulation Nr 303 of [1].



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The function of the interface switch might be combined with either the main switch or the generator switch in a single switching device<sup>4</sup>. In case of a combination, the single switching device shall be compliant with 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 a solar PV generating unit and the POC.

### 4.3 Normal 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 47,5Hz to 52,5Hz.
- when the voltage at the POC stays within the range 90% to 110% of the rated voltage.

### 4.4 Immunity to disturbances

#### 4.4.1 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 secure faults on the higher voltage level networks. The requirements below apply to all kind of disturbances (1ph, 2ph and 3ph) and are independent of the interface protection settings (see § 4.7.4) which overrule the technical capabilities of a generating plant.

A solar PV generating plant with a rated active power greater than 11kW 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 2. The p.u. voltage shall be calculated with respect to the nominal voltage at POC. For three-phase generating plants, the smallest phase to phase voltage shall be evaluated. The compliance to such LVRT requirement shall apply to all equipment that might cause the disconnection of the solar PV generating plant.

After the fault is cleared and the voltage returned within the voltage normal operating range, the pre-disturbance operating conditions (active & reactive power) shall be recovered as fast as possible and with a tolerance of  $\pm 10\%$  of the solar PV generating plant rated power.

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<sup>4</sup> For connection schemes using a single main switch, the combination of the interface switch with the main switch 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, if any.

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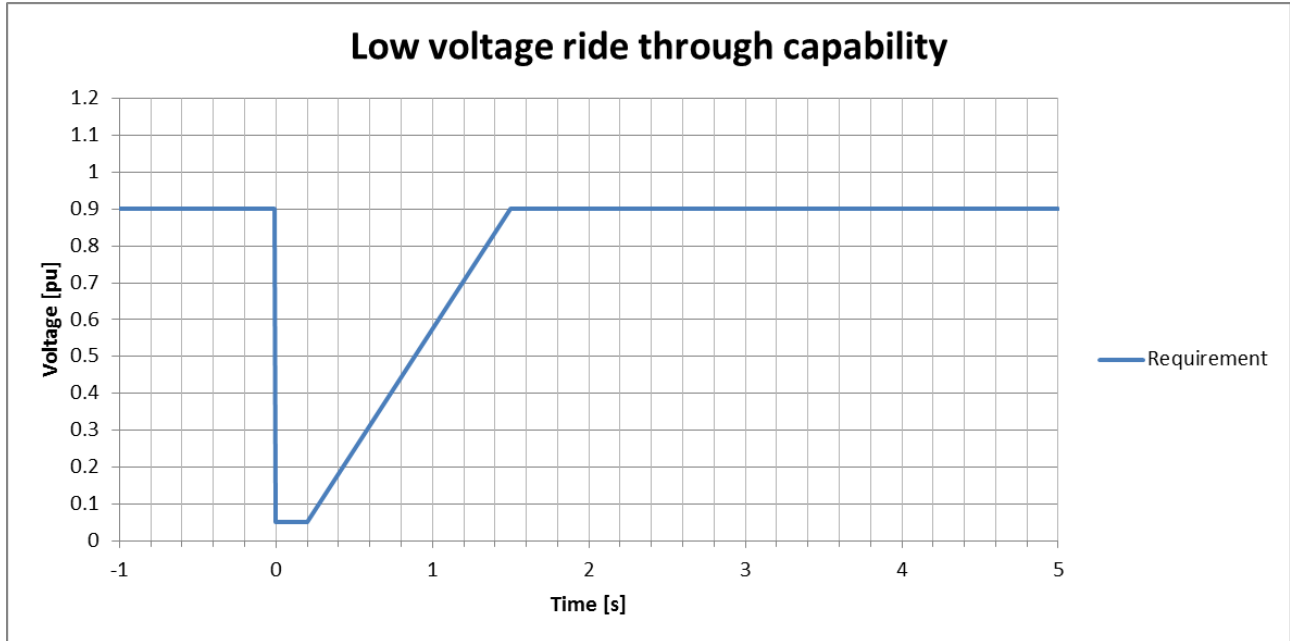


Figure 2: LVRT characteristic for solar PV generating plant > 11kW

### 4.4.2 ROCOF withstand capability

Solar PV generating plants, when generating power, shall be able to go through frequency transients with frequency within the frequency normal operating range (§4.3) and with ROCOF value up to 2 Hz/s.

## 4.5 Requirements for the frequency stability of the power system

### 4.5.1 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 3<sup>5</sup>, with frequency threshold and droop settings adjustable and to be specified by EWA;

- the frequency threshold shall be settable at least between 50 Hz and 52 Hz inclusive; if not explicitly specified by EWA, the threshold shall be set to 50,3Hz;
- the droop settings shall be between 2% and 12%; if not explicitly specified by EWA, the droop shall be set to 4,4%;
- the pu active power shall be referred to the actual active power value when the threshold is reached and the active power response is activated.

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

<sup>5</sup> In the figure, the power 1 p.u. refers to the actual output power at the time the frequency threshold is reached.

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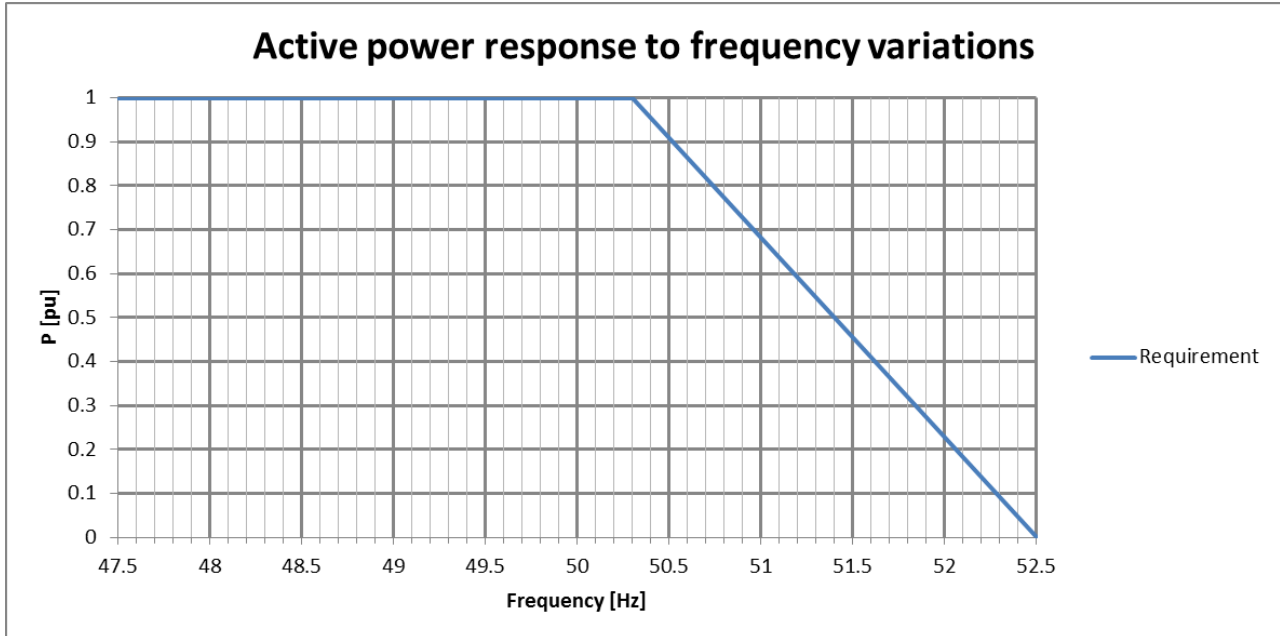


