Annex 15

Commissioning Tests

Macao Installation

REVISION HISTORY

Revision Level	Change Summary	Elaborated by	Approved by	Date

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1 Overview

The Contractor will be responsible for the Commissioning of the System and performing the Performance Tests.

The testing phases are divided as follows

1.1 Commissioning Tests

Measures, checks and tests to be done prior to and including the connection of the Plant to the electrical grid.

2 General Requirements

2.1 Operation during Testing and Commissioning

During the Commissioning and the Provisional Acceptance Test, the Plant will be operated by the Contractor until PAC, with the O&M Contractor's staff in attendance under the direction and supervision of the Contractor.

After the issue of the Provisional Acceptance Certificate, the O&M Contractor shall operate the Plant in accordance with the O&M manuals provided by the Contractor. The Contractor shall remain responsible for the satisfactory performance of each test.

2.2 Procedures and Testing Equipment

The Contractor shall be responsible for providing all the necessary equipment, manpower, materials, consumables and services to meet his commitments with regard to this phase of the work.

The Contractor shall comply with all of the Distribution Network Operator (DNO from now on) safety procedures and be responsible for all coordination of installation and testing protocols including system and F21/F22 testing and commissioning. The Contractor shall liaise with the DNO and programme the DNO's commissioning engineer in sufficient time so that the testing proceeds without delay.

All tests and such activities may be witnessed by the Owner's agent or representative. Third parties may also witness some or all of the tests if and when required.

The Contractor shall make all necessary arrangements to obtain and record all test data as may be required while the Owner may check data as desired.

The contractor must send prior notification of the test to be performed to the client, if the client does not receive notification, the test carried out will not be valid and will have to be repeated.

2.3 Commissioning Plans, Procedures and Programme

The Contractor shall submit detailed commissioning and testing procedures to the Owner for all commissioning activities and Performance tests to be carried out. The procedures shall cover all required safety measures together with all necessary inspections, adjustments and tests to achieve progress through operation from no load to full load capacity

The Owner shall review the Contractor's submission and notify the Contractor in writing whether or not all test pre-requisites have been satisfied. If the Owner provides comments, then the Contractor shall revise the Test Protocol to address these comments and resubmit it for review and approval within two (2) business days thereafter.

If the Contractor fails to timely provide any of the required notices, such that the Owner or his Representatives are not able to witness the test then the Contractor may be required to repeat the tests at his own cost.

The procedures shall be divided into sections for each item of Plant or system and shall include:

- **Documentation identifying the major components with references to the relevant**

instrumentation and interlocks.

- **A description in the form of a list, table or similar or the design operating conditions with details of all restrictions, precautions and limits on Plant operation applicable to that section of the Plant during the pre-commissioning and commissioning periods and then to subsequent operation.**
- **A detailed program, for the activities to be carried out for the completion of its commissioning and performance trials.**

2.4 Copies of the Contractor's check sheets for the pre-commissioning, commissioning and testing of each Plant item or system. Test Records

- **The Contractor shall be responsible for supplying to the Owner copies of all test documentation for the complete Plant. All original and signed test records sheets shall become the property of the Owner and shall be handed to the Owner following each test.**
- **Unless noted otherwise, the Contractor shall promptly prepare and submit a detailed test report to the Owner within 15 business days of completion of any test. The test report shall include the test procedure, description of any deviations from the test procedure of unusual event(s), which occurred during the test, copies of test data sheets, calculated results, copies of lab analyses, copies of instrument calibration records, technician name and supervisor.**
- **Test results should be recorded and submitted to the Owner, the forms should always provide a means for recording:**
  - **The equipment under test and expected results**
  - **Test equipment used and calibration certificates.**
  - **The name of the person(s) who performed the test & date/time the test was carried out**
  - **Details of the operational testing carried out, the results of the tests and of any adjustments necessary to enable the equipment to meet its specified requirements.**
  - **Confirmation of pass/fail or any remedial action**
  - **Relevant standards (e.g. IEC 61724, Photovoltaic systems performance monitoring - Guidelines for measurement, data exchange and analysis)**
- **The Contractor shall certify to the Owner in writing that the Test results and supporting data provided by the Contractor are complete, current and accurate.**
- **The Owner shall confirm his acceptance or rejection of the test reports within five (5) business days of receipt.**
- **If the Test results are rejected or incomplete, the Owner shall provide the basis for rejection and/or identify the missing information together with the necessary corrective action (which may include a repetition of the test).**

2.5 In case of Dispute

- **If the Contractor disputes the Owner's rejection of any Test results or other Owner determinations with regard to the Tests Protocol, Contractor shall follow the procedure for Determinations under the Contract and if no agreement is reached the Disputes Resolution procedures set forth in the Contract.**

3 Commissioning Tests

The Commissioning Tests are designed to verify that the Plant is completed, connected and energised to the grid (with the F21 and F22 witness test certificate issued by the local DNO). The test sequence shall follow a structured programme with logical progression for each sub- system and system until the Commissioning is completed

The Contractor shall undertake all installation checks, preliminary mechanical and electrical checks, proving the integrity of all connections (mechanical and electrical), safety systems and verification that all Plant is functionally complete.

