STANDARD OPERATIONAL PROCEDURES FOR SOLAR PARKS

VOL. III
OPERATION AND MAINTENANCE MANUAL FOR SOLAR PARKS

THE EUROPEAN UNION'S FOREIGN POLICY INSTRUMENTS (FPI) PROGRAMME FOR INDIA

GOVERNMENT OF INDIA
MINISTRY OF NEW AND RENEWABLE ENERGY

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This project is funded by the European Union

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“Standard operational procedures for solar parks” is a technical brochure developed by the consortium IBF International Consulting, EQO-NIXUS (OCA Global) and IDOM.

This publication was produced with the financial support of the European Union. Its contents are the sole responsibility of the consortium IBF International Consulting, EQO-NIXUS (OCA Global) and IDOM and do not necessarily reflect the views of the European Union.

IBF International Consulting, EQO-NIXUS (OCA Global) and IDOM

VOL. III

Operation and maintenance manual for solar parks

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List of acronyms

AJB	Array Junction Box
CCTV	Closed Circuit Television
DC	Direct Current
IEEE	Institute of Electrical and Electronic Engineers
IEGC	Indian Electricity Grid Code
LBB	Local breaker Back-up
LOM	Loss of Mains protection.
LV	Low Voltage
MNRE	Ministry of New and Renewable Energy
MV	Medium Voltage
PV	Photovoltaic Plant
O&M	Operation and Maintenance
QCA	Qualified Coordinating Agency
RLDC	Regional Load Dispatch Centre
SECI	Solar Energy Corporation of India
SPD	Solar Project Developer
SLDC	State Load Dispatch Centre
SPPD	Solar Power Park Developer
RPC	Regional Power Committee
PPE	Personal Protective Equipment
PR	Performance Ratio

Definitions

CTU	Central Transmission Utility
ETDA	External transmission development agency. It is the entity under the MNRE mode 7 responsible do design and implement the electrical transmission infrastructure of the solar park.
IEGC	Indian Electricity Grid Code specified by the State Commission under clause (h) of sub-section (1) of Section 86 of the Act.
Inter-State transmission system	Any system for the conveyance of electricity by means of a main transmission line from the territory of one State to another State, built, owned, operated, maintained and controlled by a central transmission unit.
Intra-State transmission system	The transmission of electricity within the territory of State on a system built, owned, operated, maintained and controlled by the State Transmission utility (STU).
Lead generator	The lead Generator will be as termed in the CERC (Grant of Connectivity, Long-term Access and Medium-term Open Access in inter-State Transmission and related matters) (Amendment) Regulations, 2010 as follows: One of the generating stations using renewable sources of energy, individually having less than 50 MW installed capacity, but collectively having an aggregate installed capacity of 50 MW and above, and acting on behalf of all these generating stations, seeking connection from CTU at a single connection point at the pooling sub-station under CTU or connecting at pooling substation within the solar or wind power park, termed as the Lead generator. Lead Generator will formalize a written agreement/arrangement among all the associated generators to undertake all operational and commercial responsibilities for the renewable energy generating station(s) in following the provisions of the Indian Electricity Grid Code and all other regulations of the Commission, such as grid security, scheduling and dispatch, collection and payment/adjustment of Transmission charges, deviation charges, congestion and other charges etc.
Pooling station	Substation where pooling of generation of individual solar generators (SPDs) is done for interfacing with the next higher voltage level, the grid.
Principal Generator	The Principal Generator, will be as recognized in the CERC (Grant of Connectivity, Long-term Access and Medium-term Open Access in inter-State Transmission and related matters) (Third Amendment) Regulations, 2013, as follows: The existing generating station which agrees to act as the “Principal Generator” on behalf of the renewable energy generating station(s) which is seeking connectivity through the electrical system of the existing generating station and formalizes a written agreement/arrangement among them to undertake all operational and commercial responsibilities for the renewable energy generating station(s) in following the provisions of the Indian Electricity Grid Code and all other regulations of the Commission, such as grid security, scheduling and dispatch, collection and payment/adjustment of Transmission charges, deviation charges, congestion and other charges etc., and submit a copy of the agreement to the CTU, along with the application for connectivity, with copy to the respective RLDC in whose control area it is located.

Qualified Coordinating Agency	Agency coordinating on behalf of solar generators connected to a pooling station. The QCA may be one of the generators or any other mutually agreed agency for the following purposes: Provide schedules with periodic revisions. Undertake commercial settlement on behalf of the generators of such charges pertaining to generation deviations only including payments to the Regional / State UI pool accounts through the SLDC. Undertake de-pooling of payments received on behalf of the generators from the State UI pool account and settling them with the individual generators based on actual generation. QCA will be treated as State Entity and will be registered with SLDC.
Regional load dispatch centre	Load dispatch centre at a regional level, which may encompass several States
Solar park	Concentrated zone of development of solar power generation that provides developers an area, which is well characterized, proper infrastructure and with access to amenities, where the risk of the projects can be minimized.
Solar park EPC contractor	Contractor for the execution of the solar park infrastructure.
Solar park internal transmission system	Internal electrical transmission network within the solar park formed by transmission lines and towers, and the pooling stations or substations with its protections.
Solar park operator	Operator whose mission is to operate and maintain the solar park infrastructures, namely electrical, roads, water and common facilities. Solar park operator can be the same SPPD or other company acting on its behalf.
Solar plant	Each one of the solar power generation units connected within a solar park.
Solar plant operator	Operator whose mission is to operate and maintain a solar plant, namely the power generation, but not limited to. Solar plant operator can be the same SPD or other company acting on its behalf.
Solar power park developer	Solar power park developer (SPPD) will develop the solar park and will be tasked with acquiring the land for the park, make it suitable for solar projects, construct and provide connectivity, accesses and shared facilities as well as allocating the solar plots to SPD.
Solar plant developer	Solar plant developer (SPD) is a bidding company or consortium that got selected through a bidding process under Central / State Government scheme to build a solar plant in an allocated plot in a solar park.
Solar Plant substation	Electrical substation of the solar plant that contains main protections, switchboard, control panels and transformer and is owned by the solar plant developer and operated by the solar plant operator.
State load dispatch centre	State load dispatch centre (SLDC) means load dispatch centre of a specific State, responsible of coordinating scheduling of the State.
STU	State transmission utility.
Time-block	A time block of 15 minutes, for which specified electrical parameters and quantities are recorded by a special energy meter with the first time block starting at 00.00 hrs.

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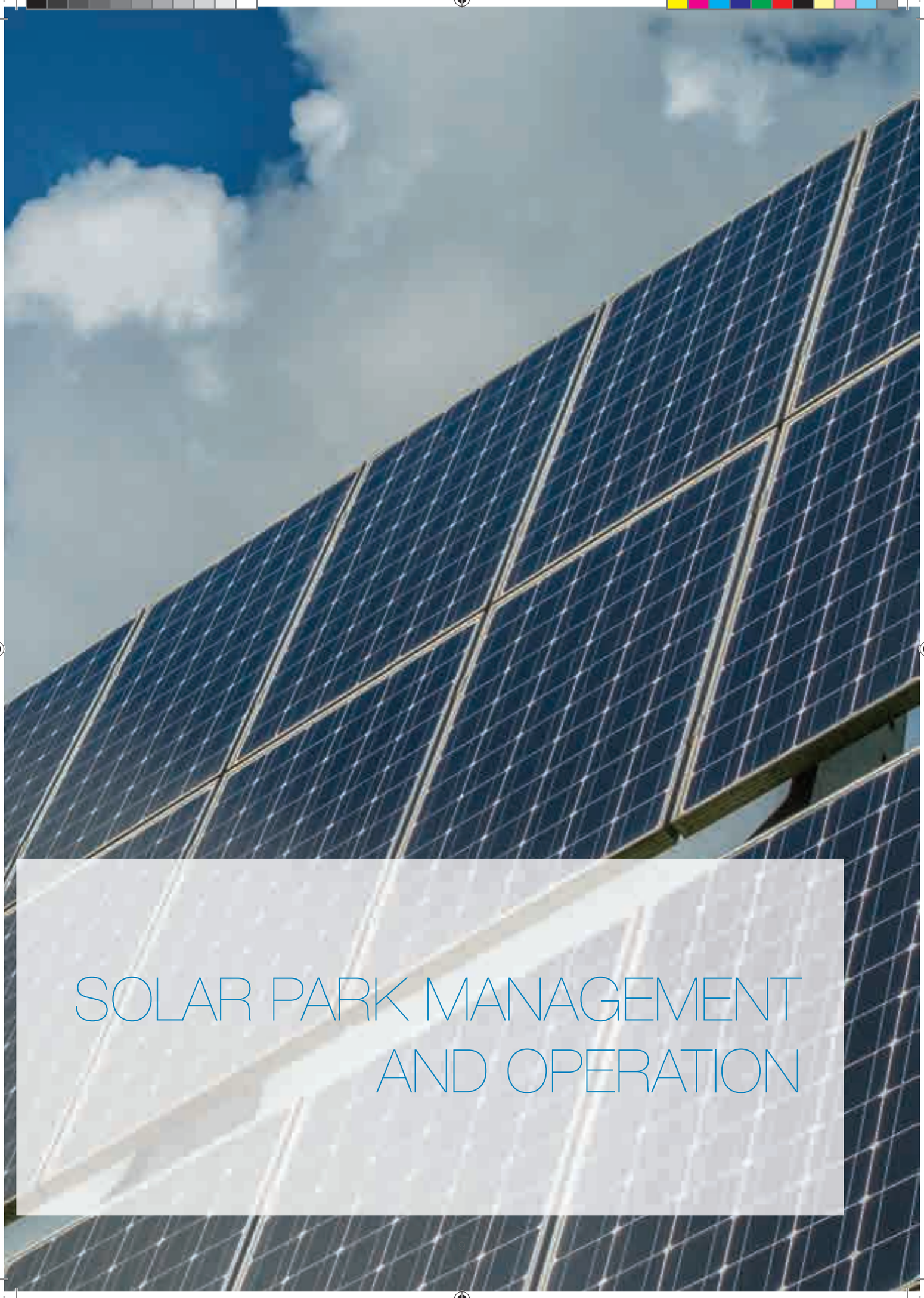


SOLAR PARK MANAGEMENT AND OPERATION

Indian solar park scheme

In December 2014, the Ministry of New and Renewable Energy (MNRE) of India announced the approval of the implementation of a Scheme for Development of Solar Parks and Ultra Mega Solar Power Projects in the country commencing in 2014-15. At that time, the objective of the scheme was to set up at least 25 solar parks, each with a capacity of 500 MW or more, with a total target of 20 GW.

