Hub Guide 15 - Commissioning, Operation and Maintenance Requirements of Solar Farms

Introduction

This Hub Guide is an introduction to the requirements typically encountered to commission[1], operate and maintain a solar farm. The Greater South East Net Zero Hub has also developed a series of Hub Guides which are available on our website and complement the LGA Renewable Energy Good Practice Guidance. This includes our Guide to assist anyone undertaking due diligence when looking to develop renewable energy generation, with particular reference to power projects: Hub Guide 4 - Due Diligence in Large-Scale Renewable Energy Projects.

The terms *solar farm*, *solar PV scheme,* and *plant* are used interchangeably in this Guide as short-hand for any free-standing grid connected ground-mounted solar Photovoltaic (solar PV) array of sufficient generating capacity to warrant the employment of an Engineering, Procurement and Construction (EPC) contractual arrangement. However, the principles of solar PV measurement, performance and management discussed in this Guide can be applied, with caution, to other forms and scales of solar PV array, and indeed other renewable power generation technologies.

If you have any questions, please refer to the Greater South East Net Zero Hub website www.gsenetzerohub.org.uk or contact info@gsenetzerohub.org.uk.

Basic Principles

The commissioning of any solar PV scheme is the point at which it is tested electrically and connected to the generation network. The basis of the commissioning process, and the development of the operation and maintenance (O&M) contract, is to ensure that the production of electricity from the plant is maximised. The initial engineering, procurement, and construction contract (EPC) should provide guaranteed levels of electricity generation. This guide concentrates on the nature and implementation of these guarantees. During the O&M period, the focus is on the extent to which the solar farm is available to produce electricity and performance optimisation.

Roles and Responsibilities

Depending on the delivery model, the following roles usually apply:

Owner – For the development and subsequent operation of a solar farm, the role of client may be the sole responsibility of a single organisation from project concept to operation, or the responsibility of different organisations if the project is sold on or transferred. For the purposes of this guide, this role acts as the counterparty (contractually, *the employer*) to the EPC and O&M contractor.

[1] The tests and procedures that are undertaken such that a solar PV generating station is capable of commercial operation.

Engineering, Procurement and Construction (EPC) and EPC contractor – Contracting is a version of design-build, where the contractor bids and builds a full turnkey facility for the plant owner with the contract specifying plant performance guarantees. These guarantees can include guaranteed plant output capacity, annual energy production and availability. Upon completion of start-up and testing on EPC projects (i.e. commissioning) the EPC contractor is responsible for delivering a solar PV scheme that meets all performance criteria by a specified date. The various activities may be the responsibility of a single contractor or broken down to sub-contracts.

Operation & maintenance (O&M) contractor - The Operations and Maintenance (O&M) contractor is appointed by the solar farm owner to oversee the technical operation of the plant. This will include routine maintenance and cleaning, site grounds maintenance, security and unscheduled fault finding and repair, to optimise the output of the installation. The various activities may be the responsibility of a single contractor or broken down to sub-contracts.

Network operator – Depending on the point of connection and voltage level, the solar farm will connect either to the Transmission Grid, which is managed by the Transmission System Operator, or the Distribution Network, which is operated by the Distribution Network Operator. Their role is to manage connections to their part of the power network and maintain its operation to regulated system standards. The network operator will inspect and sign off the connection according to the prevailing system protection code, in this case *ER G99 Requirements for the connection of generation equipment in parallel with public distribution networks*. In particular, the network operator will undertake a technical appraisal called *acceptance tests*, prior to allowing the solar farm to export power to the network.

Third party technical assessor – As part of the due diligence process, an independent technical assessor may be employed to validate the process of commissioning, as set out in the EPC contract on behalf of the employer.