Figure 3: active power frequency response for solar PV generating plant

### 4.5.2 Active power delivery at under-frequencies

A solar PV generating plant shall be resilient to reductions of frequency at the POC, limiting as low as possible the reduction of its maximum active power due to under-frequency operating conditions.

### 4.5.3 Remote limitation of active power

A solar PV generating plant with a rated active power greater than or equal to 11kW shall be equipped with an interface (input port) which is able to receive, from a remote control center, an instruction requiring the reduction of the active power output.

The reduction of active power shall be carried out as fast as possible and with an accuracy greater than 5% of  $P_n$ .

In accordance with the provisions set forth in §4.7.5, EWA 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.

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4.6 Requirements for the voltage stability of the power system

4.6.1 Reactive power capability

When voltage and frequency at POC are within their normal operating ranges, a solar PV generating plant shall be able to provide reactive power in any operating point within the boundaries of the reactive power capability defined in Figure 4<sup>6</sup>.

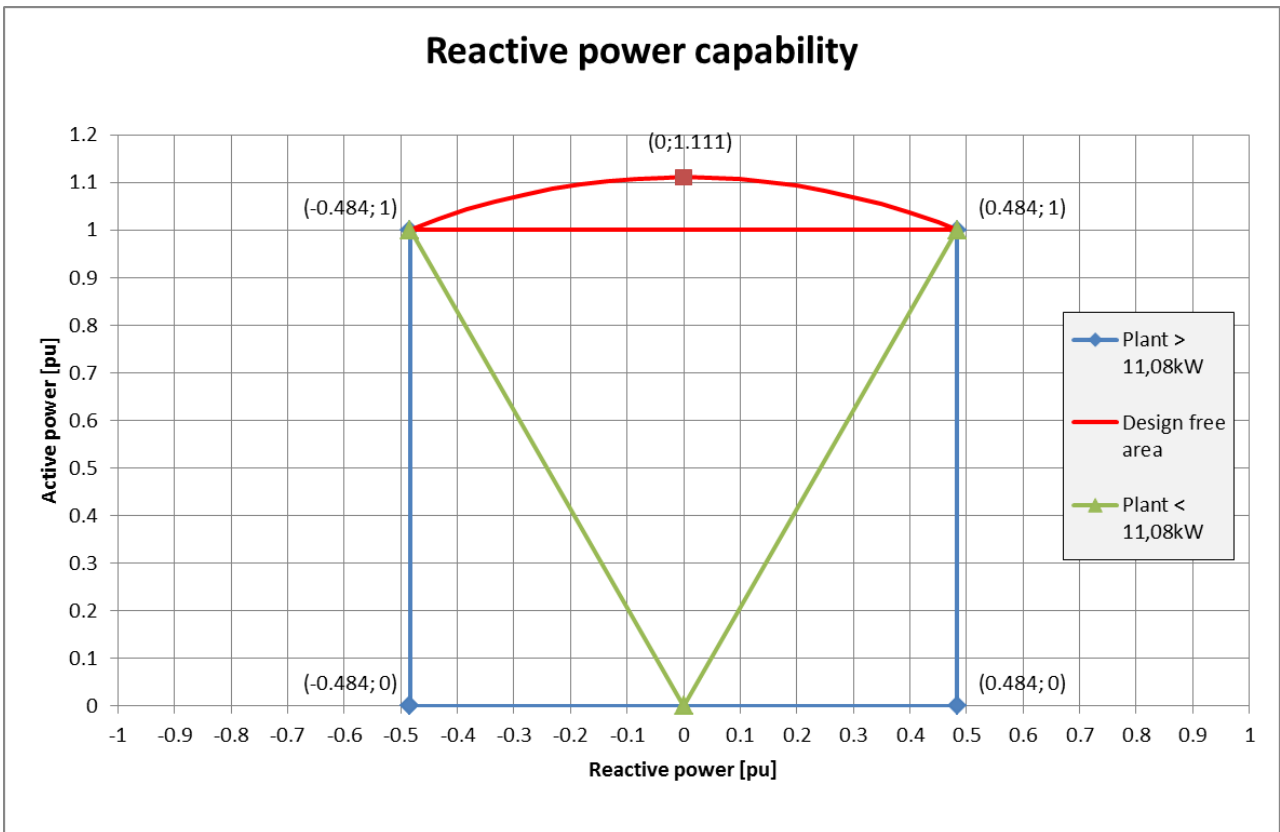


Figure 4: Reactive power capability

With reference to Figure 4, 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  $S_n$ , the required reactive power shall be provided with an accuracy of  $\pm 2\% S_n$ . Below the threshold of 10% of  $S_n$ , deviations above 2% of accuracy are permissible; nevertheless the accuracy shall always be as good as technically feasible and shall not exceed 10% of  $S_n$ .

<sup>6</sup> The active power 1 p.u. shall refer to the rated active power value of the solar PV generating plant: at 1 p.u. of active power, the reactive power capability of a solar PV generating plant corresponds to a power factor varying between 0,9 leading to 0,9 lagging.

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### 4.6.2 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:

- fixed Q: the reactive power is controlled in order to have a fixed value ;
- fixed  $\cos \varphi$ : the reactive power is controlled in order to have a fixed power factor;
- $\cos \varphi$  (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.