The concept of “Solar Park” involves developing solar power generation projects in a concentrated zone, by providing promotors or developers with an area that has been surveyed and is suitable. Dedicated shared infrastructure should be provided to reduce the costs for each solar developer located in the zone.

In March 2017, given the positive progress achieved in the implementation of these solar parks, MNRE reviewed the objective of the scheme, and increased the target capacity from 20 to 40 GW by setting up at least 50 solar parks, each with a capacity of at least 500 MW or more by 2019-20.

As stated in the administrative sanctions for implementation of the scheme, the objective of the same is to provide a huge impetus to solar energy generation by acting as a flagship demonstration facility to encourage project developers and investors, prompting additional projects of similar nature, triggering economies of scale for cost-reductions, technical improvements and achieving large scale reductions in GHG emissions. It will enable States to bring in significant investment from project developers, meet its Solar Renewable Purchase Obligation (RPO) mandate and provide employment opportunities to local population. The states will also reduce its carbon footprint by avoiding emissions equivalent to the solar park’s installed capacity and generation. Further, the States will also avoid procuring expensive power.

Stakeholders and roles

The Ministry of New and Renewable Energy (MNRE) of the Government of India (GOI), will implement the scheme through the Solar Energy Corporation of India (SECI). SECI will thus administer the scheme under the direction of MNRE, and also manage the funds to be made available under the scheme.

The solar power park developer (SPPD) is responsible for the development and the installations, to the extent that the Solar Power Developers (SPD) will be able to set up their solar power projects. The evacuation of the solar park will be either through the state transmission utility (STU); or the central transmission Utility (CTU).

The SPPD will be responsible for creating, operating and maintaining all infrastructure: road access, water, the solar park internal transmission network, and request any external transmission network improvements required, as well as any other common installations.

In addition, the SPPD may also be entrusted with providing the following facilities to the SPDs for the development of the solar park:

- Telecommunication facilities.
- Housing facility for basic manpower wherever possible.
- Security.
- Cleaning services and waste disposal.

Under the MNRE mode 7 only the Solar Energy Corporation of India (SECI) is allowed to be the SPPD. The external transmission development authority (ETDA) will develop the electrical infrastructure for the park.

SOLAR PARK OPERATION MANUAL

General operation of the solar park internal grid

The solar park operator will be in charge of operating the common internal transmission network which will connect each solar plant with the intra-state (STU) or inter-state transmission system (CTU). The following subchapters describe how this operation should be performed under different operational scenarios.

Transmission and substations

In general, the solar park energy production should be evacuated by the transmission operator (corresponding load dispatch centre) with the highest priority. However, the solar power generation may be required to be reduced or even interrupted in case it may endanger the grid security or safety of any personnel or equipment, thus it is recommended that the solar park operator considers staffing the pooling substations.

Solar parks will meet certain technical requirements while operating under normal conditions according to the Indian Electrical grid code (IEGC):

- Generating output of the solar park should not be intentionally reduced by more than 100 MW unless for security reasons without previous consent with corresponding dispatch centre. This is specifically critical when grid frequency is falling or is below 49.5 Hz.

- The solar park generation will not cause voltage and current harmonics on the grid which exceed the limits specified by the Institute of Electrical and Electronic Engineers (IEEE) standard 519. The generating station will not inject DC current greater than 0.5% of the full rated output at the interconnection point.

- The solar park operator will take all possible measures to ensure that the grid frequency always remains between 49.90 – 50.05 Hz and grid voltage remains within allowed voltage range as per IEGC standards. In any case, the solar park will provide adequate voltage control and frequency measure through voltage and frequency relay respectively, to prevent voltage collapse by tripping the plant when needed.

Each solar plant will be capable of supplying dynamically varying reactive power support, so as to maintain the power factor within the limits of 0.95 lagging to 0.95 leading. Moreover, the solar park operator will cooperate with the Regional Power Committee, and the appropriate load dispatch centre with respect to, but limited to, the matters listed below:

- Protection coordination and settings of its protective relays accordingly.

- Agree to maintain the meters and communication system in good condition in its jurisdiction.

- Participate in contingency operations such as load shedding, increasing or reducing generation, islanding, black start, providing start-up power and restoration as per the procedure decided by the appropriate load dispatch centre.

- Furnish data as required by the appropriate transmission utility or transmission license, appropriate load dispatch centre, appropriate regional power committee, and any governmental committee for system studies or for facilitating analysis of tripping or disturbance in the power system.

- Carry out modifications to the equipment with respect to short circuit level, protection coordination and other technical reasons considered necessary, because of operational requirements.

Abide by the coordinated outage plan of the state and region with respect to generating units and transmission lines, as approved by the regional power committee.

General procedure to connect/disconnect the solar park to/from the grid

Solar parks will be permanently connected to the grid, unless one of the following conditions is fulfilled:

- Need for scheduled or unscheduled maintenance tasks of the solar park internal transmission system or the grid.
- Automatic or manual tripping of the park.
- Under an emergency, and conditions in which such disconnection would prevent a total grid collapse and/or would enable early restoration of the power supply.
- For health and safety reasons.
- To avoid serious damage to costly equipment.
- The load dispatch centre orders the solar park to do so.

Furthermore:

- Any scheduled or unscheduled service interruption of the solar park should be notified to the corresponding load dispatch centre through the corresponding QCA, as required in IEGC.
- Interruptions due to scheduled maintenance or other foreseeable reasons should be notified, and the interruption start agreed in advance with the load dispatch centre. Unscheduled interruptions (emergency or tripping, whether manual or automatic) should be also notified by the QCA as soon as possible after the event. In both cases, the reason for the interruption and estimated time of service restoration will also be communicated.

Likewise, regardless as to whether the cause of the interruption is attributable to the solar park or not, the solar park operator should also communicate this event (whether scheduled or not) to every solar plant operator.

All reasonable attempts will be made for the solar park service restoration, as soon as possible. If the cause of the interruption is a scheduled maintenance, all attempts will be made, in order to meet the restoration date or, to reach park (or grid) availability conditions ahead of scheduled. In any case, the QCA should contact the load dispatch centre and wait for permission before the solar plant is effectively reconnected to the grid.

For the solar power plant to connect to the grid, the solar plant operator will communicate with the solar park operator, in order to synchronize the connection. The load dispatch centre will decide the time and start sequence that must be followed by the solar park.

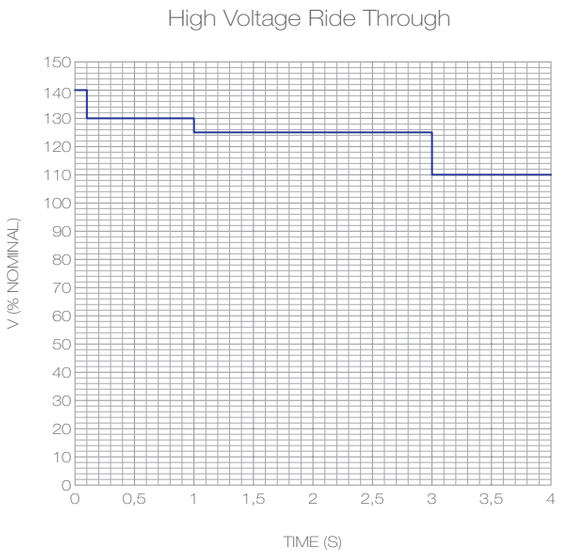
Solar park operation during a grid outage

In case of an unscheduled power outage in the inter-state or intra-state transmission system, solar plants will immediately stop supplying power to the grid. Therefore, complete solar park production will be ceased, waiting for the transmission system resumption.

The draft CEA Regulations stipulate the following:

Wind and solar generating units/stations connected at a U voltage levels to the grid, will remain connected to the grid when voltage at the interconnection point, measured on HV side, on any or all phases (symmetrical or asymmetrical overvoltage conditions) rise above the specified value given below for specified time:

Overvoltage (pu)	Minimum time to remain connected (seconds)
1.3 < V < 1.4	1
1.1 < V < 1.3	3
1.1 or below	Indefinitely



The load dispatch centre will notify the relevant QCAs, as soon as possible, about the reason/s for the outage and expected time for service resumption.

In the case the HV grid outage can be predicted, the load dispatch centre will inform the relevant QCAs in advance.

