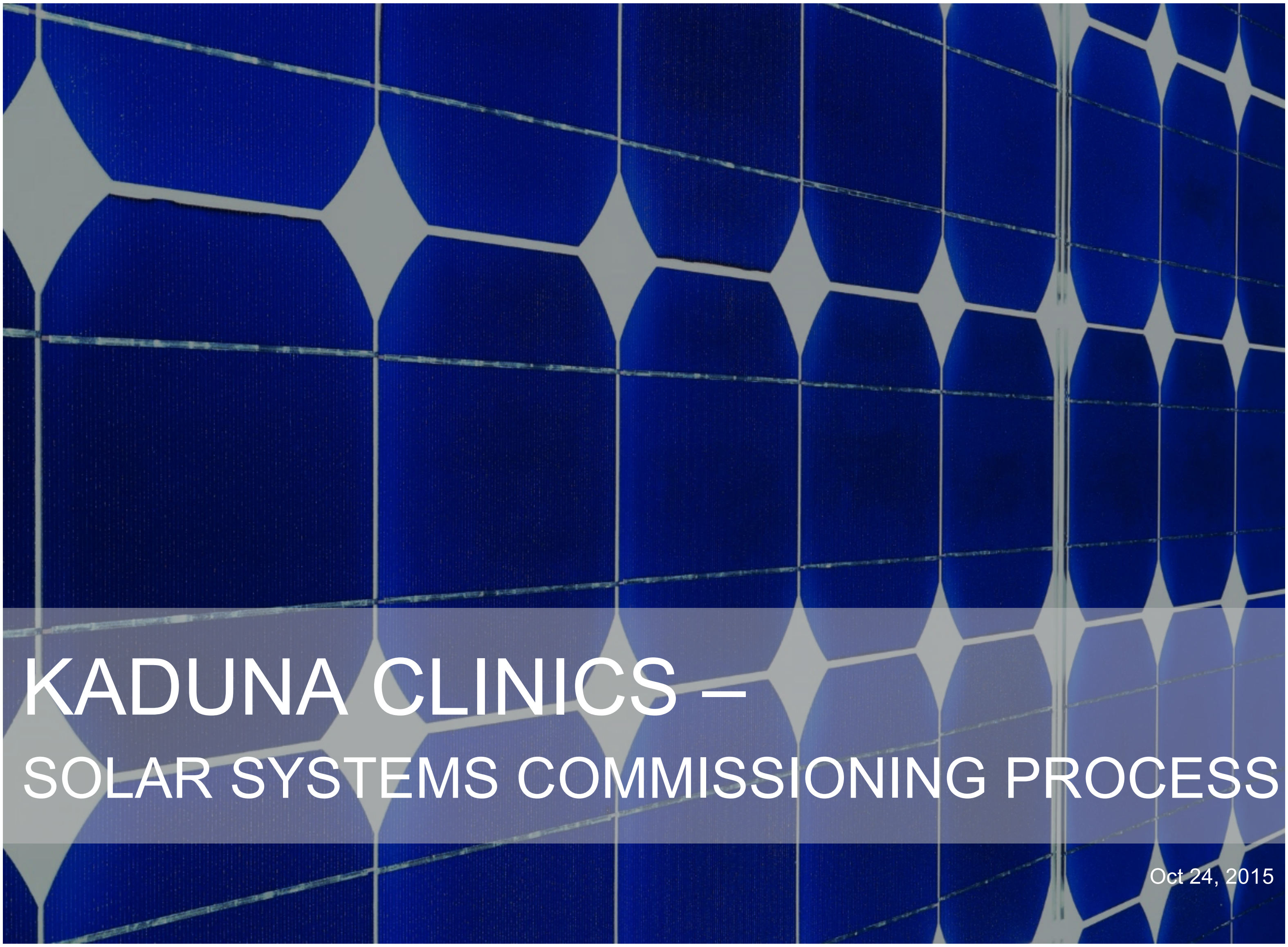


KADUNA CLINICS –

SOLAR SYSTEMS COMMISSIONING PROCESS

Oct 24, 2015

THE DESIGN AND ENGINEERING OF OFFGRID PV SOLAR SYSTEMS FOR PRIMARY HEALTHCARE CENTERS IN KADUNA STATE

Prepared for:

CROWN AGENTS

Crown Agents Limited

Prepared by:

EM-ONE Energy Solutions Canada Inc.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 ISSUE AND REVISION RECORD

Revision	Date	Originator	Checker	Approver	Narrative
1.0	09/10/15	UI/AA/ML	CK	MSI	

2 INTRODUCTION

This document is for the commissioning and inspection process of the Solar Systems implemented for 40 Public Health Centres ('PHC') of Kaduna State, Nigeria.

The PV systems being serviced as part of the project are detailed below, with summary descriptions.

Table 1: PV Systems to be serviced in Commissioning Procedures

System #	System 1	System 2	System 3	System 4	System 5	System 6	System 7
# of Systems	7	7	7	6	3	9	1
PV nominal DC power (kWp)	14.040	21.060	28.080	56.160	28.080	84.240	112.320
Inverter nominal AC power (kW)	1.500	2.650	3.600	7.200	3.600	11.500	14.500
Usable Energy Storage Needed (kWh)	75	150	175	350	75	150	300
Expected daily Energy capacity (kWh/day load)	26	48	64	128	64	204	336

All systems are providing electricity to PHC systems. The systems are concisely described within the single line diagrams (SLD) and updated from time to time. Although covering a significant range of PV plant sizes from 13.260 kWp to 112.320 kWp, the systems are similarly configured. The SLD will be used as the reference document for the inspections of the systems.