Once the component or system is charged, energized or otherwise made live, the Contractor shall conduct further tests to demonstrate that the system and its constituent components function collectively as designed, that individual components operate at varying loads under steady state conditions within their stated operating parameters, and that the components and system respond correctly to transient conditions. The Contractor shall undertake whatever adjustments are necessary to achieve the optimal level of Plant reliability, capacity and performance. Base line operational temperature, voltage, current, ambient data shall be recorded for all equipment and systems.

3.1 System documentation requirements

Prior to the start of Commissioning Tests, the Contractor shall ensure that the Owner has been provided with the latest version of all relevant documents and drawings as detailed in Annex 9.

3.2 DC Circuits (Module Strings)

Commissioning Tests shall will be carried out in accordance with IEC 62446.

The following referenced documents are indispensable for the application of this standard.

For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

- **IEC 60364 (all parts, to the extent to which they may be applicable), Low-voltage electrical installations**
- **IEC/TR 60755:2008, General requirements for residual current operated protective devices.**
- **IEC 61557 (all parts), Electrical safety in low voltage distribution systems up to 1000 V AC and 1500 V DC – equipment for testing, measuring or monitoring of protective measures**
- **IEC 62446, Minimum requirements for system documentation, commissioning tests**

These tests are to verify that the strings have been correctly configured prior to connection to the electrical network and should be carried out when the irradiation is greater than 600W/m².

All measurements must be carried out using suitably rated & calibrated measurement devices which have a measurement accuracy of ±1% or better.

All personnel must wear the correct PPE and be trained in the safety aspects of

performing these tests.

The tests performed on all strings of the plant must be presented inside a unique Excel file using the following format:

Stringbox A1.1.1

			String ref.	Temp.	Open circuit voltage	Short circuit curr.	Insul. Resis. Short Circ.	Insul. Resis. Negative	Insul. Resis. Positive	Modules in series	Module 1	Module 2	Module 3
				T	*Voc*	*Isc*	*Rins-sc*	*Rins-*	*Rins+*				
				[°C]	[V]	[A]	[MΩ]	[MΩ]	[MΩ]	[#]	S/N	S/N	S/N
Stringbox ref.	A1.1.1		A1.1.1.1	34.0	801	8.12	0.99	1.59	1.05	22	A000000000001	A000000000002	A000000000003
Date	dd/mm/yyyy		A1.1.1.2	34.0	801	8.01	1.38	1.05	1.03	22	A000000000001	A000000000002	A000000000003
			A1.1.1.3	34.0	801	8.12	2.20	1.03	1.00	22	A000000000001	A000000000002	A000000000003
Start time	hh:mm		A1.1.1.4	35.0	708	8.12	1.25	1.00	1.00	22	A000000000001	A000000000002	A000000000003
Ambient temp.	34.3	°C	A1.1.1.5	33.0	801	8.12	1.16	1.00	1.16	22	A000000000001	A000000000002	A000000000003
Irradiance POA	825	W/m2	A1.1.1.6	35.0	802	8.11	0.98	1.00	0.98	22	A000000000001	A000000000002	A000000000003
			A1.1.1.7	33.2	801	9.00	3.00	1.00	3.00	22	A000000000001	A000000000002	A000000000003
Finish time	hh:mm		A1.1.1.8	35.0	802	8.12	1.00	1.08	1.59	22	A000000000001	A000000000002	A000000000003
Ambient temp.	34.2	°C	A1.1.1.9	34.0	802	8.12	1.12	1.01	1.05	22	A000000000001	A000000000002	A000000000003
Irradiance POA	829	W/m2	A1.1.1.10	33.0	801	8.14	1.00	2.16	1.03	22	A000000000001	A000000000002	A000000000003
			A1.1.1.11	32.0	799	8.12	1.59	0.50	1.00	22	A000000000001	A000000000002	A000000000003
			A1.1.1.12	30.0	756	8.12	1.05	2.56	1.00	22	A000000000001	A000000000002	A000000000003
			A1.1.1.13	30.0	780	8.12	1.03	2.89	1.00	22	A000000000001	A000000000002	A000000000003
			A1.1.1.14	30.0	801	8.12	1.00	1.16	1.00	22	A000000000001	A000000000002	A000000000003
			A1.1.1.15	30.0	803	8.12	1.00	0.98	1.08	22	A000000000001	A000000000002	A000000000003
String averages and st.dev.			A1.1.1.16	30.0	801	8.12	1.00	3.00	1.01	22	A000000000001	A000000000002	A000000000003
Temperature avg	31.8	°C	A1.1.1.17	30.0	801	8.12	1.00	1.00	2.16	22	A000000000001	A000000000002	A000000000003
Temperature st.d	2.1	°C	A1.1.1.18	30.0	800	8.12	1.08	1.12	0.50	22	A000000000001	A000000000002	A000000000003
Open circuit volt	794	V	A1.1.1.19	30.0	801	8.12	1.01	1.00	2.56	22	A000000000001	A000000000002	A000000000003
Open circuit volt	21	V	A1.1.1.20	30.0	801	8.12	2.16	1.59	2.89	22	A000000000001	A000000000002	A000000000003
Short circuit curr	8.15	A	A1.1.1.21	30.0	801	8.12	0.50	2.20	1.16	22	A000000000001	A000000000002	A000000000003
Short circuit curr	0.18	A	A1.1.1.22	30.0	801	8.12	2.56	1.25	0.98	22	A000000000001	A000000000002	A000000000003
Insulation resista	1.42	MΩ	A1.1.1.23	30.0	801	8.12	2.89	1.16	3.00	22	A000000000001	A000000000002	A000000000003
Insulation resista	0.68	MΩ	A1.1.1.24	30.0	801	8.12	2.12	0.98	1.00	22	A000000000001	A000000000002	A000000000003