The solar park operator will ensure the proper operation of essential services, even under outage conditions. These services should be, at least:

- Communications between solar plants and solar park, and between the solar park and the load dispatch centre.
- If applicable, lighting in the solar park, e.g. at main solar park entrance, pooling station, in perimeter areas for security reasons, etc.
- If applicable, security system (CCTV) and access control.
- The pooling stations will meet all regulatory requirements, in terms of autonomy of electrical protections, electrical manoeuvres, emergency lighting and communications.

Once the electrical protections detect lack of power in the inter-state or intra-state transmission system, the circuit breaker will automatically open and the system put into island operation. This mode consists of supplying power by autonomous generators for essential equipment in order to safeguard the integrity of persons and power plant devices.

At the same time as a lack of power is detected, the remote system or the solar park operator will open the circuit breakers of the solar plant substation. It is recommended that internal batteries start feeding essential equipment and diesel generators assist the internal batteries in the briefest time possible. The internal battery system has to be sized for the maximum essential demand time in the park in order to

feed emergency equipment. Once the inter-state or intra-state transmission system has resumed normal operation, the relevant QCAs will wait for the load dispatch centre permission to reconnect. At this point, a reconnection sequence will be defined between the SLDC and the relevant QCAs, in order to permit the progressive resumption of power supply to the solar park internal transmission system. This reconnection sequence will be defined, depending on the connection scheme of the different solar plants and rated power, as well as the intra or inter state transmission system capacity.

Furthermore, the solar park pooling station, during islanding condition, will:

- Be capable of regulating load connections in block load.
- Control frequency, in the case of over frequency and under frequency within the whole active power output range, between minimum regulating level and maximum capacity.
- Be capable of coordinate parallel operation with the different solar plants.
- Control automatically during the system restoration phase.

Solar park operation during an emergency. Saf eshutdown and restart procedure or black start

In an emergency event, the solar park operator should proceed as quickly as possible in order to isolate that part of the solar park that is being affected by an exceptional event so as to avoid disturbing the rest of the park and/or the transmission grid.

In case an emergency arises in a specific solar plant it should be isolated by opening the corresponding circuit breaker or disconnector in the solar plant substation. This can be done either by the solar park operator (by local action on the solar park pooling station), or by the solar plant operator or due to automatic trip depending on emergency cause. It is recommended that it is done by the solar plant operator. From that point on, the solar plant operator should find out the exact cause of the emergency, isolate and repair it. If the emergency is on the solar park internal transmission system, the solar park operator will proceed in a way that the affected infrastructure can be properly isolated and the rest of the park is kept under normal operation as long as possible. The relevant QCA will inform the SLDC.

As a last resort, and as long as previous approaches are not feasible to mitigate possible consequences of emergency, the whole solar park should be disconnected from inter-state or intra-state transmission system in order to focus on the emergency origin, isolate the affected part and restore the rest of the park production as far as possible. In that case, diesel generator and batteries will be connected to the solar park system as per the procedure defined before. The relevant QCA will inform the SLDC.

In any case, the main priorities of the solar park operator when dealing with an emergency situation should be as follows:

- Communicate with the solar plant operators.
- Ensure the physical integrity of the personnel involved in O&M tasks both in the solar park and in the solar plants.
- Ensure no damage or disturbance is caused in inter-state or intra-state transmission system.
- Ensure no damage is caused in main equipment of the solar plants or the remaining equipment of the solar park.
- Reduce losses in electricity production as far as it is reasonable achievable.

QCA must notify the load dispatch centre of any service disturbance whose power derating implies a reduction of minimum 100 MW of nominal power (or 25% of nominal power of the solar park whichever is lowest) due to actions taken following an emergency event. This communication will be done within ten minutes of the event along with best estimation of solar park complete power resumption. Other relevant QCAs will be informed as well at the same time.

All relevant QCAs to establish full power connection to inter-state or intra-state transmission system will wait for a load dispatch centre permission.

Solar park operation during scheduled maintenance works

Scheduled maintenance works will be performed reducing, as much as possible, the impact on the solar park overall energy production. Likewise, in an emergency situation, the part of the solar park under maintenance should first be isolated from the rest, whether it is a solar plant or a portion of the solar park transmission system.

In the case an entire solar plant needs to be disconnected from the solar park transmission system, the general procedure, as described in following sections, will be followed. The remaining solar parks will operate normally.

In the case maintenance works need to be carried out on a portion of the internal transmission grid, that portion will be properly isolated, by performing corresponding manoeuvres in the affected solar plant substation.

All maintenance works involving power reduction will be scheduled in advance, to the extent possible. Solar plant operators must inform the solar park operator of their maintenance programs. The QCA must integrate the solar plant maintenance programs into the maintenance program of the solar park and, in turn, report to the load dispatch centre, who will finally allow power reduction or suggest any alternative schedule when needed for operational reasons.

For those maintenance tasks that involve complete solar park outages, the relevant QCA will report, in writing, to the regional power committee (RPC) secretariat before 30th November of each year, according to the IEGC (section 5.7.4. “Outage planning process”). By the end of the year, the RPC secretariat will respond with a confirmation of those dates or alternatively propose another date. In any case, the solar park operator will follow the finally agreed dates for their complete outages for maintenance, and inform the relevant QCAs in advance of any possible deviation.

When possible, solar park maintenance should be scheduled in a low solar irradiation season or even at night, especially maintenance tasks involving a significant reduction of the power supply.

Solar power plants

Safety instructions related to solar plant operation and requirements on solar plants operation staff

Solar plants operations may pose risk of personal injury or even loss of life, due to the high voltages involved, therefore, according to applicable legislation, the system should only be accessed by qualified, authorized solar plant personnel.

Major safety requirements during PV servicing include the proper use of lockout/tagout procedures, the use of personal protective equipment (PPE), safety procedures for disconnecting live circuits, and appropriate observation of and compliance with all PV-specific system signals and warnings.

Lockout/tagout procedures are designed to ensure safe working practices and must be strictly followed whenever systems are de-energized prior to servicing.

Lockout/tagout is required when energized equipment is serviced or maintained, safety guards are removed or bypassed, a worker has to place any part of his or her body in the point of operation of the equipment, or hazardous energy sources are present.

Lockout/tagout steps include:

- Notify others that the equipment will be shut down.
- Perform a controlled shutdown to power down the equipment.
- Open all of the energy isolating devices identified on the equipment.
- Lock and tag all energy isolating devices.
- Dissipate or restrain stored or residual energy.
- Verify that the equipment is completely de-energized.

The lock placed on equipment during servicing should be removed, only by the person who placed it.

Some of the switches used to control the DC circuits of PV systems are not rated for load-break operation. Non-load-break-rated switches, which must be labelled as non-load-break-rated, must never be opened while the system is operating. Before opening a DC switch that is not rated for load break, the system should be shut down by turning off the connected inverter.

All personnel must adhere to the above safety procedures when performing work on the system, including inspection, installation, operation, service work, repair, and testing.

These instructions are for use by qualified personnel only, and only pairs of authorized persons should be hereby permitted to work on the system. Site access is intended for authorized personnel only, and only authorized persons may shut down the system or open any system enclosure.

In general, following security rules should be observed by solar plant personnel when doing some operation or maintenance activities in the plant:

- Always allow for 5 minutes for the energy storage devices in the inverters to safely discharge dangerous voltages.
- Always follow local and National guidelines and regulations.
- Always check for ground faults. If there is a ground fault, there may be a voltage potential between the inverter and ground. Further, check that the normally grounded pole is properly grounded and has not been energized by a fault.
- Do not work alone when servicing PV equipment. A team of two is required until the equipment is properly de-energized, locked-out, and tagged-out. Verify with a meter that the equipment is de-energized.

General requirements during operation

The IEGC sets the operation specifications of the solar power plants. The requirements described below refer to draft second amendment in CEA (Technical Standards for connectivity to the Grid) regulations, 2007.

Voltage ranges

It is defined as the ability to operate continuously within the limits of voltage operation under normal conditions. The solar plant will take all possible measures to ensure that the grid voltage always remains within the following operating range.

Voltage – kV rms

Nominal	Maximum	Minimum
765	800	728
400	420	380
220	245	198
132	145	122
110	121	99
66	72	60
33	36	30

Frequency

The solar plant will be capable of operating within the frequency range 47.5 to 52 Hz and will be able to deliver rated output in the frequency range of 49.5 to 50.5 Hz.

If the frequency range is below 49.5 Hz and above 50.5 Hz, or, as prescribed by the Central Commission from time to time, the output should fall within the frequency response requirement detailed below.

Low Voltage Ride Through

The solar plant connected to the grid, will remain connected to the grid when voltage, at the interconnection point (measured on the HV side of interconnection) on any or all phases, dips up to the levels depicted in the figure in paragraph B(iv) of draft second amendment in CEA (Technical Standards for connectivity to the Grid) regulations, 2007 as amended.

During the voltage dip, the solar park should generate active power in proportion to the rated voltage.

During the voltage dip, the power plant should maximize supply of reactive current until the time voltage starts recovering or for 300 ms. (whichever is lower).