The inspection covers PV generation plant, DC-DC converters, inverters, battery storage, switchgear, and structures, from the PV array to the consumer main AC Distribution Board (DB). The AC distribution systems downstream of the consumer DB are inspected separately.

Commissioning is intended to confirm that: work is done to standard, equipment is to standard, equipment is operational within acceptable efficiencies and tolerances, and that component warranties could commence on that basis.

2.1 Requirements and Assumptions

- The inspections are intended to be done by a qualified electrical engineer or solar PV engineer, trained and with the relevant tools to carry out testing and commissioning of low voltage electrical systems
- Operational status of each system
  - Has never been switched on?
  - Has been switched on and charging battery without load?
  - Has been in full use?
- SLD documents are present on site.
- Downstream AC distribution system has been installed, checked and separately certified. Certificates are available on site.
- Management information system has all major components already scanned and verified on site. Certificate is available.
- The approved SLD for each system type is the reference document for checking the commissioning of the PV plant. It is assumed that the SLD design has been verified and signed off according to requisite standards and best practice, for each system. This should typically include:
  - Overall design layout, planning of primary junctions and enclosures, and switches
  - Isolators and breakers positioned at all necessary locations to facilitate:
    - plant safety during operation
    - commissioning and maintenance checks
    - isolation of components that are out-of-service.
  - All major components are appropriately configured and rated in the design:
    - to match both the upstream and downstream components,
    - considering maximum power handling, maximum currents and maximum voltages. Temperature de-rating is taken into account.
  - All isolators and breakers are rated and over-rated for PV applications as required, (voltage and current), and to take into account surge or in-rush conditions
  - Correct and consistent labelling of key components, enclosures, isolators and breakers

2.2 Reviewed SLD diagrams

The reviewed SLD drawing numbers are shown below for each system. Unless otherwise noted, the approval of a document with a later date supersedes the approval of the prior document, and therefore only the latest version is approved unless otherwise noted[1] (for instance some diagrams may have been approved for installations completed before a certain date, e.g. during the Pilot Phase of the project).

---

[1] Some SLDs may be approved and applicable to installations completed before a certain date.

Table 2: Reviewed SLDs for commissioning reference

System name	SLD name	Date submitted	Date approved
System 1	KCS/EM/SSD/SLD/SYS1		
System 2	KCS/EM/SSD/SLD/SYS2		
System 3	KCS/EM/SSD/SLD/SYS3		
System 4	KCS/EM/SSD/SLD/SYS4		
System 5	KCS/EM/SSD/SLD/SYS5		
System 6	KCS/EM/SSD/SLD/SYS6		
System 7	KCS/EM/SSD/SLD/SYS7		

3 TOOLS AND MEASUREMENT EQUIPMENT

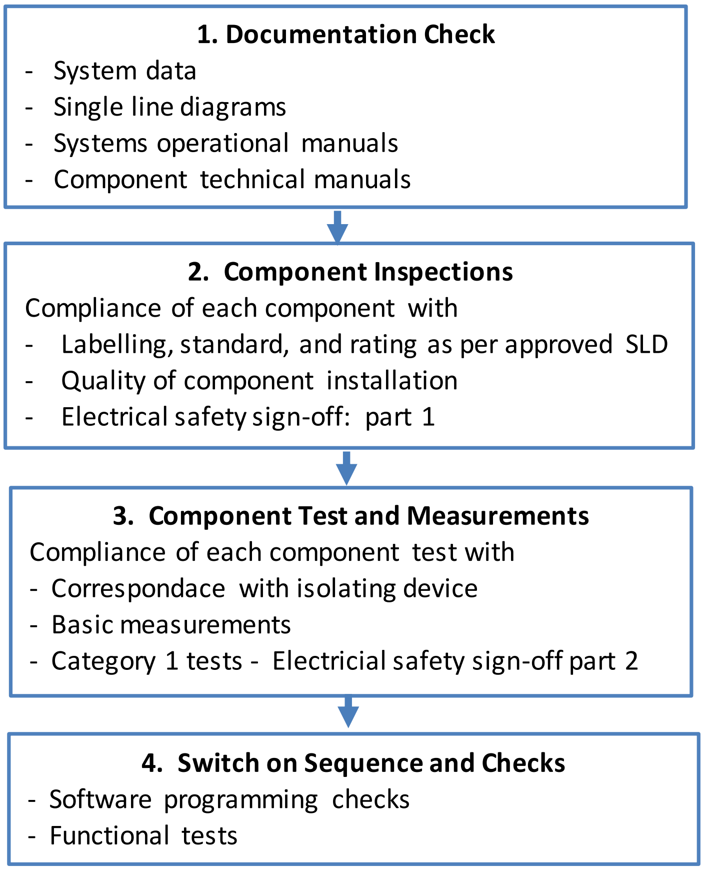
The following are the minimum tools and equipment required for the tests.