#### 4.6.2.1 Fixed control modes

When operated with fixed Q or fixed  $\cos \varphi$  control mode, the solar PV generating unit shall control the reactive power or the  $\cos \varphi$  of its output according to a set point set in the control system of the solar PV generating plant.

For a solar PV generating plant with a rated active power greater than or equal to 11kW, the solar PV generating plant shall also be able to receive the set-point from a remote control center in accordance with the provisions set forth in §4.7.5.

#### 4.6.2.2 Power related control mode

The power related control mode  $\cos \varphi$  (P) controls the  $\cos \varphi$  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 5 shall be configurable within the control systems of the solar PV generating plant; a change in active power output results in a new  $\cos \varphi$  set point according to the characteristic.

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

- A       $P = 0 P_n$        $\cos \varphi = 1$
- B       $P = 0,5 P_n$        $\cos \varphi = 1$
- C       $P = P_n$        $\cos \varphi = 0.9$  (with the solar PV generating plant absorbing reactive power)

The response to a new  $\cos \varphi$  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 the requirements of §4.6.1.

The implementation of a lock-in and lock-out voltage level shall be configurable, each in the range 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 not activated, the solar PV generating plant shall be controlled with a unit power factor.

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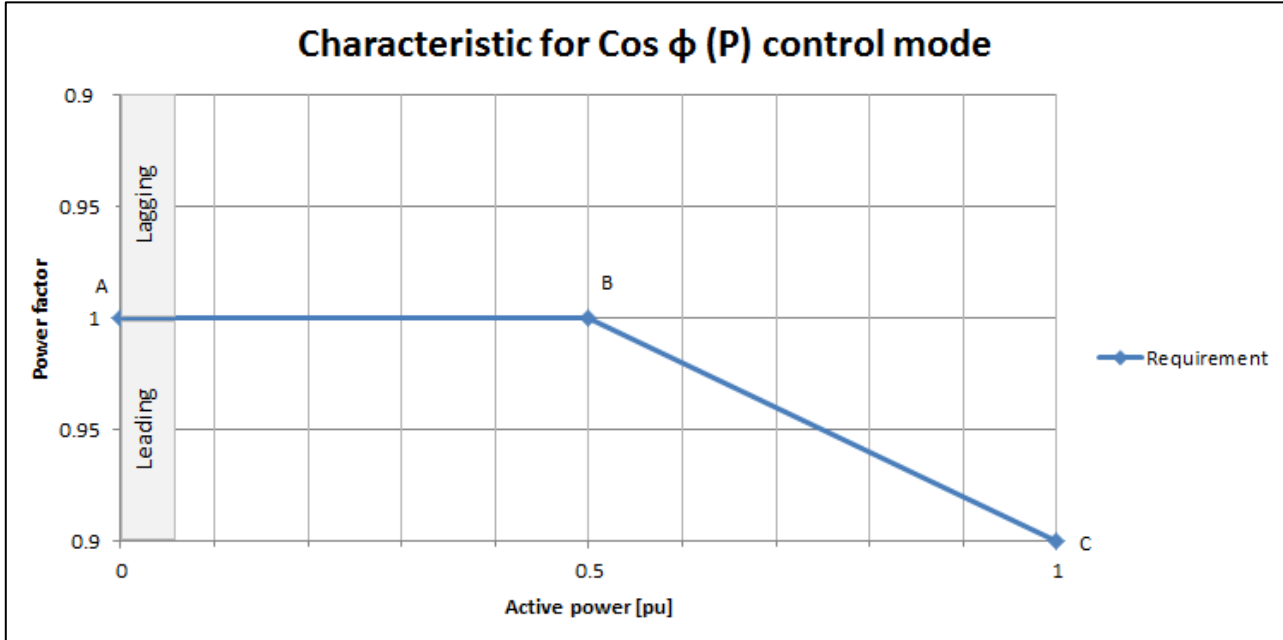


Figure 5: Characteristic for Cos φ (P) control mode

### 4.6.3 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 power) as a function of the rising voltage at POC. The implemented logic can be chosen by the manufacturer/customer. Nevertheless, the implemented logic shall not cause steps or oscillations in the power output.

### 4.6.4 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 power system of the Kingdom of Bahrain.

## 4.7 Requirements for the management of the power system

### 4.7.1 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  $47,5 \text{ Hz} \leq f \leq 50,05 \text{ Hz}$ ;
- Voltage range  $94\% U_c \leq U \leq 106\% U_c$ ;
- Minimum observation time 180s.

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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<sup>7</sup>.

The synchronization 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 §4.5.1, 4.5.3 and 4.6.3).

### 4.7.2 Remote disconnection

A solar PV generating plant with a rated active power greater than or equal to 11kW shall be equipped with a logic interface (input port) in order to disconnect from the network following an instruction received at its interface.

In accordance with the provisions set forth in §4.7.5, EWA 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 network.

### 4.7.3 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  $47,5 \text{ Hz} \leq f \leq 50,05 \text{ Hz}$ ;
- Voltage range  $94\% U_c \leq U \leq 106\% U_c$ ;
- 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.

### 4.7.4 Interface Protection

The purpose of the interface protection is to:

- disconnect the solar PV generating plant from the distribution network in the following cases
  - EWA switches off the distribution network (or the feeder) the generating plant is connected to (i.e. to prevent unintentional islanding);
  - Voltage or frequency transients of the power system out of the normal operating ranges as defined in §4.3.
- prevent the solar PV generating plant, when generating power, to cause overvoltages in the distribution network it is connected to;

<sup>7</sup>It means that the switch used for the synchronisation with the network cannot be a manual switch.

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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]<sup>8</sup>;
- 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 §4.4 (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 11kW, it is permitted to integrate the interface protection into the solar PV generating units.

The interface protection shall command the interface switch; for a solar PV generating plant with a rated active power greater than 11kW, unless explicitly agreed by EWA, only one interface protection and one interface switch shall be used for a solar PV generating plant.

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<sup>9</sup>. When the back-up switch is triggered because the interface switch had failed to open, only manual reclosure shall be possible<sup>10</sup>.

For a solar PV generating plant with a rated active power greater than 11kW, the power supply of the interface protection shall include an uninterruptible power supply.