High Voltage Ride Through

The solar plant connected at all voltage levels to the grid will remain connected to the grid when voltage at interconnection point, measured on the HV side, on any or all phases (symmetrical or asymmetrical overvoltage conditions), rise above the specified value detailed below for the specified time:

Overvoltage (pu)	Minimum time to remain connected (seconds)
1.3 < V < 1.4	1
1.1 < V < 1.3	3
1.1 or below	Indefinitely

Ramp Rate control – frequency response

The solar plant, with installed capacity of more than 10 MW, should provide an immediate real power primary frequency response, proportional to frequency deviations from scheduled frequency, similar to governor response. The rate of real power response to frequency deviations should be similar to or more responsive than the droop characteristic of 3 to 6% used by conventional generators. The solar pant should have controls that provide both for down-regulation and up-regulation. For this purpose, the solar plant in combination with energy storage systems such as, but not limited to BESS (Battery Energy Storage System), flywheels and hybrid systems, are acceptable options.

For small frequency deviations e.g. less than 0.3 Hz, the solar park response should be proportional to the frequency deviation, based on the specified droop characteristic. The frequency response dead band should not exceed +/-0.03%. For large frequency deviations e.g. in excess of 0.3 Hz, the solar park should provide an immediate real power primary frequency response of at least 10% of the maximum AC active power capacity. The time response should be less than 1 second.

If energy storage systems are utilized to comply with the frequency regulation requirements, and during a disturbance, the system frequency falls suddenly and stays below 49.7 Hz, the solar plant frequency response should act immediately (within one sec) and should be maintained for at least 10 min. After the 10th minute, the real power primary frequency response should not decrease at a ramp rate higher than 10% of the maximum AC active power capacity per minute.

The operational range of the frequency response and regulation system should be from 10% to 100% of the maximum AC active power capacity.

Active power control

A solar plant with installed capacity of more than 10 MW connected at voltage level of 33 kV and above will be able to control active power injection in accordance to a set point, which will be capable of being revised based on the direction of the appropriate load dispatch centre. The solar plant controller will have a droop of 3 to 6% and a dead band not exceeding ±0.03 Hz.

Provided that for large frequency deviation e.g. in excess of 0.3 Hz, the solar park should provide an immediate (within 1 second) real power primary frequency response of at least 10% of the maximum AC active power capacity.

If the solar plant has a capacity of 50 MW or more, it should have storage capacity of at least 10% of installed capacity as common facility irrespective of generation capacity owned/developed by different owners/ developers.

The solar plant will be able to control the rate of change of power output at a rate not more than ±10% per minute, independent of meteorological conditions. The ramp rate control tolerance will be ±10%.

Voltage regulation

The solar park will have a continuously-variable, continuously-acting, closed loop control voltage regulation system (VRS) i.e. an equivalent to the automatic voltage regulator (AVR) in conventional machines.

The VRS set-point will be adjustable in the range prescribed by the appropriate commission and it will also be adjustable via SCADA.

The VRS controller regulation strategy will be based on proportional plus integral (PI) control actions with parallel reactive droop compensation. The VRS Droop will be adjustable from 0 to 10%.

The VRS will be calibrated so that a change in reactive power will achieve 95% of its final value no later than 1 second following a step change in voltage. The change in reactive power will not cause excessive voltage excursions or overshoot.

The VRS will be in service as long as the solar park is electrically connected to the grid, regardless of MW output including no generation from the unit.

The VRS dead band will not exceed ±0.1%.

Short-circuit ratio

The short-circuit ratio for the solar park will not be less than 5.

Voltage and current Harmonics

The limits of voltage harmonics of the solar plant in the solar plant substation and method of harmonic measurement and other matters, will be in accordance with the IEEE 519-2014 standards, as modified from time to time.

Measuring and metering of harmonics will be a continuous process with permanent meters complying to IEC 61000-4-30 Class A and capable of detecting direction of harmonics (whether it is upstream or downstream) and data in regard to harmonics will be available with LDC and it is to be shared with solar park and solar plant operators. This is to ensure continuous compliance as distortion limits are to be calculated based on daily and weekly percentile values.

In addition to harmonics, periodic measurement of other power quality parameters like voltage sag, swell and disruptions will be done on monthly basis and reports will be also shared in the same way.

Reactive power control

The solar plant will provide adequate reactive compensation to compensate reactive power requirement in their system so that they do not depend upon the grid for reactive power support. The power factor will not be less than 0.95.

Initial compliance test

It is recommended that as part of the initial compliance simulations at commercial operation date, the following described below is provided to the solar park operator:

Active power controllability and control range test:

- The solar plant will demonstrate its technical capability to operate at a load level not higher than the set point set by the inter or intra state transmission system.
- The test deemed passed provided that the load level of the solar plant is kept below the set point.
- Limited frequency system mode response for under frequency (LFSM-U) response test.
- The solar plant will demonstrate its technical capacity to continuously modulate active power to contribute to frequency control in case of large drop of frequency in the system.
- The test is deemed passed provided that undamped oscillations after the step change response does not occur.

- The test will be carried out by simulating the frequency steps and ramps big enough to activate at least 10% of maximum capacity active power change with a starting point of no more than 80% of maximum capacity, taking into account the droop settings and the deadband. Simulated frequency deviation signals will be injected in the solar power park.

Frequency Sensitive Mode (FSM) response test:

- The solar plant will demonstrate its technical capability to continuously modulate active power over the full operating range between maximum capacity and minimum regulating level to contribute to frequency control and will verify the steady-state parameters of regulations, such as insensitivity, droop, deadband and range of regulation, as well as dynamic parameters, including frequency step change response.

- The test will be carried out by simulating frequency steps and ramps big enough to activate the whole active power frequency response range, taking into account the droop settings and the deadband. Simulated frequency deviation signals will be injected to perform this test.

Frequency restoration control test:

- The solar plant will demonstrate its technical capability to participate in frequency restoration control. The cooperation of both FSM and frequency restoration control will be checked.

- The test is deemed passed, provided that the test results for both dynamic and static parameters are in line with the requirements of the previous section.

- Reactive power capability test.

- In the reactive power capability test the solar plant will demonstrate its technical capability to provide leading and lagging:

  - The reactive power capability test will be carried out at maximum reactive power, both leading and lagging, and concerning the verification of the following parameters.
  - Operation in excess of 60% of maximum capacity for 30 min;
  - Operation within the range of 30 – 50% of maximum capacity for 30 min; and
  - Operation within the range of 10 – 20% of maximum capacity for 60 min.

Voltage control mode test:

- The solar plant will demonstrate its technical capability to operate in voltage control mode. The voltage control mode test will apply concerning the verification of the following parameters:

  - The implemented slope and deadband of the static characteristic.
  - The insensitivity of the regulation.
  - The time of reactive power activation.
  - The accuracy of the regulation.

- The test is deemed passed, provided that the following conditions are cumulatively fulfilled:

  - The implemented and deadband of the static characteristic.
  - The insensitivity of voltage control is not higher than 0.01 pu.
  - Following a step change in voltage, 90% of the change in reactive power output has been achieved.

Reactive power control mode test:

- The solar plant will demonstrate its technical capability to operate in reactive power control mode.
- The reactive power control mode test will be complementary to the reactive power capability test.
- The reactive power control mode test will apply concerning the verification of the following parameters:
  - The reactive power set point range and step.
  - The time of reactive power activation.
  - The accuracy of the regulation.

Power factor control mode test:

- The solar plant will demonstrate its technical capability to operate in power factor control mode.
- Power factor control mode test will apply concerning the verification of the following parameters
  - The power factor set point range.
  - The accuracy of the regulation.
  - The response of reactive power due to step change of active power.

Procedure to connect and disconnect the solar plants to/from the solar park pooling substation

The shutdown of a solar plant, for the purpose of scheduled maintenance works, development of improvements in the solar park grid, or simply for any operational reason coming from inter-state or intra-state transmission system should be arranged in advance, to the extent possible.

To that end, communication should be issued in advance between the solar plant operator and the solar park operator (or vice versa, depending on the cause of scheduled disconnection) including, as a minimum, exact start time of disconnection, estimated duration as well as reason for that scheduled disconnection.

Urgent breakage maintenance may be carried out without advance notice by the solar park operator, inter-state or intra-state transmission system in accordance with lawful authorities.

Solar plant operation during a solar park internal outage

During a solar park internal grid outage (loss of mains event), the solar plants should be disconnected, all or those directly affected by the outage. The solar park transmission system should not be powered by the solar plants, this is also known as island operation. This should be avoided in order to not contribute to potential external grid fault and also to prevent any injury on utility staff doing maintenance works on the grid.

A circuit breaker in each solar plant substation should be automatically tripped by Loss of Mains (LOM) protection. The circuit breaker will be reconnected automatically by the protections after an outage and after a five (5) minutes of stable voltage. A reconnection sequence will be defined for the solar plants in order to allow for a progressive resumption of power supply to the solar park grid. This reconnection sequence will be defined depending on different solar plants connection scheme and rated power, as well as intra or inter state transmission system capacity.

For other grid disturbances that do not constitute a complete outage as for example: frequency out of the range 49.5 – 50.2 Hz or voltage out of the range +/- 10%, the inverters themselves will be tripped without shutting off the solar plant main circuit breaker.

During a complete outage, and further to main circuit breaker tripping, solar inverters also detect the outage and stop feeding power to the grid.