Equipment	Test and Measurement Process Reference Performance Tests
• Multi-meters (at least 2 of each) each capable of true RMS: similar to SEAWARD Solar Power Clamp™ ○ AC voltage (240Vac), DC voltage (1,000Vdc multi-ranging), resistivity, temperature	3.2; 3.3; 3.4; 3.5
• Current clamp-meters: similar to SEAWARD Solar Power Clamp™	
○ AC current (200Aac multi-ranging range)	3.2; 3.3; 3.4
○ DC current arrays (multi-ranging 100Adc)	3.5
○ DC current inverters (multi-ranging 400Adc)	3.2; 3.3; 3.4
○ Busbar measurements (1,000- 4,000Adc)	Optional for 3.4
• Power meter single phase – similar to SEAWARD Solar Power Clamp™ or Fluke 485 ScopeMeter™ ○ AC and DC ripple currents and clipping (50Hz range) ○ True power meter, harmonic distortion, power factor measurement • Meter /scope probes with clips seal sets	Optional only for 3.2; 3.3; 3.4; 3.5
• PV tester kit similar to SEAWARD Solar PV150 kit ™ with IV curve tester ○ With MC adaptors, memory cards, chargers	3.1
• Integrating solarimeter / multifunction irradiance meters - similar to SEAWARD SolarSurvey 100/200R™ or Kipp&Zonen™ CC20 with logger ○ – should have better than 5% accuracy	3.5
• Temperature sensor	3.1.1, 3.2.1, 3.2.3, 3.3.1,
• Tools ○ Insulated safety tools ○ Torque measurement	

4 INSPECTION AND COMMISSIONING PROCESS

The recommended commission process is linear and is described in the diagram below:

Figure 1: Flow of commissioning procedures



5 DOCUMENTATION CHECK

The minimum documentation required on site for the commissioning is detailed below. This information ensures that key information is available to the user, inspector, or maintenance engineer.

5.1 System data

5.1.1 Basic system information

As a minimum, the following basic system information shall be provided. This “nameplate” information would typically be presented on the cover page of the system documentation pack.

a) Project identification reference (where applicable)
b) Rated (nameplate) system power (kW DC and kVA AC)
c) PV modules, MPPT, batteries and inverters - manufacturer, model and quantity
d) Installation date
e) Commissioning date
f) Customer name
g) Site address

5.1.2 System designer information

As a minimum, the following information shall be provided for all bodies responsible for the design of the system. Where more than one company has responsibility for the design of the system, the following information should be provided for all companies together with a description of their role in the project.

a) System designer, company
b) System designer, contact person
c) System designer, postal address, telephone number and e-mail address.

5.1.3 System installer information

As a minimum, the following information shall be provided for all bodies responsible for the installation of the system. Where more than one company has responsibility for the installation of the system, the following information should be provided for all companies together with a description of their role in the project.

a) System installer, company
b) System installer, contact person
c) System installer, postal address, telephone number and e-mail address

5.2 Wiring single line diagram

5.2.1 General

The Contractor is expected to develop as built drawings as part of commissioning process. As a minimum, the single line drawing provided by the client has to be updated single line wiring diagram. This diagram shall be annotated to include the information detailed in the following sub-clauses.

5.2.2 General specifications

The system specification shall include the following array design information:

a) Module type(s)
b) Total number of arrays
c) Number of modules
d) Battery types
e) Number of batteries,
f) Inverter types,
g) Number of Inverters
h) Interconnections, busbars, cables
i) Switching and protection devices, Load limiters and timers

5.2.3 Array electrical details

The wiring diagram or system specification shall include the following array electrical information:

a) Array type
b) Module type(s),
c) Number of strings, modules per string
d) String cable specifications – size and type
e) String over-current protective device specifications (where fitted) – type and voltage/current ratings
f) Blocking diode type (if relevant)
g) Array main cable specifications – size and type
h) Array junction box / combiner box locations (where applicable)
i) DC switch disconnector, location and rating (voltage / current)
j) Array over-current protective devices (where applicable) – type, location and rating
k) MPPT information (power / voltage / current)

5.2.4 DC busbar system

The wiring diagram or system specification shall include the following DC system information:

a) DC isolator location, type and rating
b) DC overcurrent protective device location, type and rating
c) DC busbar rating
d) Battery type / rating
e) Battery fuse-holder and fuses
f) Cabling between battery and busbar, size and type
g) Cabling size and type between busbar and MPPT, and busbar and inverter

5.2.5 DC-AC system

The wiring diagram or system specification shall include the following AC system information:

a) Inverter types / ratings
b) AC isolator location, type and rating
c) AC overcurrent protective device location, type and rating
d) Residual current device location, type and rating (where fitted)

e) AC cabling is assumed to be commissioned outside the scope of this inspection
f) Load limiter: types, ratings and settings

5.2.6 Earthing and overvoltage protection

The wiring diagram or system specification shall include the following earthing and overvoltage protection information

a) Details of all earth / bonding conductors – size and type. Including details of array frame equipotential bonding cable where fitted.
b) Details of any connections to an existing Lightning Protection System (LPS).
c) Details of any surge protection device installed (both on AC and DC lines) to include location, type and rating.

5.3 Operation and maintenance information

Operation and maintenance information shall be provided and shall include, as a minimum, the following items:

a) Procedures for verifying correct system operation.
b) A checklist of what to do in case of a system failure.
c) Procedure for component replacement.
d) Emergency shutdown / isolation procedures.
e) Start-up procedures
f) Maintenance and cleaning recommendations (if any).
g) Considerations for any future building works related to the PV array (e.g. roof works).
h) Warranty documentation for PV modules and inverters - to include starting date of warranty commences and period of warranty.
i) Documentation on any applicable workmanship or weather-tightness warranties.