Initial Assessment

Each solar panel has an output rating in watts, which represents its maximum power production, and is expressed as *kilowatts peak* (kWp). Forecasts for power generation are expressed in annual kilowatt hours (kWh) per kWp installed. This can be estimated using the free PVGIS Europa tool. During the design work for a solar scheme, energy yield assessment is established. This in turn should form the basis of performance requirements for the EPC contract at the invitation to tender (ITT) stage. The ITT should require an EPC contractor to commit to guaranteed production figures and this is done via a performance ratio. The Performance Ratio (PR) is the ratio between the actual energy yield generated by the plant, and the theoretical yield that would be generated if the solar panels converted the irradiation received into useful energy according to their rated capacity.

Guaranteeing Power Output Through Contract Measures

It is standard practice to require EPC contractors to quote a guaranteed performance ratio as part of their tender submission. This will form the basis of both the testing and commissioning process and underpin the calculation of any liquidated[2] damages for performance.

Typically, bespoke software such as PVSyst is used to model the anticipated system performance during the project development phase, and modelling output should be an integral part of any EPC tender return. The models are technically complex and will need to be produced and reviewed by a suitably qualified and experienced engineer. The assumptions underpinning the model are key to the quality of the evaluation, and include factors such as anticipated irradiation levels, specification of equipment to be used, and loss factors, such as electrical losses from cables and dirt on the solar panels. The performance ratio generated for an EPC tender submission will form the basis of the energy generation guarantees in an eventual EPC contract.

The EPC contract will use the performance ratio in three different completion tests, which are set out in the commissioning section below.

The performance ratio is not typically used in O&M contracts to underpin guarantees, as it is significantly impacted by both design and build quality, which are often the responsibility of the EPC contractor. It can however be a useful tool in monitoring and evaluation and in incentivising O&M contractor performance.

The IEC standard *EC TS 61724-2:2016(E)* defines the procedure for measuring and analysing the power production of a photovoltaic system, with the goal of evaluating the quality of the PV system performance. This applies both at commissioning and subsequent performance testing during the life of the installation. It does so by comparing the measured power produced to the expected power. To do this properly, both a weather station and at least one pyranometer[3] must be installed in the same plane as the solar panels. The O&M contract must ensure that the pyranometer is cleaned on a regular (ideally monthly) basis.

Yields and yield losses

Models and test reports, whether at commissioning or subsequent performance monitoring, may involve yields and yield losses. A yield is the ratio of the quantity of energy produced to the power rating of the array. It indicates the actual performance of the array relative to its rated capacity. A reference yield is the sum of solar irradiance and the nameplate capacity of the panels at standard conditions. Yields are expressed in units of kWh/kWp. Yield losses represent the amount of time the array would be required to operate at its rated capacity to provide for the respective losses during the reporting period.

[2] A fixed or determined sum agreed by the parties to a contract to be payable on breach by one of the parties.
[3] A pyranometer is used for measuring actual solar irradiance on a particular surface.

Generation availability

The continuity of power production is termed availability. It is expressed as a percentage (%), and usually measured over a period of months or a year. The O&M contract should specify that the technical or actual availability will not be less than the guaranteed availability set out in the O&M contract. For example, remedial action and damages should be triggered if the plant operation falls below a set level of availability.

Availability calculations need to be reviewed carefully to ensure that they capture losses down to a string[4] level. To do this, both the EPC and O&M contracts should specify that monitoring will be at a string level. The contractors, whether under the EPC or O&M contract, will be entitled to have certain events discounted in the availability calculations, for example, if the grid capacity is not available for export, or if a component has failed and its replacement cannot be sourced rapidly. Ideally, an O&M contract will provide guaranteed availability of at least 98.5%.

Clipping

Clipping refers to the situation where the generation capacity of a solar array exceeds the capacity of the inverter[5] and energy production is lost or 'clipped'. This is however a normal part of most solar PV design. The oversizing of peak power to inverters by a ratio of up to 1:1.3 is standard practice, as this maximises production at other times, so some clipping during peak production on sunny summer days is both expected and desirable.