Solar plant operation during a solar park emergency. Safe shutdown and restart procedure

In an emergency situation, it is agreed that both the solar plant as well as the solar park will be allowed to shut down the facilities immediately. In the case of an emergency in the solar plant, the solar plant operator will disconnect the plant from the solar park grid within maximum 10 minutes, and isolate the eventual cause of the emergency (fire, lightning, short-circuit, etc.), by manipulating/adjusting the corresponding equipment. In general, the procedure for operating the plant under these situations will be as follows:

- Disconnect the entire plant by opening main circuit breaker at solar plant substation.
- Locate and isolate the damaged equipment by opening corresponding switches in different transformer centres throughout the solar field, if applicable.
- If an entire transformer needs to be isolated, the following actions are recommended to be undertaken:
  - Open corresponding MV switches in the same MV internal loop, upstream and downstream of affected transformer.
  - Open all other switches and/or circuit breakers in the affected transformer that allow for complete equipment isolation (transformer, switchboard, inverter, etc.).
  - In case the damaged equipment is an inverter, disconnect the DC feeding by opening the DC main switch in the inverter, if accessible. Otherwise, open switch and/or fuse disconnectors of all junction boxes feeding the DC side of the inverter.
- Once the damaged equipment has been identified and electrically isolated, and as long as the emergency has not affected the solar plant substation, reconnect all other equipment in order to allow the rest of the plant to continue its normal operation during repair of damaged equipment:
  - Reconnect the plant by closing main circuit breaker at solar plant substation.
  - Close those open switches that are not related with specific damaged equipment isolation.
- After complete repair, the isolated section of the system can be reconnected and re-started. If an entire transformer is reconnected, the following steps are recommended starting from a situation where all the switches in the affected transformer centre are open:
  - Start closing corresponding switches upstream and downstream of the affected transformer centre in the same MV loop, as well as switches and circuit breakers of the affected transformer centre MV cabinets.
  - Close switches at LV switchboards, one by one.
  - Connect the DC side of inverters by closing switch and/or fuse disconnectors of all junction boxes if needed.
  - Start up the inverters one by one by following instructions described in manufacturer O&M Manual. If all is correct, and after five (5) minutes of stable voltage, inverters will synchronize and start the power feeding process.

Apart from the solar plant operator, the solar park operator shall (just in case) disconnect the solar plant by remote shutoff of the circuit breaker of the solar plant substation. At the end of the exceptional state on the inter-state or intra-state transmission system, the solar park operator will automatically reconnect the circuit breaker again and inverters will proceed with the automatic start-up process.

Solar plant operation during solar park scheduled maintenance works

The solar park scheduled maintenance should be communicated to the solar plant with at least 30 days in advance. Within the following 5 calendar days solar plant operator should notify the solar park operator the impact in terms of electricity generation. In case the scope of the maintenance works on the solar park requires the complete disconnection of the plant, the following steps are recommended:

- Disconnect the entire plant by opening main circuit breaker at solar plant substation.
- Perform required maintenance works.
- Reconnect the plant following the steps described below:
  - Reconnect the entire plant by closing main circuit breaker at solar plant substation.
  - Close internal MV ring by closing all switches in solar plant substation as well as in all transformer centres.
  - Connect all transformers one by one:
    - Close corresponding switches and circuit breakers of transformer MV cabinets.
    - Close LV switches in transformer centres LV switchboards.
    - Start up the inverters one by one by following instructions described in manufacturer's O&M manual. If all is correct, and after a five (5) minutes period of stable voltage, inverters will synchronize and start the power feeding process.

It is recommended that the maintenance of solar parks occurs in the evening or outside of solar production hours.

Roads

The solar park operator is also in charge of operating and maintaining the internal roads in the solar park.

The solar park operator is not responsible for maintaining and operating the roads within each solar plant. These will be operated and maintained by the solar plant operators.

The use of internal roads will be based on due consideration of safety, environmental conditions and the traffic/transportation requirements for the solar plant construction, operation and maintenance.

The solar park operator will be responsible for surveying all routes to ensure access for vehicles and equipment for all foreseeable operation and maintenance tasks, including all scheduled maintenance events. Roads shall allow for unimpeded traffic flow.

Water pipelines, overhead tanks, pump stations

The solar park operator should provide water at a single source through a meter for each solar plot. Solar plant operators will be charged according to the water consumption.

The solar park operator will operate and maintain the following minimum water infrastructure:

- Overhead water storage tanks (one or various tanks depending on water consumption and external water supply flow).
- Pressure stations ensuring minimum pressure conditions at any point in the park, if applicable.
- Water reticulation system (piping), underground or above ground, as the case may be.
- Water mains at each plot, including valve and meter.

Operation procedure for ensuring water availability

It is recommended for each solar plant to have a cleaning schedule that is communicated to the solar park operator, so as to better deal with simultaneous consumption needs. It is nonetheless recommended that each solar plant should have its own water storage facilities where water harvesting and recycling may also add to increasing the available water quantity.

Monitoring and SCADA operation

The solar park operator shall operate a SCADA system that will integrate data from each solar plant as well as data from its own transmission system infrastructure and meteorological stations.

It is recommended that the solar plant operator installs the necessary equipment to continuously measure solar irradiation, ambient temperature, wind speed wind direction, humidity, rainfall, and soiling if possible, and simultaneously measure the generation of DC power and AC power generated by each solar plant. The solar park operator shall also operate and maintain the solar ground measurement station(s)

A standard protocol will be signed between the solar park and the solar plants in order to share this critical information of each plant, so as to allow the solar park operator to have real time information about solar plants production.

All solar plants shall be connected to a telecommunications network.

The solar park operator must manage the integrated SCADA and monitoring data of the solar park. The relevant QCAs should send the Information to the corresponding load dispatch centre, including energy production forecast for the next few days. The QCA may also accept the forecast provided by the SLDC.

Shared services, common facilities and access

Apart from the internal transmission, roads and water supply, the solar park developer may provide, operate and maintain the following common installations/facilities:

- Telecommunications.
- Security.
- Drainage.
- Lighting.
- Warehouse.
- Weather forecast.
- Diesel generator.

The following subchapters offer a general idea of operation and service of each.

Telecommunications

The solar park may lay optical fiber to all the solar plants and along the transmission lines. The optical fiber will be laid in conduits, ducts, trenches, racks and an underground buried installation.

Telecommunications will allow, as a minimum:

- Data transfer from solar plants to solar park including real time production and other main parameters related with solar plants operation (alarms, reactive power, etc.).
- Remote control and operation of the plant by the solar plant operator.
- Remote control of the main circuit breakers of the solar plant substation by the solar park operator. Direct commands such as trip the plant or permission to recovery connection from solar park to solar plants.
- Data transfer from solar park to solar plants such as weather forecast.
- Voice and data in general.

The solar park operator will be in charge of the operation and maintenance of telecommunications.

Security

The solar park operator may fence in the site and implement a security system.

CCTV may be provided to monitor the main gate and perimeter protection alerting the solar park operator of any intruder. The system will be capable of:

- Recording images both night and day.
- Cover the entire perimeter of site and activate remote alarms on intruder detection.
- Hard drive backup.
- Remote access.

It is recommended that at least one security officer remain permanently at the main gate of the park (24/7) taking care of plant security. Should any security event arise in one of the solar plants, the security officer will immediately notify the solar plant operator.

Drainage

The solar plant operator will lay and maintain the main drains along the internal roads. The different solar plants may connect their internal projected drains to this system. One drain will be constructed along the periphery of each solar plot.

Solar plants developers will lay out the plant in a way that storm water runs off- towards these drainage channels or otherwise build an internal drainage system to effectively lead to the main drainage channels.

Lighting

A street lighting system will be operated and maintained by the solar park operator. In at least the following locations:

- Solar park main roads.
- At each solar plant gate.
- Along each solar plant.
- Solar park pooling sub-stations.
- Water overhead tanks and water reservoirs.

Warehouse

A warehouse may be constructed and managed by the solar park operator. This warehouse is intended for storage of the spare parts and equipment required for the solar park maintenance. It may also be used for the storage of material related to the solar plants.

Weather forecast and meteorological data

The solar park should install and operate its own weather stations, in order to collect meteorological parameters and create an historical data base for the site.

Weather stations will be located in the common areas of the park. There may be more than one in order to be more representative of the actual conditions of the park. They will include, at least:

- Double calibrated cell for global solar irradiance measurement on horizontal.
- Pyranometer for global solar irradiance measurement on horizontal.
- Anemometer and weather-vane for wind speed and direction measurement.
- Thermometer for ambient temperature and relative humidity.
- Rain gauge.

Solar plants operators will be able to access the solar park data base at any time to get real time information or simply to compare the data with their own meteorological data.

Moreover, the solar park will subcontract a meteorological forecast service in order to know the best weather forecast for the days to come. This forecast will be made available to all solar plant operators, to aid in the estimation of solar plants production.

Diesel generator

The solar park operator will install a diesel generator for island operation. This generator will be oversized by 20% according to the essential demand of main pooling station and all emergency common services of the solar park.

Any variation of the essential demand by the solar plant operator will be communicated immediately to the solar park operator in order to ensure that all essential consumers are properly supplied. Following a periodic maintenance plan for diesel generators will also help to keep the equipment in good operation conditions and ensure a reliable supply to all the consumers in emergency situations.

SOLAR PARKS MAINTENANCE MANUAL

General Requirements

Preventive maintenance will be performed at a level that assures that the unscheduled outage performance of customer equipment is at least as good as that of the electrical grid to which it is connected. Maintenance of equipment will be performed so that the facility owner is able to comply with any local interconnection agreements. Loss of a piece of equipment, due to lack of sufficient maintenance, can lead to unnecessary higher operating costs and unnecessarily long outage time, consequently compromising transmission reliability. Additionally, the maintenance of spare equipment must not be overlooked.