Test equipment	**Serial**	**Calibration date**
Equipment num. 1	serial num. 1	dd/mm/yyyy
Equipment num. 2	serial num. 2	dd/mm/yyyy
Personnel		
Responsible Technitian name and surname		

3.2.1 Open Circuit Voltage Check

Calculate and record the expected string open circuit voltage using the following formula $V_{ocs} = N \cdot V_{oc} (1 + TC \cdot (T - 25))$

Where

V_{ocs} **is the expected string open circuit voltage**

N **relates to the number of modules in the string**

V_{oc} **is the module open circuit voltage at stc.***

TC **is the Temperature Coefficient of Open Circuit Voltage***

T **is the temperature recorded on the photovoltaic module representing the tested string, measured with an infrared thermometer with a precision better than ± 1%;**

*** taken from module datasheet**

The test shall measure and record the actual open circuit voltage (V_{actual}) of all PV strings in the Solar Park. This can be done without disconnecting cables by

making the measurements in the string boxes.

Before taking voltage measurements in each string box measure and record the irradiance in the array plane.

With all string fuses open, measure and record the voltages across the positive and negative terminals in the string boxes for 100% of strings in the Solar Park.

For test periods where the irradiance conditions are stable, then compare the voltages between strings and verify that these all have the same polarity and are all within ±5% of the average value and are all within ±10% of the calculated value.

For non-stable irradiance conditions, then a correction factor will need to be applied

3.2.2 Short Circuit Current check

The string box is arranged to measure two strings in parallel, but the short circuit current check will be done in each single string separately.

Prior to commencement of the short circuit test, measure and record the irradiance in the array plane.

With all inputs isolated from each other and all disconnecting means in their open position, introduce a temporary short circuit across the strings under test using a purpose designed and suitably rated "short circuit switch test box", measure and record the s/ccurrent.

The isc obtained must be compared with +/- 5% of the measured value-IEC 62446

3.2.3 Insulation Resistance (short circuited string to ground)

ALWAYS OBSERVE THE OPERATING INSTRUCTIONS OF THE TEST EQUIPMENT PROVIDER

Whilst the array string is still connected in short circuit, connect a Megger or other suitable device to the system to enable the application of a test voltage of 1500V between the short circuited array string and ground. Alternatively, an specific device that measure Voc, Isc and cable isolation, all 3 measures at once, can be used instead of a Meger.

Record the resulting insolation resistance and verify that this is greater than

1MΩ. Disconnect the Megger from the circuit and remove the short circuit

from arraystring.

3.2.4 Insulation Resistance (Principal DC Cables)

ALWAYS OBSERVE THE OPERATING INSTRUCTIONS OF THE TEST EQUIPMENT PROVIDER

Connect a Megger or other suitable device to the system to enable the application of a test voltage of 1500V between the short circuited cable from Combiner boxes to Power Stations and ground.