5.4 Technical Manual

Technical manual shall be provided with all component data-sheets and operation manuals. As a minimum, datasheets must be provided for the following system components

a) Module datasheet for all types of modules used in system
b) Inverter datasheet, installation and operation manuals
c) MPPT datasheet, installation and operation manuals
d) Battery datasheet, installation and operation manuals

NOTE: The provision of datasheets for other significant system components should also be considered.

5.5 Simplified User Manual

A highly simplified User manual and information shall be provided and shall include, as a minimum, the following items:

a) System capability and constraints - maximum capacity and energy outputs in simple explanation.

b) What comprises a system failure and what is system protection (i.e. load-shedding due to over-usage or inclement weather versus breakdown)
c) System failure - checklist of what to do, who to call
d) Emergency shutdown / isolation procedures – 1 page maximum
e) User maintenance and cleaning recommendations (if any).

6 COMPONENT INSPECTIONS

The inspections are undertaken prior to energising the system and prior to testing. The inspections include system configuration and safety of earthing inspections, basic correspondence of key component and quantities with SLD and labelling, quality of installation, inspection for damage during installation.

6.1 Electrical Safety Sign-off - Part 1

The objective is to sign-off on the items numbered *5.1.1 – 5.1.*8 for the system as a whole. Practically this requires at least a visual inspection of each component and checking the items.

Note: To make this simpler, a separate checklist shall be provided for each component, cross referenced to these main items. Non-compliance of any component would refer back to these main items.

6.1.1 System design is appropriate

a) SLD are approved (i.e. the DC system has been designed, specified and installed to the requirements of IEC 60364 in general and IEC 60364-9-1 in particular.)
b) System has been mechanically designed to standard and conditions on site, including wind, temperature and corrosion.

6.1.2 System components are suitable for purpose

Confirm that components are suitable for purpose as per SLD, and appropriately installed:

a) Main components installed and comply with ratings as per *approved SLD*,
b) All necessary switching components are installed as per SLD to comply with IEC 60349-9-1
c) Wiring systems have been selected and erected to with stand external influences such as wind, temperature, UV radiation, and general tampering.
d) Connectors of appropriate nature are used and comply with IEC60349-9-1

6.1.3 DC system - Protection against the effects of insulation faults

Inspection of the DC installation shall include, as a minimum, verification of the measures in place for protection against the effects of insulation faults, including:

a) Galvanic separation in place inside the inverter/MPPT or on the AC side – **yes /no**
b) Functional earthing of any DC conductor – **yes / no**

NOTE: knowledge of the galvanic separation and functional earthing arrangements are necessary in order to determine if the measures in place to protect against the effects of insulation faults have been correctly specified.

c) That a PV Array Earth Insulation Resistance detection and alarm system is installed – to the requirements of IEC 60364-9-1

NOTE: this is typically provided within the inverter/MPPT

d) That a PV Array Earth Residual Current Monitoring detection and alarm system is installed – to the requirements of IEC 60364-9-1

NOTE: this is typically provided within the inverter/ MPPT

6.1.4 DC system - Protection against overcurrent

Inspection of the DC installation shall include, as a minimum, verification of the measures in place for protection against overcurrent in the DC circuits:

a) For systems with array / sub-array over-current protective devices: verify that:
   - Over-current protective devices are fitted and correctly specified to the requirements of IEC 60364-9-1.

b) For systems without string over-current protective device: verify that:
   - $I_{MOD\_MAX\_OCPR}$ (the module maximum series fuse rating) is greater than the possible reverse current;
   - string cables are sized to accommodate the maximum combined fault current from parallel strings

   Note: see IEC60364-9-1 for calculation of array reverse currents

c) For systems with string over-current protective device: verify that:
   - String over-current protective devices are fitted and correctly specified to the requirements of IEC 60364-9-1.

6.1.5 DC system – earthing and bonding arrangements

Inspection of the DC installation shall include, as a minimum, verification of:

a) Array frame bonding arrangements have been specified and installed to the requirements of IEC 60364-9-1
b) Where protective earthing and/or equipotential bonding conductors are installed, verify that they are parallel to, and bundled with, the DC cables
c) Array structure earth spike(s) connected to ground. This should be clearly marked on the SLD.
d) NO earthing of the DC side of the electrical installation- or only one DC earthing location (NO in our case)
e) Where the PV system includes functional earthing of one of the DC conductors, the functional earth connection has been specified and installed to the requirements of IEC 60364-9-1. And clearly marked in SLD.(NONE in our case)
f) Where a PV system has a direct connection to earth on the DC side, a functional earth fault interrupter must be provided to the requirements of IEC 60364-9-1 and clearly marked in the SLD.

6.1.6 DC system - Protection against the effects of lightning and overvoltage

Inspection of the DC installation shall include, as a minimum, verification of:

a) To minimise voltages induced by lightning from the array circuits, verify that the area of all incoming wiring loops has been kept as small as possible
b) Measures are in place to protect long DC cables (e.g. screening or the use of DC-rated Surge Protection Devices (SPD)
c) Where DC-rated SPDs are fitted, check that they have been installed to the requirements of IEC 60364-9-1, and are clearly marked in the SLD.