Substation equipment will be maintained by qualified personnel, in accordance with applicable industry standards, to provide maximum operating performance and reliability. The work team should consist of:

1. Supervising engineer.
1. Specialized technicians.
1. Qualified operators.

Incorrect operation of equipment or equipment failure should be thoroughly investigated and documented, to determine the root cause of the problem. Operation and or equipment failures that adversely impact the electrical grid should be investigated.

These operations will follow the manufacturer´s instructions and recommended practices. An activity schedule and book-manual of preventive maintenance will be kept, and all anomalies will be registered in this document.

Electrical infrastructures

The equipment diagnostic tools and tests can be used for the evaluation of maintenance requirements. Examples include dielectric testing and analysis, breaker timing, thermography scans and acoustic monitoring. The solar park operator plan should be clear as to the application of these diagnostic tools. Pass/fail ranges and testing intervals should be well documented. Adequate spare parts should be kept on hand for maintenance purposes.

The following activities should be carried out according to respective equipment user's manual which describes specific tasks and how they should be carried out, to ensure the optimum performance of the equipment. However, and notwithstanding these specific instructions, maintenance tasks as described below must be performed as a part of the general preventive maintenance plan.

Step-up Transf ormer

Activity	Execution	Frequency
Check cooler fans. Clean and lubricate engine.		1M 3M **6M** 1Y 5Y
Check Control board. Clean, lubrication of linkages and check connections.		1M 3M **6M** 1Y 5Y
Check and retighten terminals and connectors Thermography needed.		1M 3M 6M **1Y** 5Y
Check and retighten earth terminals.		1M 3M 6M **1Y** 5Y
Check and clean bushings.		1M 3M 6M **1Y** 5Y
Check and clean switchboards.		1M 3M 6M **1Y** 5Y
Check circulating pump. Clean and lubrication.		1M 3M 6M **1Y** 5Y
General inspection. Check temperature, pressure and electrical indicators.		**1M** 3M 6M 1Y 5Y
Check mechanical protections. Buchholz relay, pressure valves, flow relay, etc.		1M 3M 6M **1Y** 5Y
Testing isolation resistance.		1M 3M 6M **1Y** 5Y
Testing transformation ratio.		1M 3M 6M **1Y** 5Y
Testing ohmic resistance windings.		1M 3M 6M **1Y** 5Y
Take a sample of oil.		1M 3M 6M **1Y** 5Y

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Auxiliary Transformer (if applicable)

Activity	Execution	Frequency
Check and retighten terminals and connectors Thermography needed.		1M 3M 6M **1Y** 5Y
Check and retighten earth terminals.		1M 3M 6M **1Y** 5Y
Check and clean bushings.		1M 3M 6M **1Y** 5Y
Check and clean switchboards.		1M 3M 6M **1Y** 5Y
General inspection. Check temperature, pressure and electrical indicators.		**1M** 3M 6M 1Y 5Y
Check mechanical protections. Buchholz relay, pressure valves, flow relay, etc.		1M 3M 6M **1Y** 5Y
Testing isolation resistance.		1M 3M 6M **1Y** 5Y
Testing transformation ratio.		1M 3M 6M **1Y** 5Y
Testing ohmic resistance windings.		1M 3M 6M **1Y** 5Y
Take a sample of oil.		1M 3M 6M **1Y** 5Y

Circuit Breaker

Activity	Execution	Frequency
Check and retighten terminals and connectors Thermography needed.		1M 3M 6M **1Y** 5Y
Check and retighten earth terminals.		1M 3M 6M **1Y** 5Y
Check porcelain insulators. Clean.		1M 3M 6M **1Y** 5Y
Check and renovate SF6 pressure.		Manufacturer indications.
Check Drive system. Calibrate and adjust.		1M 3M 6M **1Y** 5Y
Check remote and local control.		1M 3M **6M** 1Y 5Y
Testing isolation resistance.		1M 3M **6M** 1Y 5Y
Testing contacts.		1M 3M **6M** 1Y 5Y
Testing fuses resistance.		1M 3M **6M** 1Y 5Y

Disconnector

Activity	Execution	Frequency
Check and retighten terminals and connectors Thermography needed.		1M 3M 6M **1Y** 5Y
Check and retighten earth terminals.		1M 3M 6M **1Y** 5Y
Check porcelain insulators. Clean.		1M 3M 6M **1Y** 5Y
Check and clean control switchboards.		1M 3M **6M** 1Y 5Y
Adjust grounding switches.		1M 3M 6M **1Y** 5Y
Adjust Gear closing manual.		1M 3M 6M **1Y** 5Y

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Busbars

Activity	Execution	Frequency
Check and retighten terminals and connectors Thermography needed.		1M 3M 6M **1Y** 5Y
Check and retighten earth terminals.		1M 3M 6M **1Y** 5Y

Current transformer

Activity	Execution	Frequency
Check and retighten terminals and connectors Thermography needed.		1M 3M 6M **1Y** 5Y
Check and retighten earth terminals.		1M 3M 6M **1Y** 5Y
Check porcelain insulators. Clean.		1M 3M 6M **1Y** 5Y

Lightning conductor

Activity	Execution	Frequency
Check and retighten terminals and connectors Thermography needed.		1M 3M 6M **1Y** 5Y
Check and retighten earth terminals.		1M 3M 6M **1Y** 5Y
Check porcelain insulators. Clean.		1M 3M 6M **1Y** 5Y

High voltage switchboard

Activity	Execution	Frequency
Check and retighten terminals and connectors Thermography needed.		1M 3M 6M **1Y** 5Y
Check and retighten earth terminals.		1M 3M 6M **1Y** 5Y
General inspection. Check temperature and electrical indicators.		**1M** 3M 6M 1Y 5Y
Testing isolation resistance.		1M 3M **6M** 1Y 5Y

Earth grid of pooling station

Activity	Execution	Frequency
Check and retighten earth electrodes.		1M 3M 6M **1Y** 5Y
Check and retighten earth terminals.		1M 3M 6M **1Y** 5Y
Testing ohmic resistance.		1M 3M **6M** 1Y 5Y
Testing electrical continuity.		1M 3M **6M** 1Y 5Y

Diesel generator

Activity	Execution	Frequency
Check oil density and possible leaks. Change oil depending on its density and use.		1M 3M **6M** 1Y 5Y
Check, clean or replace cooling system filter.		1M 3M **6M** 1Y 5Y
Check, clean or replace fuel filter.		1M 3M **6M** 1Y 5Y
Check, cleaning and test batteries.		1M 3M 6M **1Y** 5Y
Visual check of the panel and electrical parameters.		**1M** 3M 6M 1Y 5Y
Check noise level.		1M 3M **6M** 1Y 5Y
Check, clean or replace air system filter.		1M 3M **6M** 1Y 5Y

Transmission line

Activity	Execution	Frequency
Check cover and insulation of cable. Furthermore, the mechanical protections.		1M 3M **6M** 1Y 5Y
Check and retighten terminals and connectors Thermography needed for the electrical box.		1M 3M 6M **1Y** 5Y
Check isolation of phases.		1M 3M 6M 1Y **5Y**
Visual inspection of any obstacle that may contact with the transmission line.		**1M** 3M 6M 1Y 5Y

Civil infrastructures

Road and accesses

Activity	Frequency	Observations
Check appropriate regulatory signs.	1M 3M 6M **1Y** 5Y	
Check gates or other barriers to restrict access at all access points from other public roads.	1M 3M 6M **1Y** 5Y	
Check highly visible apparel of personnel.	1M 3M 6M **1Y** 5Y	
Check visual aspect of road and possible holes.	1M 3M **6M** 1Y 5Y	
Remove any accumulation problem.	1M 3M **6M** 1Y 5Y	

Water infrastructures

Water pipeline, overhead tanks, pump stations

Activity	Frequency	Observations
Visual check leak in pipes.	1M 3M 6M **1Y** 5Y	
Visual check leak in pipes joints.	1M 3M 6M **1Y** 5Y	
Inspection of oil level pumps.	1M 3M 6M **1Y** 5Y	
Check temperature and grease pumps and bearings.	1M 3M **6M** 1Y 5Y	
Check noise levels and excessive vibrations in pumps.	1M 3M **6M** 1Y 5Y	
Check correct flow of water.	1M 3M 6M **1Y** 5Y	
Check electrical installation.	1M 3M **6M** 1Y 5Y	

Common facilities

Telecommunications

Activity	Frequency	Observations
Check and retighten terminals and connectors Thermography needed.	1M 3M 6M **1Y** 5Y	
Check and retighten earth terminals.	1M 3M 6M **1Y** 5Y	
Check and verify good communications.	**1M** 3M 6M 6Y 5Y	
Visual check of the panel and electrical parameters.	**1M** 3M 6M 1Y 5Y	

Security

Activity	Frequency	Observations
Check good performance and visual field of surveillance cameras.	**1M** 3M 6M 1Y 5Y	
Check good recording of videos in PC.	**1M** 3M 6M 1Y 5Y	
Clean surveillance cameras.	1M 3M **6M** 1Y 5Y	
Visual check of control panels and parameters.	**1M** 3M 6M 1Y 5Y	

Drainage

Activity	Frequency	Observations
Regular grass cutting.	**1M** 3M 6M 1Y 5Y	
Litter removal.	**1M** 3M 6M 1Y 5Y	
Inlet and outlet cleaning.	**1M** 3M 6M 6Y 5Y	
Remove excess silt.	1M 3M **6M** 1Y 5Y	
Remove any other accumulation problem.	1M 3M **6M** 1Y 5Y	