Curtailment

Curtailment refers to a situation where the power generated by the plant exceeds the limit of what the grid can accept, and the network operator consequently switches off a number of generation stations to manage this. This is particularly common in areas where active network management[6] is in operation. The grid connection offer and connection agreement should set out where the solar scheme is in the queue to be switched off when over-production occurs and provide a forecast of how frequently this is expected to occur. Understanding the level of curtailment will be necessary when assessing the investment return as part of the business case for a scheme. Some network operators publish data and mapping to indicate the likely level of curtailment an energy generator may expect where active network management is being applied. Connection offers in such circumstances may be referred to as flexible or non-firm connections.

[4] Solar panels are generally connected in series. These connected panels are referred to as a 'string' and typically contain between 10 and 30 modules. These are then connected through inverters to the network via a customer and Distribution Network Operator sub-station.
[5] An inverter converts the Direct Current (DC) power produced by the plant into the Alternating Current (AC) to be used by industry and homes.
[6] Active Network Management is a system that allows network operators to control and alter the output of generators connected to their network.

Commissioning Requirements

A key part of the commissioning process is ensuring that the protection relays[7] are working properly, both to protect the solar farm from problems on the network (for example voltage fluctuations or power cuts) and to prevent damage to the network should the solar farm not perform as intended.

Prior to commissioning, the EPC contractor will need to have completed most of the electrical testing of components and sections of the solar farm.

Once the build has been completed, the solar farm will enter an extended period of commissioning and testing. It will not achieve full sign-off under the terms of the EPC contract for at least two years after it starts to produce electricity. The tests are set out below:

- Connection and G99 connection testing – The Engineering Recommendations (EREC) that cover the connection of distributed generation to the electrical distribution network are *EREC G98* (for smaller generation capacities less than 16A per phase) and *EREC G99* (for all other projects). Commissioning can only take place once the construction is complete. EREC G99 details the commissioning tests that the EPC contractor needs to perform on behalf of the developer. For generating units covered by EREC G99, it is the developer's obligation to undertake appropriate commissioning tests, which the DNO may (and probably will) choose to witness. The connection agreement issued by the DNO may also set additional requirements that will need to be met at commissioning and during ongoing operation over the life of the installation. Prior to undertaking the connection tests, the EPC contractor will need to have physically completed the electrical installation, including provision of the meters and the meter cabinets.
- The first stage of acceptance testing after commissioning is works acceptance. This is a physical check of the installation, similar to practical completion in a standard building contract. This work is done by the EPC contractor and is generally independently inspected by the third-party technical assessor, where the site is being handed over to *the employer* to operate. Once works acceptance has been achieved, the EPC contractor issues a Works Acceptance Certificate (WAC) alongside a punch list. The punch list details the actions needed to bring the site up to the expected contractual standard from the minimum allowed at this stage for acceptance.
- Provisional Acceptance Certificate (PAC) is issued when the plant is ready for hand over and the O&M contract can start. Key elements of the PAC comprise:
    - The Provisional Acceptance Tests (PAT) form a critical part of Provisional Acceptance. These are undertaken by the EPC contractor over several days when the measured irradiance at the site is greater than a threshold set in the contract (usually around 300 watt/m2 for at least 5 hours) and the measured availability is 100%. Days do not have to be consecutive but are usually within a set period. Ten days within a 30-day period would be usual for a summer

[7] A protection relay is a device designed to trip a circuit breaker when a fault is detected.

connection. Winter tests can take longer as fewer days meet the minimum irradiation criteria. The data provided by the EPC contractor to demonstrate that the installation has passed the tests should be audited and signed off by a suitably qualified engineer, usually as part of the third-party assessment role.

- Provision of the Health and Safety Manual (which should also be accompanied by an O&M manual)
- Provision of as-built drawings including asset numbers
- Provision of a full suite of electrical test certificates
- Provision of all warranty documentation
- Any further tests or documentation required in the contract such as thermal imaging
- WAC certificate and punch list.