6.1.7 AC system- earthing and bonding

Inspection of the AC system shall include, as a minimum, verification that:
a) AC system downstream of the AC DB is approved and signed off
b) Electrical earthing of the AC system is made to standard, on the AC outgoing side of the inverters, in the main AC DB, and clearly marked in SLD
c) Bonding between neutral and earth in main AC DB or elsewhere, necessary for ELP operation, is clearly marked in SLD.

6.1.8 AC system - Protection against the effects of lightning and overvoltage

Inspection of the AC installation shall include, as a minimum, verification of:
a) To minimise voltages induced by lightning from the AC load circuits, verify that the area of all wiring loops been kept as small as possible
b) Measures are in place to protect long AC cables and underground cables (e.g. screening or the use of AC-rated SPDs)
c) Where AC-rated SPDs are fitted (underground cables or long overhead cables, they have been installed to the requirements of IEC 60364-9-1 in the AC DB, and are clearly marked on the SLD.

6.2 Component inspection sequence

These visual inspections descriptions highlight the important items to be checked. The full details should be on individual component inspection checklist sheets.

6.2.1 Array structure - visual inspection

Check for mechanical soundness of structure, including upper structure quality, foundation quality, corrosion resistance and galvanisation quality. Confirm module mounting using stainless bolts, and avoidance of contact between dissimilar metals or confirm module clamping location against manufacturer specification. Check for obvious torsional stress on modules.

Check cable tray quality, to same standards as per structure.

Check orientation, tilt angle, possible shading.

Confirm array structure earthing, including connection quality to module frames, continuity between arrays, and check for dissimilar metals (future corrosion). Verify that array frame and/or module frame protective earthing conductors have been correctly installed i.e. ground wire attachment with nut and bolt combination including star washer or WEEB clip installation, and are connected to earth. Confirm earth spike location

6.2.2 Array - visual inspection

Check for correspondence of each array labelling with SLD, arrangement and numbering including substring numbering. Check module type. Check quantity of arrays, modules per array, series and parallel connections.

Confirm each module has serial numbers for scanning, and correct product labelling with specifications for warranty support.

Check for any damage: surface and glass damage, back-plate and EVA damage, torsional stress on modules.

6.2.3 Array Junction Box - visual inspection

Check for correspondence of labelling with SLD, especially arrangement and numbering.

Check quality: Combiner Box is outdoor rated, IP65 and gland seals, internal CB and rating compared with SLD, internal Lightning Protection (LP) devices.

Check and inspect “strain reliefs” and gland seals to ensure cables cannot be pulled or chaffed against knockouts

Check cable routing, and quality and consistency of MC connectors.

Confirm earthing arrangement of internal LP devices. Confirm absence/presence of array conductor cable earthing. Confirm cable labelling.

6.2.4 Array cable entry & combiner - visual inspection

Check correspondence of labelling with SLD: arrangement and numbering, combiner box numbering

Check quality: Combiner Box is outdoor rated, internal CB and rating compared with SLD.

Confirm absence/presence of array conductor cable earthing. Confirm cable labelling.

Check cable entries to room, and quality of entry. Check and inspect “strain reliefs” and gland seals to ensure cables cannot be pulled or chaffed against knockouts

6.2.5 MPPTs - visual inspection

Check correspondence of labelling with SLD: arrangement and numbering, MPPT type, quantities. Check modules/MPPT

Check that sufficient space for ventilation surrounding the MPPT has been allowed.

Check quality of connectors: DC input (500Vdc), connectors DC output (48Vdc), CB to Busbar and rating compared with SLD, DC Cable to Busbar

Check and inspect “strain reliefs” and gland seals to ensure cables cannot be pulled or chaffed against knockouts

Check earthing arrangement and configuration: chassis earthing and earth cabling connection, DC positive or negative earth connection (No), ground fault protection installed and activated (fuse and jumper).

6.2.6 Busbar DB - visual inspection

This busbar is a live connection to the battery – a significant energy storage and safety concern if improperly installed. In general, a busbar with battery fuses and protection should be mounted inside its own enclosure, with incoming and outgoing CB for protection and isolation.

Check for correspondence of labelling with SLD: MPPT DC CB and ratings and numbering, inverter DC CB and ratings and numbering, battery fuse quality and rating, cabling quality and rating. Check busbar rating itself, and in larger systems with more than one battery bank, check overall busbar configuration.

Busbar safety and access issues: accessible for working, lockable enclosures or covers for safety, and isolation devices.

Confirm whether there sufficient safety signage and warning signage? Adequacy of the actual signage content is to be explored later.

6.2.7 Battery & enclosure - visual inspection

Arrangement and numbering, in correspondence with SLD: Battery type (Ah, model), labelling per cell and per bank, quantity of cells/bank, number of banks. Fuse holder to standard and rating, fuse rating.

Check quality of installation with respect to Inter-connector quality to standard with insulation, battery cable size and quality to busbar (95mm^2 only), fuse holder location before busbar.

Battery enclosure and rack safety issues: arrangement and numbering, general safe and unhindered accessibility around batteries for inspection personnel, safety and insulation to prevent reach with metallic spanner from battery terminals to metallic structures, terminal covers firmly installed, terminals greased.

Confirm safety signage in place at battery enclosure, and emergency signage in place at battery enclosure.