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Lightning

Activity	Execution	Frequency
Check and retighten terminals and connectors Thermography needed.		1Y
Check and retighten earth terminals.		1Y
Check porcelain insulators. Clean.		1Y

Warehouse

Activity	Frequency	Observations
Check electrical panel.	1Y	
Check electric lamps and lighting.	1Y	
Check and remove any accumulation problem.	1Y	
Check visual aspect of floor and possible holes.	6M	
Check visual aspect of paint and possible moisture.	6M	

Weather f orecast and meteorological data

Activity	Frequency	Observations
Check for pyranometers correct position so that they are lined up with the same exact tilt angle as solar modules. Replace faulty lamps and damaged components.	3M	
Clean weekly the external glass dome of pyranometers allowing for an accurate and actual solar radiation measurement.	1W, 1Y	Restore normal operation condition, replace damaged component or start repair process.
Check correct position of ambient temperature sensor. It should not be exposed directly to sun radiation.	3M	
Check correct functionality of wind sensor.	3M	
Check correct position of solar cell temperature sensor. It should be properly attached to rear part of representative solar module.	3M	

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Activity	Frequency	Observations
◈ Check tightening of electrical connections and cable fastening.	1M **3M** 6M 1Y 5Y	Restore normal operation condition, replace damaged component or start repair process.
◈ Verify in SCADA historical data that all meteorological sensors are providing consistent measurements.	1M **3M** 6M 1Y 5Y	

Periodic maintenance reports minimum contents

The periodic maintenance reports should be available to relevant external agents, in order to check good performance operation in the solar park.

The periodic maintenance procedure should include, at least, the following data:

- The technical operations carried out, including the name of the operator responsible.
- Date and time of the fault occurrence.
- Description of the actions/activities carried out to fix the fault.
- Date and time of rectification of the fault.
- Pictures of the damaged equipment and/or infrastructure showing its previous and final condition.
- Information related to any stoppage of operation, required during corrective maintenance, including the date and time of the stoppage and date and time of restart of operation.

Any emergency corrective maintenance should be documented and attached to the periodic maintenance reports. As a recommendation, 24h on-site approach could be adopted as a general rule, that is, the operator in charge (on-site) will respond, while a well skilled technician will visit within the first 12 hours, to inspect the failure or malfunction, and within 24 hours the failure or malfunction must be corrected and the defective parts changed.

The solar plant operators will submit their monthly maintenance report, to be attached to the periodic maintenance report, indicating any corrective maintenance.

The periodic maintenance reports may be sent to the dispatch load centre in suitable format, if required.

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IBF International Consulting, EQONIXUS (OCA Global) and TÜV
Operation and maintenance manual for solar parks.

SOLAR PLANTS MAINTENANCE MANUAL

Solar plant maintenance and requirements on solar plants maintenance staff

Given that the photovoltaic (PV) market is already mature, the industry must now focus on properly operating and maintaining the systems. The life-cycle of PV installations is expected to be 25 years or more, so safe and proper maintenance is an integral part of maintaining a successful and reliable operation.

The solar plant maintenance personnel should be experienced, well-trained and qualified to maintain all of the plants' components and systems. As commonly accepted, a qualified person is defined as one who has received training and has demonstrated skills and knowledge in the construction and operation of electrical equipment and installations and the hazards involved.

Additionally, in order to be considered a qualified person for PV service and maintenance, the person must have training in and be familiar with:

- The skills and techniques necessary to identify and distinguish exposed live parts from other parts of the electrical equipment,
- The skills and techniques necessary to determine the nominal voltage of exposed live parts,
- The clearance distances to be maintained and the corresponding voltages to which the qualified person will be exposed.
- The pertinent sections of the applicable safety regulation,
- The characteristics of PV sources and the hardware typically used in PV systems,
- The characteristics of the hardware used in the PV system the person is working on.

It is strongly recommended that anyone working around energized PV systems complete a minimum 10-hour health and safety training program. Local legislation may specify the necessary training, skills, certifications, or licenses required to perform the work included in this report.

In addition to personal protective equipment (PPE), the solar plant maintenance personnel should be provided with other necessary equipment such as light vehicles, mobile phones, and the necessary tools to carry out the maintenance works as required.

Preventive maintenance. Time schedule and procedures for main equipment maintenance

Preventive maintenance entails the routine inspection and servicing of equipment to prevent breakdowns and unnecessary production losses. This section describes the typical preventive maintenance operations of a solar plant. These operations should be carried out according to respective equipment user's manual which describes specific tasks and how they should be carried out, to ensure the optimum performance of the equipment. However, and notwithstanding those specific instructions, maintenance tasks as described below must be performed as part of the general preventive maintenance plan.

All maintenance procedures must be reported in a logbook which should be kept in a safe place in the control room, so that all maintenance historical information can be made available to plant staff.

Photovoltaic modules

Activity	Frequency	Observations
◈ VISUAL INSPECTION ◆ Check for any glass damages. ◆ Check for any module browning (bird droppings, …). ◆ Check for any frame deformation. ◆ Check for changes in cell colour and/or film, visible hot-spots. ◆ Check for any blisters on sealant. ◆ Check diodes in junction boxes (sample test). ◆ Check for humidity in junction boxes (sample test). ◆ Check for PV cable connections and fastening and tighten them when necessary.	3M 6M 1Y 3Y 6Y 12Y	◈ In case of any module browning detection it should be cleaned immediately so as to avoid reverse currents producing hot-spots and module degradation. ◈ Any other module defect must be corrected by replacing the damaged module.
◈ MODULES CLEANING ◆ Clean all the solar modules with clean water and a brush. ◆ Clean solar radiation sensors at the same time.	3M 6M 1Y 3Y 6Y 12Y	◈ Module cleaning will be performed, at least, once every three months, or when PR of the plant is below 3% of expected PR for that time of the year, or simply when deemed necessary according to dust pollution at the site.

3M Every 3 months 6M Every 6 months 1Y Yarly 3Y Every 3 years 6Y Every 6 years 12Y Every 12 years

Activity	Frequency	Observations
ELECTRICAL TESTING • PV String – open circuit voltage measurement • PV String – operational current measurement	3M 6M 1Y 3Y 6Y 12Y	V_{oc} must be measured on the line side of the fuseholders (DC junction boxes) after removing the fuses. It should be measured with a suitable dc voltmeter. I_{mpp} must be measured under plant normal operation with suitable dc clamp meter. Both test must be performed under stable irradiation conditions and without shades on the strings (midday hours). V_{oc} and I_{mpp} values for different strings connected to the same inverter should not differ more than 5%. All measured values for each string should be recorded in corresponding logbook.

THERMOGRAPHY ON PV MODULES
• Perform a thermography analysis in order to diagnose:
  • Hot spots in solar cells.
  • Contact faults and short circuits in solar cells.
  • Penetrated humidity and contamination.
  • Cracks in cells or in module's glass.
  • Nonfunctioning or disconnected modules.
  • Mismatches losses (loss of performance due to different capacities of individual modules).
	3M 6M 1Y 3Y 6Y 12Y	Replace damaged module as shown on thermography analysis.
		Thermography analysis should be made on all solar modules once a year but especially on those strings underperforming when needed in order to detect and correct in advance any eventual damage.
		Thermography should be performed under high irradiance conditions (ideally higher than 500 – 600 W/m^2) and under plant normal operation.
		Record irradiance values from pyranometers at the time thermography is carried out.

Module mounting structure (MMS)

Activity	Frequency	Observations
◆ Check for tables levelling and solar panels alignment. ◆ Check for any structural profile deformation. ◆ Check galvanization for any wear, rust or degradation. ◆ Check tightness of bolts. ◆ Check correct position and bonding of PV mesh cable tray.	**3M** 6M 1Y 3Y 6Y 12Y	◈ Restore normal operation condition, replace damaged component or start repair process.

Inverters

Activity	Frequency	Observations
◈ VISUAL INSPECTION ◆ Check that inverter is properly identified showing inverter number as per approved diagrams. ◆ Check for any mechanical damage to the casing. ◆ Check for any suspicious noise from fans bearings. Replace if necessary. ◆ Check for dustiness, corrosion and abnormal operating temperature. ◆ Check cabling and inside cabinets for any evidence of rodent or pest infestation.	3M **6M** 1Y 3Y 6Y 12Y	
◈ INVERTER FUNCTIONALITY ◆ Check configurations as specified in user's manual. ◆ Check inverter normal operation parameters (MPP function mode, no alarm messages). ◆ Measure input voltage. ◆ Measure input current. Refer to and record simultaneous irradiance value. ◆ Measure voltage, current and frequency for each phase output. ◆ Compare measured values with values showed in inverter control display.	**3M** 6M 1Y 3Y 6Y 12Y	◈ Measurements must be done at midday hours: ◆ All measurements data must be recorded in a logbook, including values showed in inverter control display as well as inverter serial number. ◆ Suitable multi-meter must be used when measuring electrical parameters. It is advisable to use always the same multi-meter so that values from different maintenance campaigns can be properly compared.