Successful completion of the PAT tests will trigger the end of the construction phase of works and will be confirmed through the issuing of a Provisional Acceptance Certificate. EPC Contracts generally include the date by which PAC must be achieved and after which delay damages are triggered. Delay damages are set out in the contract and represent the lost production revenues. All remaining payments, except a defined retention, are issued to the EPC contractor on issue of the PAC certificate. Retentions are around 5% but should always be sufficient to cover the difference between guaranteed performance and minimum performance levels set out in the contract. Note that below the minimum performance level the owner usually has additional remedies including rejection of the installation.

- Interim Acceptance Certificate (IAC) – This is usually undertaken by the EPC contractor at the first anniversary of the solar farm's successful completion of the PAC stage. The requirements for IAC comprise the completion of outstanding items on the punch list and successful completion of the IAC. The IAC is calculated over a full year of production and compares the actual energy produced with the energy production guaranteed in the EPC contract, accounting for actual irradiation and weather conditions throughout the year (as measured by the pyranometer and weather station). Successful completion of IAC usually triggers a release of 50% of the remaining retention to the EPC contractor.
- Final Acceptance Certificate (FAC) Test – The methodology for FAC is the same as for IAC, but a full two-year period from the issue of the PAC certificate should be included, regardless of whether the IAC was passed. Failure to pass the FAC test by the date set out in the EPC contract (usually two years after PAC) results in performance damage owed to the employer by the EPC contractor becoming due.

Some periods may be excluded from the calculations, such as periods of DNO curtailment. As previously stated, It is recommended that a specialist engineer is retained by the employer in the third-party assessor capacity to ensure the test calculations and methodology are correct in the EPC contract and in the performance of the tests.

Note that the last two years of the EPC contract from PAC to FAC need to run concurrently with the first two years of an O&M contract. They are generally both provided by the EPC contractor at this stage. The EPC contract damages relate to guaranteed energy production under the production guarantees, whereas the O&M contract will deal with the availability of the plant to produce energy.

Ongoing Operation and Maintenance (O&M)

A connected solar farm will need an O&M contract. This will include both visual and electronic monitoring, testing and inspection, and the provision of an appropriate level and quality of spare replacement parts, which may be critical to continued operation if failure is experienced. The O&M contract should specify both minimum schedules of inspection, monitoring and testing, as well as stock levels of spares, and response times to return to expected output in the event of any drop of operational performance. The O&M contractor should also be responsible for site safety and security and for the management of warranty claims.

Ensuring that string-level monitoring has been specified in the EPC contract will significantly improve the quality of information about underperforming areas of the solar farm.

Schedules will also cover activities like grounds maintenance (e.g. grass cutting cycles) and panel cleaning to maintain performance of the panels.

Performance will be measured according to agreed schedules of activity, performance benchmarks and response times, as well as following observed drops in plant performance, using some or all of the key performance measures discussed in this Guide. Damages payments will be calculated by the owner against the O&M contractor using a guaranteed level of availability.

O&M contracts can incorporate performance standards and a range of associated mechanisms for compliance:

- **Service-level agreements (SLA)** specify compliance timeframes for responding to and resolving a range of plant conditions, based on equipment type and issue severity level. For example, specifying response times following a report of an outage or failure.
- **Availability or 'uptime' guarantees** define the percentage of time that a system must be fully able to produce electricity. Availability guarantees are typically set at 98–99% per year but will exclude events such as grid curtailment periods, network unavailability or sections of the solar farm which are waiting for replacement equipment that is not held as spare parts.
- **Production targets** state annual plant production targets, independent of weather conditions. Insurance coverage can be used to mitigate weather risk, though it can be an expensive policy to underwrite.
- **Performance incentive** can be used to reward plant performance that exceeds target levels.

Asset Management

To fully optimise a solar farm, an asset management contract could be let in addition to the O&M contract. Asset management will manage the O&M contractor and undertake engineering review and optimisation work, as well as providing book-keeping and other management services. It is possible for O&M contractors to achieve the minimum performance standards in their contracts without fully optimising the performance of the plant, so using an asset management service increases the focus on electricity (and therefore income) generation. Asset management typically costs around £2,500/MW pa, so the additional performance achieved by this service should cover its costs as a minimum.

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