6.2.8 Inverters - visual inspection

Check for correspondence of labelling with SLD: inverter type and model, arrangement and numbering, quantities.

Check that sufficient space for ventilation surrounding the inverters has been left. Check AC CB output to AC Busbar and rating compared with SLD.

Check and inspect “strain reliefs” and gland seals to ensure cables cannot be pulled or chaffed against knockouts

Check earthing arrangement and configuration: chassis earthing and earth cabling connection, and confirm DC positive or negative cables are unearthed at inverter.

For functional earth leakage protection, confirm inverter ELP compatibility and N-E bridge location.

6.2.9 Load limiter / timer - visual inspection

Check for correspondence of labelling with SLD: arrangement and numbering, labelling. Check Main Contactor rating, check for timer and load limiter unit.

Check and inspect “strain reliefs” and gland seals to ensure cables cannot be pulled or chaffed against knockouts.

6.2.10 AC DB - visual inspection

Check for correspondence of labelling with SLD: arrangement and numbering, labelling. Check Main CB rating compared with SLD.

Check and inspect "strain reliefs" and gland seals to ensure cables cannot be pulled or chaffed against knockouts

Earthing and bonding check: ELP compatibility, check for N-E bridge location in DB. Confirm AC Electrical earth spike location, and equipment bonding spike location.

6.2.11 Communication kit - visual inspection

The communications components cover those for interlinking the major power components within the site, as well as a link to the outside world.

Confirm presence of Xanbus interconnection to: each MPPT, each Inverter, one load limiter, remote battery temperature for MPPT and Inverter, a remote display. Confirm presence of at least one ComBox, and optional SCP.

6.2.12 Cables and connectors - visual inspection

Cable inspections are done in two stages: visual and then measurements. This visual inspection checks cables types, and general cable routing practices. (The second measurement inspection deals with cable with sizes, lengths, and voltage drops that may affect performance of key power components.)

Visual inspections to confirm cabling types are appropriate:

- PV 1 cabling for arrays pos and neg (double insulated), from array to MPPT input
- Battery cable 95mm^2 type to busbar
- MPPT DC output type to busbar
- Inverter cabling to Busbar
- AC cable types

Check cable routing by opening conduits and cable trays:

- For all enclosures, check and inspect "strain reliefs" and gland seals to ensure cables cannot be pulled or chaffed against knockouts
- DC cables are separated from AC cables, and separated from COMMS cables at all routings.
- Where protective earthing and/or equipotential bonding conductors are installed, verify that they are parallel to, and bundled with, the DC cables (IEC 60364-7-712.54:2002).
- To minimise voltages induced by lightning, verify that the area of all wiring loops has been kept as small as possible (IEC 60364-7-712.444.4:2002).
- Inspect for any joins and splicing of cables hidden underneath cable trunking, inside conduits or in cable trays. All wiring joining and splicing should be avoided. All cable connections, especially high power DC ones, should be INSIDE INSPECTION ENCLOSURES. Splicing and joins with ferrules and heat shrink are UNACCEPTABLE! And will heat up over time.

6.2.13 Signage and labelling - visual inspection

The signage and labelling installed on site is critical. Inspection of the PV system shall include, as a minimum, verification that:

a) Approved single line wiring diagram is displayed on site
b) All labelling is in correspondence with the SLD
c) All circuits, protective devices, switches and terminals are suitably labelled to the requirements of IEC 60364 in general and IEC 60364-9-1 in particular
d) All long cable runs are labelled as necessary
e) All DC junction boxes (PV generator, PV array boxes, PV combiner boxes, DC DB and busbars) carry a warning label indicating that active parts inside the boxes are fed from a PV array and may still be live after isolation from the PV inverter.
f) Battery warning and safety labels are present and to standard
g) Means of isolation on the AC side is clearly labelled
h) Installer details displayed on site
i) Shutdown procedures displayed on site
j) Emergency procedures displayed on site (where relevant)
k) All signs and labels suitably affixed and durable

NOTE: the requirements for signs and labelling of the PV system are detailed in IEC60364-9-1

6.2.14 Safety equipment and equipment signage - visual inspection

The safety equipment inspection shall include, as a minimum, verification that the following equipment is on site together with corresponding signage clearly indicating location of this equipment:

a) Fire extinguishers (wet foam), signage and instructions
b) Fire extinguishers (dry powder), signage and instructions
c) First aid kit and signage
d) Fire blanket and signage
e) Battery eye wash, signage and instructions
f) Safety glasses
g) Emergency services contact details (fire, ambulance, etc.)

7 COMPONENT TESTS AND MEASUREMENTS

The objective is to sign off on basic functional switching, electrical safety tests vis-à-vis polarities, earthing continuity and insulation resistances, and cabling. The following checks will be undertaken:

- Correspondence of all CB and isolators, and labels thereof, with the switched equipment,
- Electrical Safety Sign-off - part 2
  - continuity of earthing and equipotential bonding conductors
  - polarity tests
  - junction and combiner box tests
  - V_{oc} and basic voltage range checks
  - PV string short circuit tests
  - PV insulation resistance tests
- Cable distance measurements for voltage drop calculations
- Terminal torque settings for main connections
- Sundry temperature measurements

Practically this requires key measurements at each component and checking the items.

Note: To make this simpler, a separate checklist has been made for each component, cross referenced to these main items. Non-compliance of any component would refer back to these main items.