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 adjustable by steps of 5%, and delay time in the range [0,1s;100s] adjustable in steps of 0,1s;
  - One threshold [27<<] in the range [0%; 100%] of the POC nominal voltage adjustable by steps of 5%, and delay time in the range [0,1s;5s] adjustable in steps of 0,05s.
- Overvoltage [59]

<sup>8</sup> Especially Section 5 "EXCESS CURRENT PROTECTION"

<sup>9</sup> 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.

<sup>10</sup> The reasons are that it is required that the plant operator first acknowledges and checks the reasons why the interface switch failed to open, then remedies the technical issues and finally resumes operation.



## CONNECTION STANDARDS

- One threshold [59>] in the range [100%; 120%] of the POC nominal voltage 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 adjustable by steps of 1%, and delay time in the range [0,1s;5s] adjustable in steps of 0,05s.
- Overfrequency [81>]
  - One threshold [81>] in the range [50Hz; 53Hz] adjustable by steps of 0,1Hz, and delay time in the range [0,1s;100s] adjustable in steps of 0,1s;
  - One threshold [81>>] in the range [50Hz; 53Hz] adjustable by steps of 0,1Hz, and delay time in the range [0,1s;5s] adjustable in steps of 0,05s;
- Underfrequency [81<]
  - One threshold [81<] in the range [47Hz; 50Hz] adjustable by steps of 0,1Hz, and delay time in the range [0,1s;100s] adjustable in steps of 0,1s;
  - One threshold [81<<] in the range [47Hz; 50Hz] 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 document 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 [2] (or other equivalent standards) which provides procedures to evaluate the performance of islanding prevention measures used with utility-interconnected PV systems.

The LOM protection functions shall 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 at least one solar PV generating unit, whereas the protection functions for underfrequency [81<] and overfrequency [81>] shall be fed by at least one line voltage.

EWA 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 the faulty feeder), there could not be any reclosure of the network switch before all the solar PV generating plants have been disconnected.

ANNEX B proposes default settings for the different protection functions. Such settings shall be actually applied in the IP of a solar PV generating plant only in case no settings have been explicitly specified and communicated by EWA.

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The interface protection shall have at least two configurable digital inputs which may be used in the future<sup>11</sup> by EWA for transfer trip, remote tripping or any other function that may be necessary to increase the capacity of the distribution networks to host distributed generation while keeping an acceptable level of reliability.

### **4.7.5 Monitoring, remote control and information exchange**

Adequate information concerning the customers connected to the distribution networks is a prerequisite for enabling EWA to maintain the stability and security of its networks. EWA needs to have a continuous overview of the state of its network, which may require, in some cases, updated information on the operating conditions of the solar PV generating plants connected to its distribution networks as well as the possibility to communicate with these plants in order to direct the operational instructions set forth by the provisions of the present document.

Such requirements are usually needed in case of growing penetration level of the solar PV generating plants in the distribution networks; they may also be introduced in the framework of other initiatives dedicated, for example, to the optimization of the control performances of the network.

A solar PV generating plant with a rated capacity greater than 11kW<sup>12</sup> shall therefore be equipped with a bi-directional communication interface which can be used for the exchange of information with EWA. Once actually needed for the operation of the network, in accordance with a cost/benefit approach, EWA shall have the right to specify additional requirements concerning especially:

- Data, which shall be collected and sent to EWA in real-time or periodically, related to the operating conditions of the solar PV generating plant;
- Operational instruction sent by EWA which shall be executed by the solar PV generating plant; such instructions shall be compliant with the requirements indicated in the present standards (especially the requirements of §4.5.3 and §4.7.2);
- Communications channels and protocols to be used for the above requirements.

If technically possible, EWA may take advantage of already existing communication channels, such as smart metering infrastructure, in order to facilitate the integration of the monitoring activities into its ICT architecture and reduce the costs of implementation.

### **4.7.6 Power quality**

#### **4.7.6.1 Voltage deviation**

Under normal operating conditions, the connection and operation of a solar PV generating plant shall not cause the voltage at its POC and at the POC of any other customer connected to the same distribution network, to vary from the system rated voltage by more than  $\pm 6\%$ .

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<sup>11</sup> In a scenario of growing penetration level of distributed generation in the distribution networks of the Kingdom of Bahrain

## CONNECTION STANDARDS

### 4.7.6.2 Rapid voltage changes

Connection and disconnection of a solar PV generating plant from the distribution networks shall not give rise to voltage variations exceeding 3% of the system rated voltage at the POC.

### 4.7.6.3 Harmonics and inter-harmonics

Voltage harmonics and inter-harmonics at the POC of a solar PV generating plant shall not exceed the limits specified below.

Voltage level (Volts)	Total harmonic voltage distortion (%)	Individual harmonic voltage distortion (%)	
		Odd	Even
400/230	5	4 for $n < 14$ 1.5 for $n \geq 14$	2
11000 V	4	3	1.75

Moreover, the customer shall be required to make provision for the possible future installation of compensating apparatus if the solar PV generating plant generates

- odd harmonics exceeding 1% voltage distortion or
- even harmonics exceeding 0.6%, or
- the contribution of the solar PV generating plant to the THD at the POC exceeds 1.6%.

For a solar PV generating plant connected to an LV distribution network, it is commonly accepted [6] that the above mentioned requirements concerning the voltage harmonics are fulfilled if the harmonic current emissions of the solar PV generating plant don't exceed the following limits:

- for generating plants with a rated active power below 600W, the limits defined in the standard IEC 61000-3-2 [3], Class C (lighting) equipment, shall apply;
- for power plant with a rated active power greater than 600W, the limits defined in the standard IEC 61000-3-12 [4], Table 2,  $R_{sce} = 33$ , shall apply.

### 4.7.6.4 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.

The single solar PV generating plant shall be equipped with a DC fault detection system which disconnects the faulty unit when the above limit is exceeded. A valid alternative to such system is the use of an AC/AC transformer which prevents from any DC injection into the network.

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### 4.7.6.5 Clusters of single-phase generating units

The use of three-phase equipment is required. In accordance with [1]<sup>13</sup>, it is anyway allowed for a solar PV generating plant with a rated active power lower than 20kW to be composed of one or more single-phase generating units. In such case, if the supply from EWA is a three-phase service and if multiple single-phase units are used, the single-phase generating units shall be equally distributed over the three phases in order to limit the overall imbalance of current between the phases<sup>14</sup>.

## 4.8 Metering

Dedicated metering systems are required for solar PV generating plants.