Record the resulting insolation resistance and verify that this is greater than 1MΩ.

Disconnect the Megger from the circuit and remove the short circuit from Combiner boxes to Power Stations.

3.2.5 I-V curves

The I-V curves will be carried out in at least 100% of the strings, with a minimum

radiation of 600 W / m2, according to IEC 62446-1, Requirements for testing, documentation and maintenance. Systems connected to the network. Documentation, start-up and inspection tests.

3.3 MV Cables

Once the MV circuit has been completed (all connections to transformers and protection devices completed) then pressure tests must be performed on all MV cables by a specialist contractor in accordance with an approved method statement .

The test to be performed must be insulation resistance before and after the VLF test, this test must be performed according to the Net ATS 2009 standard.

The VLF test must meet the IEEE 400.2 standard

3.4 Earthing

Perform a site earthing test to verify that the earth resistance is less than that given in the earthing report.

The test must be carried out on any element that has mechanical continuity such as the following:

- **100% Points of the structure,**
- **Each investor,**
- **Weather Station,**
- **The SCADA system cabinet (in each power station),**
- **Each AC box,**
- **CCTV system.**
- **Each Power station**

3.5 Grid, Inverters & MV Circuits

The procedures and timing for these tests will be subject to the agreement of the Grid operator. The test sequence will be established in conjunction with the DNO and may differ from the normal requirements noted herein

3.5.1 Cold Commissioning (F21)

Commissioning of DNO and Customer switchgear protection will be carried out, together with the DNO, to verify correct switching operations through the simulation of grid problems and verification of the protocols prior to connecting the plant to the electrical grid.

3.5.2 Provisional Electrical Connection (F22)

After completion of the cold commissioning and installation of the export meter a provisional electrical connection will be agreed with the DNO to allow testing of the inverters prior to final F22 loss of mains test.

During this period a maximum of 10% of the array strings will be connected to each

inverter to limit the total energy exported

3.5.3 Inverters

The inverter manufacture will configure the inverters, and commissioning will be carried out in accordance with their requirements and test protocols.

The inverter manufacturer will provide factory acceptance tests as part of the commissioning test report, including the recommendation of anti-islanding standards in accordance with IEEE1547 standards. • Verification of any remote inverter deactivation and reset control system, if installed, will be included. • Verification of automatic daily wake-up and sleep operations within manufacturer's specifications.

3.5.4 F22 Witness Test

Once all inverters have been tested and certified to be fully operational the Owner will call the DNO to perform the final, loss of mains, F22 witness testing.

3.5.5 Power station

Carry out the tests pertinent to the procedure that the supplier submits, including carrying out the following (non-limiting) verifications:

- **Visual verification**
- **Measurement of winding resistance**
- **Measurement of voltage ratio and verification of phase shift**
- **Measurement of short-circuit impedance and pressure drop.**
- **Measurement of low and medium voltage insulation resistance**
- **Measurement of no-load current.**
- **Verification of the ratio and polarity of the built-in current transformers.**
- **Relay test of protections with ohmicron**
- **Checking the oil level**
- **Ground connection test**
- **Cleaning verification**
- **Verification of sealing**
- **Gas leak verification**
- **Shutdown sequence checks**
- **Firing sequence checks**
- **Verify that the surge installer is installed correctly**
- **Aperture test and shots in all that apply**
- **Verification of voltage and functionality of the switches**

- **Configuration of parameters**
- **Check that MV circuit breaker operates normally in local position**
- **Check that the temperature and humidity display is normal**
- **Check that the circuit breaker protection and relevant instruments work correctly**
- **Setting humidity controller parameters**
- **Temperature controller parameter setting**
- **Shooting proof**
- **Smoke detection actions (shots and alarm)**
- **Check the fan operation**
- **Internal and external lighting test**
- **Reading of the oil temperature and the temperature of the transformer winding through the communication equipment**
- **Setting the IP address of the smart logger**
- **PLC configuration and white list in smart recorder**
- **Configure network code**
- **Check digital signal for signal chenge status (eg, operate switch, disconnector and switch and simulate alarms): Transformer alarm / trip**
- **Verify analog input using verification measurement, range, noise and trend comparison of quantities of the same type (eg oil temperature, DC chain current ...)**
- **Thermography in power station**

3.5.6 Tracker

The objective of this test is to verify the correct installation and proper assembly of the plant's solar trackers:

- **Visual check of all components (Panel, TCU, cables)**
- **Verification that there is no interference that prevents the follower from moving**
- **Verification that the TCUs are energized**
- **Checking the tightness of the cable glands**
- **Verification that the TCU is not uneven with the turning profile**
- **Adjust / Verify inclinometer with digital level**
- **Check the correct rotation of the motor**
- **Review of motor consumption**
- **Verify the correct configuration of the day and time (etc)**
- **Verify the correct operation of the Sw stop**
- **Verify correct operation of the 3 wind states**

- **Correct wind reading from Sw NCU**
- **Review and adjust shadow status in backtracking**
- **Check the angle of rotation**
- **Check the mechanical connection of the follower with its supports.**
- **Check the torsion between the follower elements.**
- **Verification of correct automatic operation**
- **Check status of inputs and outputs of the wiring of TCU and NCU**
- **Review of the complete follower follow-up**

3.5.7 Module mapping

The objective of this test is to verify the peak power of the plant by mapping the serial numbers of all the modules in the installation. The serial numbers of all the photovoltaic modules in the plant will be captured using a barcode reader. The reading of the codes must be done in a predetermined order that will be established on the floor before carrying out the procedure.

Once captured, this information will be integrated into an Excel file in which each serial number and its correlation with its position in the field are uniquely indicated (No tracker - No string –Position of the module in string- Pm (W) - Isc-Voc-Ipm-Vpm)

The information collected will be crossed with the Flash List that contains the electrical information of all the photovoltaic modules supplied, in order to calculate the peak power of each string in the field. The total power for each circuit and the total of the plant will be indicated in a table.

4.5.8 Optical Fiber

Verification of the correct installation and operation of fiber optic cabling, by means of reflectometry tests, according to the IEC 61280 standard.

3.5.8 Thermography

Scan each module in the matrix or sub-matrix in question, paying attention to blocking diodes, junction boxes, inverters, transformers, electrical connections or any matrix problems, in 100% of the plant, specifically identified that exhibits a noticeable temperature difference from your immediate environment.

For an IR camera inspection, the array must be in normal operating mode (maximum power tracking). The irradiance in the plane of the matrix must be 800 W / m² to guarantee that there is sufficient current to cause perceptible temperature differences, according to the IEC 62446 standard and the sky conditions must be stable.

The procedures for carrying out the inspection are listed in Annex D of IEC 62446

and must be followed.

The complete set of captured images will be provided to the system owner in a report and must:

- **Show the full range of temperatures in the cabinets or modules are captured in the image**
- **Make use of the camera's point temperature capability**
- **Show close-up of termination pools**
- **Minimize reflections**

3.5.9 CCTV

- **Verify that the installation corresponds to that projected on plans.**
- **Verify that the images from all the cameras are received at the Security System control center (both during the day and at night).**
- **Verify that all cameras are covered during the day and night.**
- **Verify that all equipment (primary and backup) is functional.**

3.5.10 SCADA

The following measurements must be carried out, which are not limiting:

- **Verify that the specifications of the equipment of the installed monitoring system are equal to or greater than those indicated in the plans and calculation memories.**
- **Verify that the monitoring system installation complies with all applicable codes, drawings and specifications and are installed in an environment appropriate for the proper functioning of the equipment.**
- **Verify that the weather station (s) are properly monitored.**
- **Verify that the display screen is fully operational.**
- **"Verify that the electrical parameters of all inverters are properly monitored, including but not limiting, at least:**
- **DC input voltage**
- **DC input current**
- **Calculated DC input power**
- **AC input voltage**
- **AC input current**
- **Calculated AC input power**
- **Power factor**
- **Verify that the availability of each installation is properly monitored, with a clear identification of each one.**

- **Verify that the energy generated by the plant per day, week, and month is properly monitored.**
- **Verify that alarms and faults are properly monitored along with the date and time of each event.**
- **Alarm and fault monitoring should include the type of defect and provide enough information to help identify the equipment that has generated the alarm.**
- **Verify that the monitoring system is connected to the energy meters and is equipped to provide real-time data to the electricity company (if the company agrees to monitor the billing meter).**
- **Verify that all the data from the Monitoring System is recorded and is visible from a single software platform provided as part of the monitoring system.**

3.5.11 Verification of DC low voltage drop

The purpose of this procedure is to verify that the Project meets the requirement to comply with the specified DC voltage drop in accordance with the Detailed Engineering Design and scope of work of the Agreement.

Test a sampling of 2% of the generating facility randomly distributed in the different areas of the plant at least and record the results.

The tests will be completed on a sunny, cloudless day with irradiance above 600 W / m2.