7.1 Correspondence of isolators and labels with switched devices

Check functional correspondence of all CB and isolators and labels with switched devices: i.e. check which isolators turn on which devices. This is best achieved before system switch on by measuring resistances – however some components can be checked simply by switching.

Note: Once the system has been successfully started up fully (section 7), a further check of each switch in isolation of other switches should be made to resolve issues of ground loops, or inadvertent parallel connections.

7.2 Electrical Safety Sign-off - Part 2

These tests are used to confirm measurements of basic electrical safety before system switch on.

The key measurements to be taken are summarised below. Detailed check sheets for each component are provided.

Table 3: Components for electrical safety tests

Component	7.2.1 - Continuity of earth and bonding	7.2.2 - polarity	7.2.3 - Combiner box	7.2.4 - Voltage measurement or Voc	7.2.5 – Insulation resistance
Array	Y				

Array JB	Y	Y		Y	Y
Combiner box	Y	Y	Y	Y	Y
MPPT and CB's	Y	Y		Y	Y
Busbar DB and CB	Y	Y			Y
Battery		Y		Y	
Inverter and CB	Y	Y			Y
AC DB					

7.2.1 Continuity of earthing and equipotential bonding conductors

Where protective earthing and/or equipotential bonding conductors are fitted on the DC side, such as bonding of the array frame, chassis of MPPT and inverters, electrical continuity tests shall be made on all such conductors. The connection to the main earthing terminal should also be verified.

7.2.2 Polarity tests

The polarity of all DC cables shall be verified using suitable test apparatus (i.e. Seaward Solar PV150, which can be used for testing Isc, Rpe and Riso tests along with Voc and Polarity in this section.) Once polarity is confirmed, cables shall be checked to ensure they are correctly identified and correctly connected into system devices such as switching devices or inverters.

NOTE: For reasons of safety and for the prevention of damage to connected equipment, it is extremely important to perform the polarity check before other tests and before switches are closed or string over-current protective devices inserted. If a check is made on a previously connected system and reverse polarity of one string is found, it is then important to check modules and bypass diodes for any damage caused by this error.

7.2.3 Junction and combiner box tests

The purpose of combiner box test (or indeed any junction box where paralleling of connections occurs) is to ensure all strings interconnected at the combiner box are connected correctly, before switching on the combiner breakers or fuses.

The following test sequence indicates a reverse connection through a substantially different voltage reading. The test procedure is as follows and shall be performed before any string fuses are inserted for the first time:

- Use a volt meter with voltage range at least twice the maximum system voltage.
- Ensure all strings share a common negative bus (as per SLD)
- Ensure all positive CB are off for the test.
- Measure the open-circuit voltage of the first string, positive to negative, and ensure it is an expected value.
- Leave one lead on the positive pole of the first string tested, and put the other lead on the positive pole of the next string. Because the two strings share a common negative

reference, the voltage measured should be near-zero, with an acceptable tolerance range of +/-15 volts

- Continue measurements on subsequent strings, using the first positive circuit as the meter common connection.
- A reverse polarity condition will be very evident if it exists - the measured voltage will be twice the system voltage.

7.2.4 Voc and basic voltage range checks

The purpose of these checks is to confirm that the incoming cables to electronic equipment are within allowed range (and polarity) prior to switching on of protective breakers and isolators.

Specifically, checks should include the following:

- Battery voltage is within required range for inverter DC input at the circuit breaker
- Battery voltage is within required range for MPPT DC output circuit breaker
- Array input voltage to MPPT is in range:
    - Measure V_{oc} each array at isolator
    - Confirm voltage / power ranges within the anticipated operating temperatures of all arrays is appropriate for the specific MPPT: $V_{oc\ STC}<V_{max\ MPPT}$ (150V or 600V)

7.2.5 PV string - current measurement

The purpose of PV string current measurement test is to verify that there are no major faults within the PV array wiring. These tests are not to be taken as a measure of module / array performance.

The short circuit current of each PV string should be measured using suitable test apparatus. (i.e. Seaward Solar PV150, which can be used for testing Isc, Rpe and Riso tests along with Voc and Polarity) .The making / interruption of string short circuit currents is potentially hazardous and a suitable test procedure, such as that described below, should be followed.

Measured values should be compared with the expected value. For systems with multiple identical strings and where there are stable irradiance conditions, measurements of currents in individual strings shall be compared. These values should be the same (typically within 5% of the average string current, for stable irradiance conditions).

Short circuit test procedure

A temporary short circuit shall be introduced into the string under test.

In these procedures[2] this is achieved use of a test instrument with a short circuit current measurement function (e.g. a specialised PV tester), with an irradiance meter reading or visual appraisal of the sunlight conditions may be used to consider the validity of the current readings, for on-stable irradiance conditions[3].

---

[2] (Another approach - a short circuit cable temporarily connected into a load break switching device already present in the string circuit – is not documented or followed here)

[3]NOTE: The use of an irradiance meter or visual appraisal of the sunlight conditions is included here solely as a means of determining if the measured current is within the band expected. As noted, short circuit current test is intended to detect faults rather than give any indication of system performance. System performance measurements are part of a Category-2 test regime and are best achieved by performing an I-V curve test.