As a general rule, the metering positions and the meters used for metering solar PV generating plants shall be in accordance with section 4 of [1].

In partial derogation from regulation Nr 401 of [1], a customer with a solar PV generating plant shall have two metering positions:

- A net-metering position where the main electricity meter is installed,
- A solar PV production metering position where the PV electricity meter is installed.

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

In derogation from regulation Nr 418 of [1], the PV electricity meter can be installed within the customer's premises; in such case, the PV electricity meter shall have remote meter reading capability.

## 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 EWA 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 EWA with all the documents, studies and measurements useful to demonstrate the compliance of the solar PV generating plant to the requirements defined in the present standards.

If deemed necessary, EWA shall have the right to request the customer to carry out additional tests or studies with the scope to demonstrate the compliance of the solar PV generating plant with the provisions of the present document. Such activities may be requested 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 the present standards.

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<sup>13</sup> Especially, rule nr 404 of [1]

<sup>14</sup> If feasible, a maximum imbalance of 16A between the phases is recommended.

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## CONNECTION STANDARDS

When studies are required, EWA shall provide the customer with all the technical data of the network necessary to carry out the studies.

## CONNECTION STANDARDS

### ANNEX A. CONNECTION SCHEMES

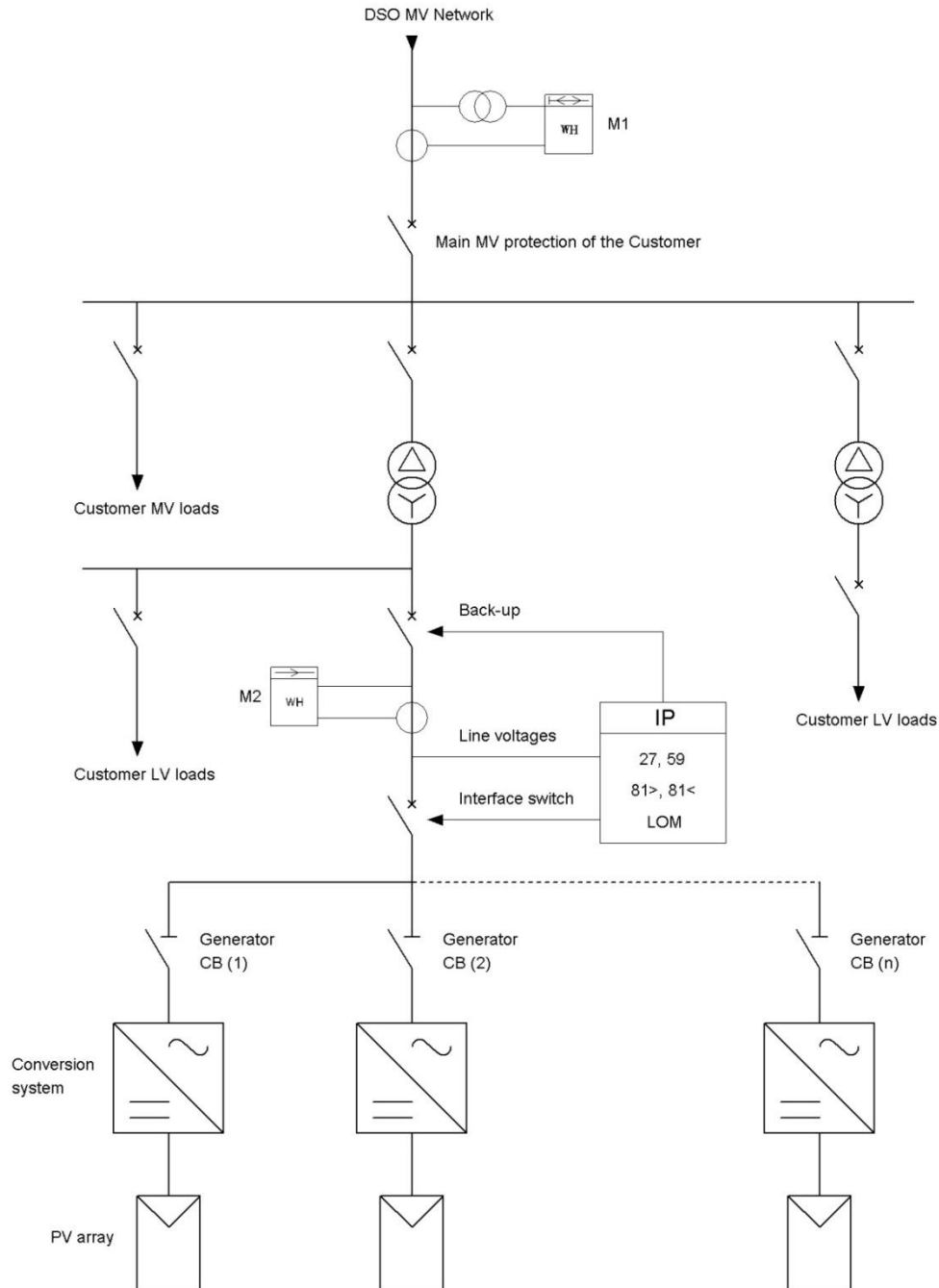
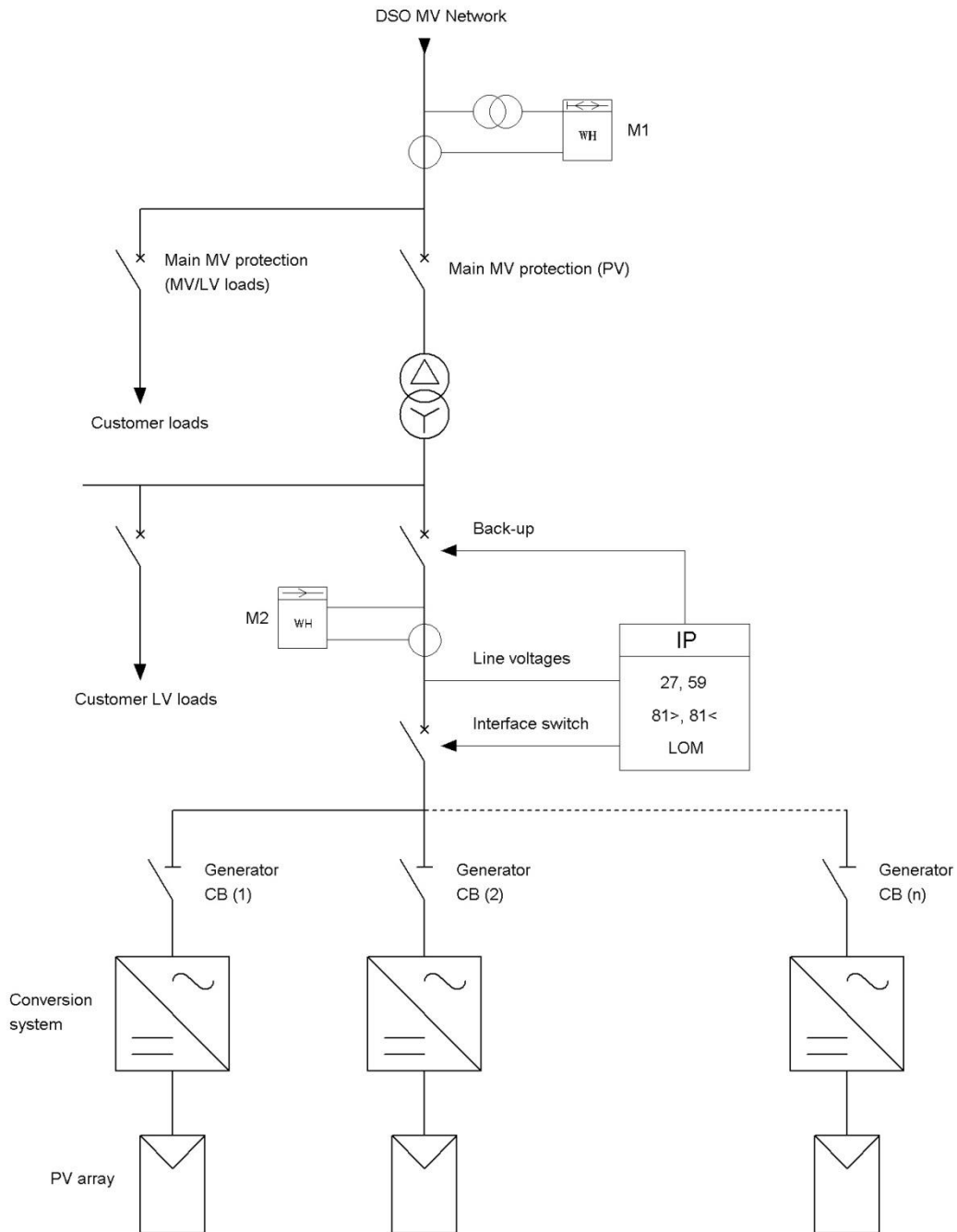