3M Every 3 months **6M** Every 6 months **1Y** Yarly **3Y** Every 3 years **6Y** Every 6 years **12Y** Every 12 years

Activity	Frequency	Observations
◈ FANS ◆ Change of inverter's fans.	3M 6M 1Y 3Y **6Y** 12Y	◈ Refer to Inverter Hardware Manual. NOTE: Maintenance work inside inverter cabinet will be made by manufacturer service engineers or by manufacturers authorized service providers, at least during warranty period.
◈ AGING ◆ Memory backup battery replacement.	3M 6M 1Y 3Y **6Y** 12Y	◈ Refer to Inverter Hardware Manual. NOTE: Maintenance work inside inverter cabinet will be made by manufacturer service engineers or by manufacturers authorized service providers, at least during warranty period.
◈ CONNECTIONS AND ENVIRONMENT ◆ Heatsink temperature check and cleaning. ◆ Cabinet air filter replacement. ◆ Check and cleaning of power connections. ◆ Replace flat ribbon cables. ◆ Check fiber optic cable connections. ◆ Check condition of contactors. ◆ Check tightness of terminals.	**6M** **1Y** **3Y** **12Y** **3Y** **3Y** **6Y**	◈ Check cleanliness of the heatsink every time the inverter runs into 1 overtemperature warning. NOTE: Maintenance work inside inverter cabinet will be made by manufacturer service engineers or by manufacturers authorized service providers, at least during warranty period. NOTE: Maintenance work outside the inverter cabinet, i.e. filter change/replacement and cleaning, can be made by a trained person.

LV switchboards

Activity	Frequency	Observations
◈ VISUAL INSPECTION ◆ Check for board's main data plate bearing the correct tag name according to plant drawings and any other necessary information. ◆ Check that single-line diagram for Auxiliary Services is available close by the switchboard and that all components in the board are individually identified and that the codes are according to those shown on the diagram.	**3M** 6M 1Y 3Y 6Y 12Y	◈ Restore normal operation condition, replace damaged component or start repair process.

Activity	Frequency	Observations
◆ Check that all mandatory warning signs are properly attached to the enclosure and are visible enough. ◆ Check for the presence of any strange bodies or traces of animals (rodents, insects) inside the board. ◆ Check for the presence of any dust, mould or traces of condensation or oxidation inside the board. ◆ Check correct operation of doors, related closures and any door interlocks. ◆ Check general conditions of area surrounding the board (cleanliness, presence of extraneous materials, obstacles impeding board access or door opening). ◆ Check tightness of the enclosure, condition of seals (doors, cableways and cable glands) and efficiency of closure elements. ◆ Check the cleanliness of the equipment and inside enclosure. ◆ Check that there are no obstructions in air-intakes for ventilation and cleanliness of air filters if any. ◆ Check busbars and cable terminals for any trace of burns or discharges.	3M 6M 1Y 3Y 6Y 12Y	
◈ LV SWITCHBOARDS FUNCTIONALITY ◆ Check that all MCB are closed and there are no opened or tripped MCB. ◆ Check that all RCCB (Residual current circuit breaker) are closed and there are no faults or tripped devices. ◆ Check function of RCCB by using test function.	3M 6M 1Y 3Y 6Y 12Y	◈ Restore normal operation condition, replace damaged component or start repair process.

3M Every 3 months 6M Every 6 months 1Y Yarly 3Y Every 3 years 6Y Every 6 years 12Y Every 12 years

SCADA system

Activity	Frequency	Observations
◈ Check that master control unit is properly connected with the rest of the equipment and is receiving consistent data from: ◆ All inverters ◆ Weather station ◆ MV switches status ◆ Transformer status ◆ Fire detection stations ◆ Meters data (main and auxiliary) ◆ IEC RTU ◈ Check that this data is properly stored in SCADA server and back-up copies are carried out periodically. ◈ Check functionality of SCADA software, review configuration parameters and check absence of alarms and error messages. ◈ Verify correct and safe communications between local SCADA and remote units controlling and supervising the plant operation.	3M 6M 1Y 3Y 6Y 12Y	◈ For SCADA specific maintenance and verifications activities refer to specific monitoring and SCADA operation manual.

3M Every 3 months 6M Every 6 months 1Y Yarly 3Y Every 3 years 6Y Every 6 years 12Y Every 12 years

Corrective maintenance. Procedure for corrective maintenance, maximum response time

Corrective or reactive maintenance addresses equipment breakdowns after the occurrence and includes all unplanned activities resulting from unforeseen events such as:

- Repairing inverter faults or breakdowns.
- Tightening cable connections that have loosened.
- Replacing blown fuses.
- Repairing lightning or harsh weather conditions damages.
- Repairing equipment damaged by intruders.
- Rectifying SCADA faults.
- Repairing mounting structure degradation.
- Others.

The operator in charge of the solar plant will be responsible for carrying out all the corrective maintenance in accordance with the applicable state regulations, the O&M contract, and the instructions of equipment manufacturer, in order to fix such defect and maintain the full functionality and performance of the facility.

When a fault is detected by the operator, the operator will promptly commence the required corrective maintenance, in order to return the facility to full operation under normal conditions as soon as possible. At the same time, maximum response time should be agreed and dully included in the operation and maintenance manual of the plant, to be signed between the owner and operator. As a recommendation, 24h on-site approach could be adopted as a general rule, that is, the operator in charge (on-site) will respond, while a well skilled technician will visit within the first 12 hours, to inspect the failure or malfunction, and within 24 hours the failure or malfunction must be corrected and the defective parts changed. This maximum response time will apply to those repair tasks which involve components and materials available on-site (stock). For any other major repairs which may require components and materials not readily available, all effort must be made to carry them out in the shortest time possible.

Corrective maintenance will be carried out in the course of preventive maintenance visits, or when a malfunction or incident affecting the plant is reported. This service will include:

- Analysis of the malfunction event.
- Supply of corresponding spare parts held in stock in the plant.
- Repair or substitution of the defective equipment or components, as well as its reconditioning (except for modules, which will be replaced using new stock) and commissioning.
- Replacement of the stock in the same quantity and quality as the components used, in the shortest time possible.
- Reporting the causes of the malfunction and the reparation tasks carried out.

The operator team will carry out the replacement of a malfunctioning component using a new or reconditioned component of equivalent quality; provided that only components already installed will be eligible for reconditioning.

The operator will provide all workmanship, parts and materials required in the course of the corrective maintenance contract. All electrical installation and maintenance work on the facility should be carried out by qualified electricians.

Corrective maintenance for equipment requiring especial attention (e.g. inverters, MV cabinets, transformers) will be managed by the plant operator and carried out by qualified manufacturer technicians or authorized service providers, especially under the equipment warranty period.

On a monthly basis, the operator will produce detailed reports of corrective maintenance activities carried out, including any and all repairs and/or other corrective measures implemented during the month. The reports will include, at least, the following:

- Date and time of fault occurrence.
- Description of the actions/activities carried out to fix the fault.
- Date and time of the rectification of the fault.
- Pictures of the damaged equipment and/or infrastructure showing its previous and final condition.
- Information related with any stoppage of operation required for carrying out corrective maintenance, including the date and time of the stoppage and date and time of operation resumption.

Condition-based maintenance. Critical parameters to be monitored

In addition to scheduled preventive maintenance, given that the PV plant is continuously monitored (24/7), immediate action can be taken, if analysis of the available data indicates a need to. This maintenance procedure should be carried out if one or more indicators show that the equipment is going to fail or that equipment performance is deteriorating. The main situations that could indicate the need for corrective actions, arising from data analysis are as follows:

Monitored parameters	Corrective action
◈ Inverter performing more that 5% below the average of the other inverters [1] & [3]	◈ Check that there is no alarm in inverter control unit showing inverter abnormal status. If so, proceed as per inverter firmware manual. ◈ Test electrical performance of strings connected to the inverter. See if there is any string(s) showing a performance clearly below the average or the expected value. ◈ If inverter underperforming can be attributed to its DC side then follow preventive tasks: ◆ Check for unwanted shadowing. ◆ Check for any damaged module or brownings. ◆ Check level of dust on modules. ◆ Check functionality of corresponding junction boxes (fuses and switch status). ◆ Perform a thermography analysis if necessary. ◈ If inverter underperforming cannot be attributed to its DC side follow preventive tasks: ◆ Visual inspection, paying especial attention to suspicious noise from fans bearings, abnormal operating temperatures and cleanliness. ◆ Check configurations in inverter control unit. ◆ Check tightness of connections and replace air filter. ◈ Contact authorized service.
◈ A JB performing more than 5% below respective inverter average [2] & [3]	◈ If measures from junction boxes current sensors show relevant underperforming of one junction box the following checks must be observed: ◆ Check for unwanted shadowing. ◆ Check for any damaged module or brownings. ◆ Check level of dust on modules. ◆ Check functionality of corresponding junction boxes (fuses and switch status). ◆ Perform a thermography analysis if necessary.
◈ Low PR of the plant according to time of the year [3]	◈ Clean all the solar modules with clean water and a brush. ◈ Check for correct position and clean external glass dome of the pyranometers.
◈ Electrical fault ground	◈ Proceed as per inverter operation manual. ◈ Proceed as per preventive maintenance.

Notes:

1. When performing this analysis, different inverter DC configuration must be accounted for and, therefore, each inverter performance must be corrected proportionally according to its respective number of DC inputs.
1. When performing this analysis, different junction box DC configuration must be accounted for and, therefore, each box output must be corrected proportionally according to number of connected strings.
1. It is understood that all three underperforming analysis parameters (inverter, junction box and PR of the whole plant) should be carried out over a significant time period, and not based on momentary readings of different measurement devices. It is also advisable that these comparative analysis, only consider data obtained at midday, so as to avoid anomalous performance behaviour that could occasionally occur during sunrise and sunset.

The project is implemented by IBF International Consulting, EQO-NIXUS (OCA Global) and IDOM

This project is funded by
the European Union