Figure 6: MV connection scheme – Interface switch on LV side

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**Figure 7: MV connection scheme – Two main switches**

## CONNECTION STANDARDS

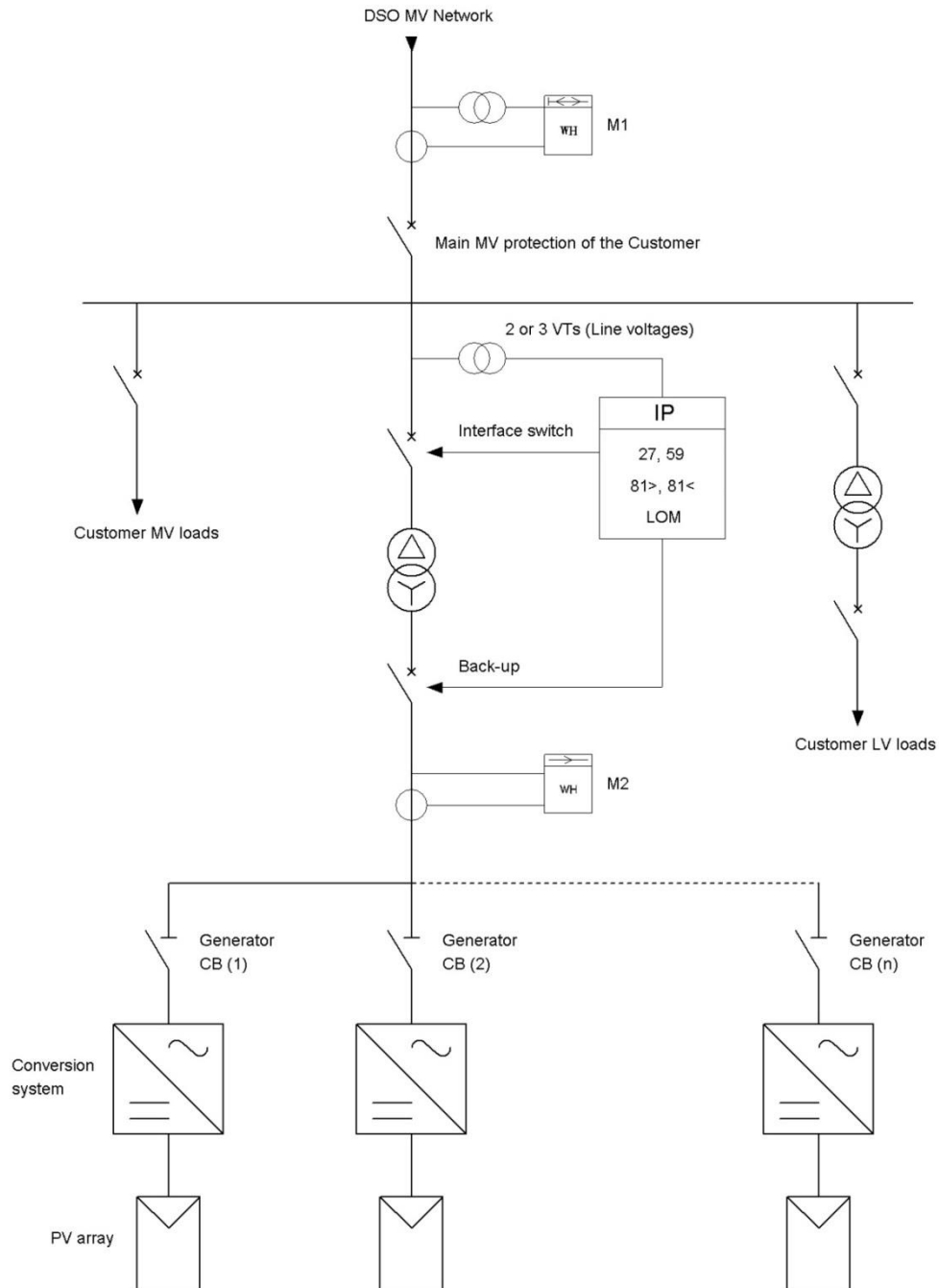


Figure 8: MV connection scheme – Interface Switch on MV side



## CONNECTION STANDARDS

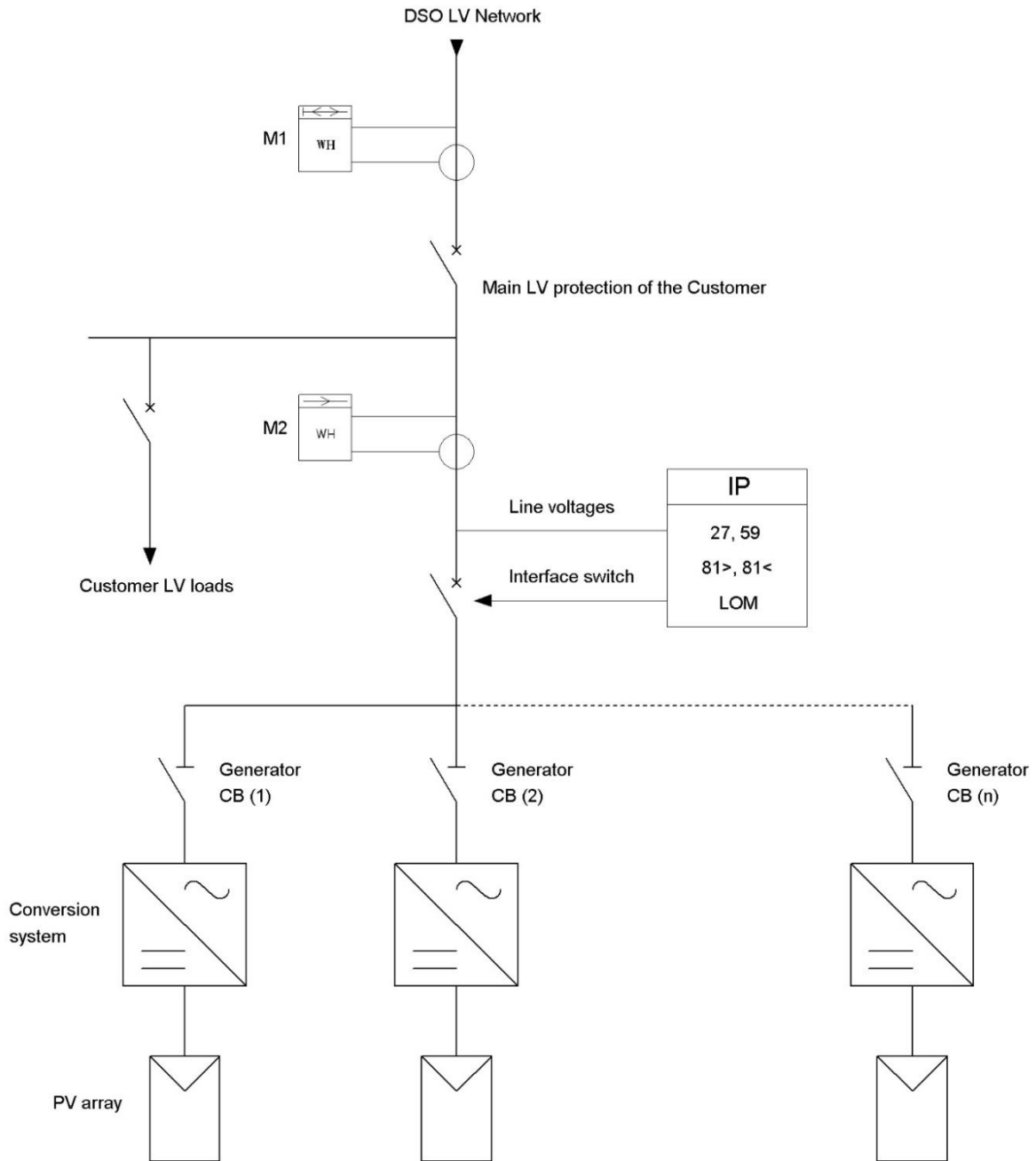


Figure 9: LV Connection Scheme

## CONNECTION STANDARDS

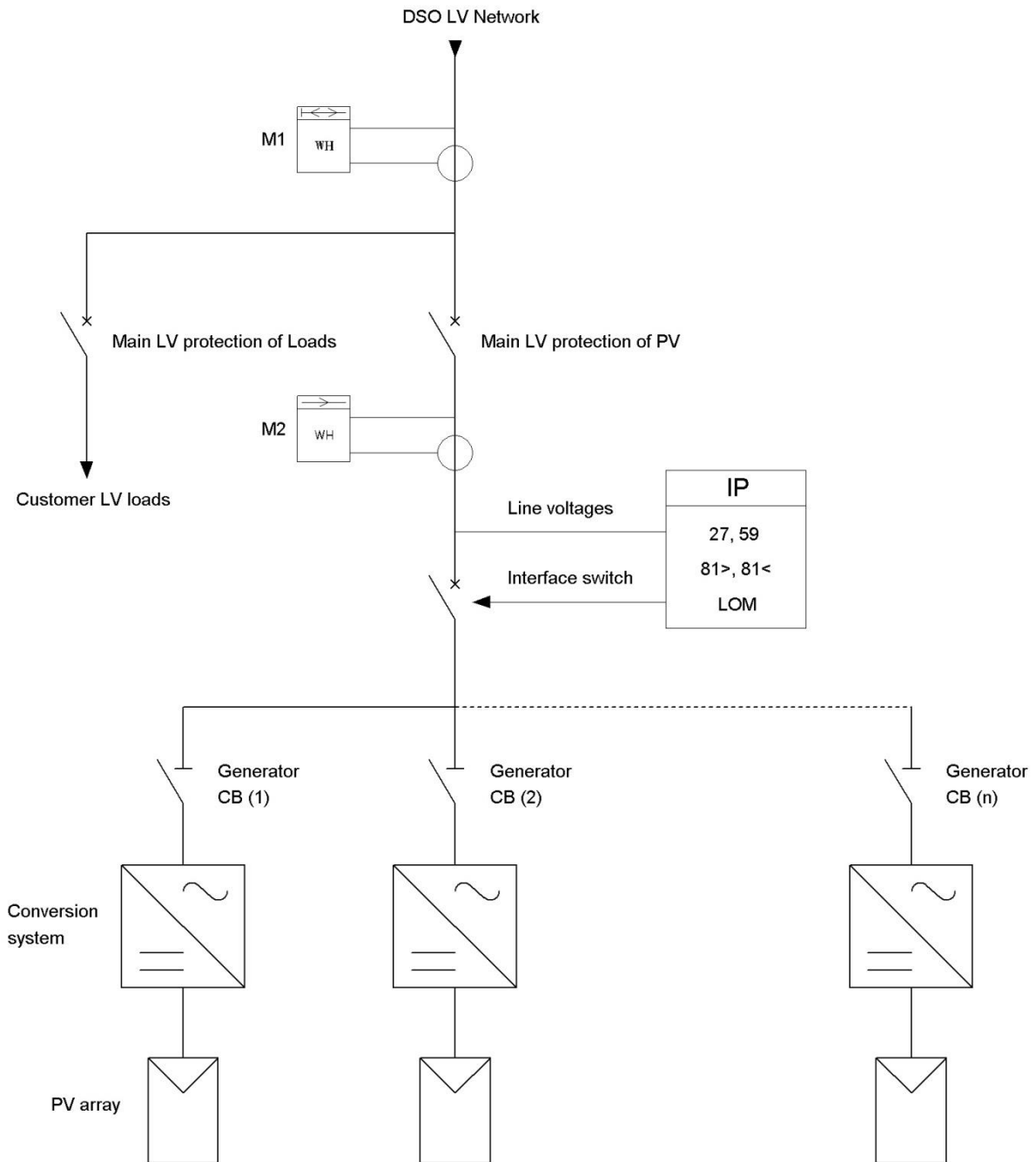


Figure 10: LV connection scheme – Two main switches

## CONNECTION STANDARDS

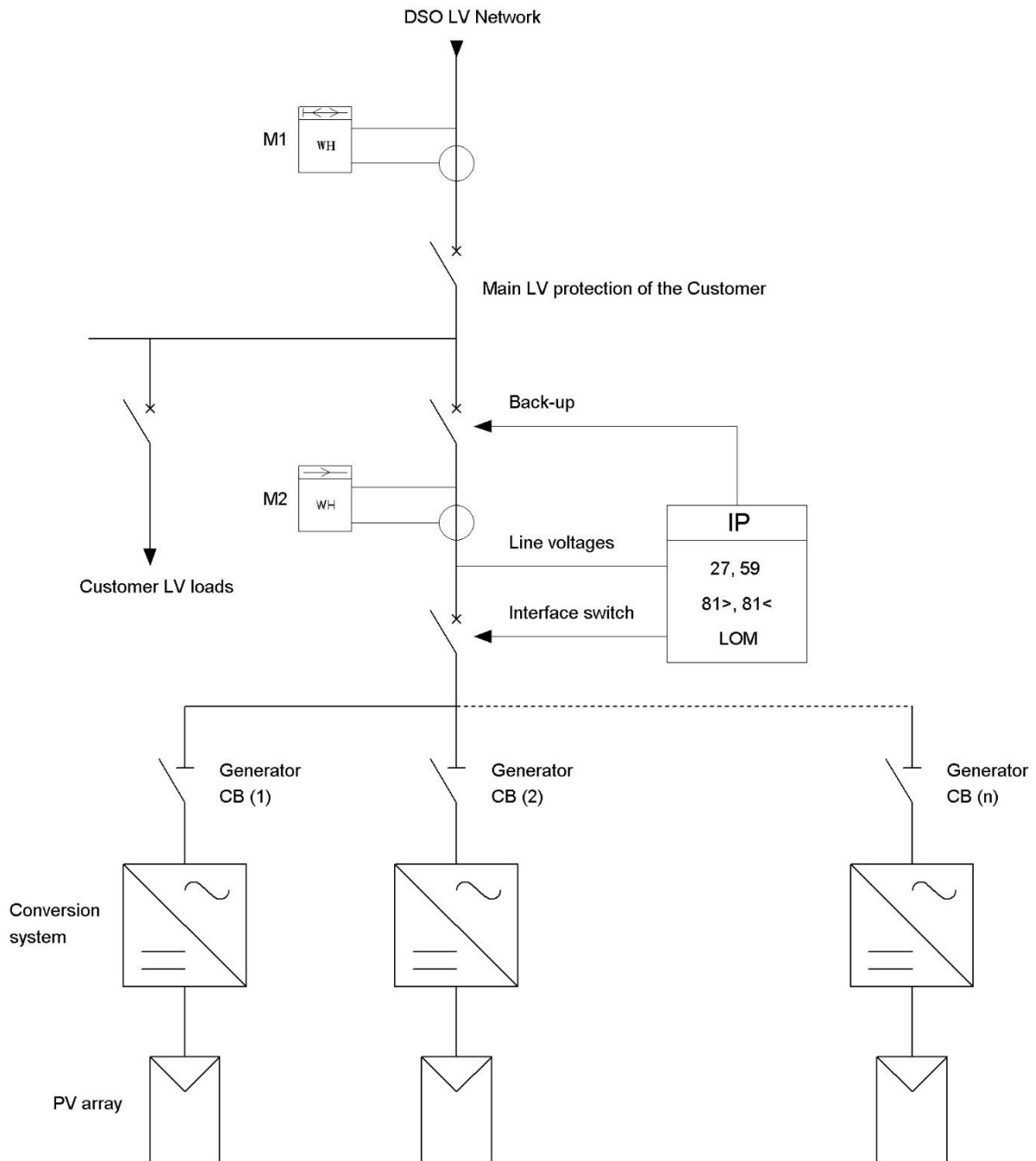


Figure 11: LV connection scheme with back-up

## CONNECTION STANDARDS

### ANNEX B. DEFAULT SETTINGS OF INTERFACE PROTECTION

The following table report the default settings to be implemented in the interface protection of solar PV generating plants when no other settings have been communicated by EWA.

Protection function	Settings	
	Threshold	Time delay
27<	90%	1.5 s
27<<	40%	0.2 s
59>	110%	1.5 s
59>>	120%	0.2 s
81>>	52.5 Hz	5 s
81<	47.5 Hz	10 s
81<<	46.5 Hz	0.1 s

Figure 12: Default settings for the protection functions of the IP