- Ensure that all switching devices and disconnecting means are open and that all PV strings are isolated from each other.
- Ensure that the test instrument has a rating greater than the potential short circuit current and open circuit voltage. It shall also be ensured that where a switching device and/or short circuit conductor is utilised to form the short circuit, that these are rated greater than the potential short circuit current and open circuit voltage.
- The short circuit current can then be measured using test instrument with a short circuit current measurement function.

7.2.6 PV array - insulation resistance tests

PV array DC circuits are live during daylight and, unlike a conventional AC circuit, cannot be isolated before performing this test. Performing this test presents a potential electric shock hazard (150-600Vdc in this case), it is important to fully understand the procedure before starting any work. It is recommended that careful safety measures are followed.

The test should be repeated for each PV Array as minimum. It is also possible to test individual strings if required.

Where the structure/frame is bonded to earth, the earth connection may be to any suitable earth connection or to array frame (where the array frame is utilised, ensure a good contact and that there is continuity over the whole metallic frame).

For installations where the array frame is not bonded to earth (i.e. class II installation) the commissioning engineer may choose to do two tests: i) between Array cables and Earth and an additional test ii) between Array cables and Frame.

Insulation resistance test procedure

It is assumed that the test shall be done using a test device such as Seaward Solar PV150 (which can be used for testing Isc, Rpe and Riso tests along with Voc and Polarity in this section).

- Before commencing with the test:; isolate the PV array from MPPT/inverter (typically at the array switch disconnector); and disconnect any piece of equipment that could have impact on the insulation measurement (i.e. overvoltage protection) in the junction or combiner boxes.
- The insulation resistance test device shall be connected between earth and the array cable(s) as appropriate to the test method adopted. Test leads should be made secure before carrying out the test.
- Follow the insulation resistance test device instructions to ensure the test voltage is according to table below and readings in MΏ.
  - For PV arrays of up to 10kWp, the insulation resistance shall be measured with the test voltage indicated in Table below.
  - The result is satisfactory if each circuit has insulation resistance not less than the appropriate value given in Table below.
- Ensure the system is de-energised before removing test cables or touching any conductive parts.

Table 4: Minimum values of insulation resistance – PV arrays up to 10kWp

System Voltage (Voc_{stc}x1.25)	Test voltage	Minimum insulation resistance
<120V	250V	0.5MΩ
120V-500V	500V	1MΩ
>500V	1000V	1MΩ

7.3 Check key cable lengths and sizes

Cable lengths induce voltage drops. Small but unacceptable voltage drops will adversely affect system performance, while large voltage drops cause heating and can result in fires. Measure and record key cable lengths, sizes and quantities for V_{drop} calculations under normal operational conditions, with consideration for surge conditions. These need to be compared with the sizes, lengths and quantities in parallel in the SLD, and vary from system to system.

Acceptable voltage drops would generally be as follows:

- Array to MPPT input: 2.5%(3.75V for 150V array, 7.5V for 300V array, 15V for 600V array)
- MPPT output to battery terminals: 2.5% (1.2V for 48V battery)
- Battery to inverter terminals: 2.5% (1.2Vfor 48V battery)
- Inverter output to load: 2.5% (6.0V for 230Vac system)

Note: these correspond to losses of 10% on cabling, in total. These include cable losses, circuit breaker, isolator and connection drops or 200mV per single pole connection. Cabling losses alone should therefore be less than 5% in total.

7.3.1 Measured cable lengths and sizes acceptable

For each set of cables, record the key parameters which will enable calculation of voltage drop at rated current. These parameters are: *Cable size (mm^2), length (one way, m), maximum current per cable, and quantity of cables in parallel.*

Key cables to measure are:

- Array to Array JB
- Array JB to Combiner Box
- Combiner Box to MPPT
- MPPT to Busbar DB
- Busbar DB to Battery
- Inverter to Busbar DB

7.3.2 Calculation of maximum cable lengths and minimum sizes acceptable for each site type

Key calculations are V drop per cable, nominal Voltage, % Vdrop and Total Current for all cables.

For copper cable, use resistivity of 0.036 ohms/mm^2/m of one way run. See the calculations in 6.2.6 to be done for each site, to determine maximum allowed cable lengths.

Table 5: Example of cable voltage drop calculations for PV system

(To be defined by system modeller and included for as built drawings)

		Cable properties				Rating per unit		Rating per cable				
Array type	Charge side calculations	mm²	Resistance (ohms/m)	distance measured (m)	Quantity in parallel	Total power (W)	current (A)	Power (W) per cable	current (A) per cable	Vdrop calculated	Nom voltage	% Vdrop
A1	Array to Array JB (per array)											
	Array JB to Combiner Box (per array)											
	Combiner Box to MPPT (per array)											
	MPPT to Busbar DB (system)											
	Qty array type											
A2	Array to Array JB (per array)											
	Array JB to Combiner Box (per array)											
	Combiner Box to MPPT (per array)											
	MPPT to Busbar DB (system)											
	Qty array type											
Busbar DB to Battery (system)												
Charge side voltage drops												
Inverter type	**Load side calculations**											
	Inverter to Busbar DB (system)											
	Qty inverter type											
Busbar DB to Battery (system)												
Load side voltage drops												
Note: Resistance for copper cable is 0.036 ohms/m.mm2 for 2 cables in one way distance measurement. So 95 mm2 has resistance 0.04/95 = 0.000421 ohms/m												

7.4 Terminal torque settings

Check connection quality of a broad selection of random locations which are critical to system performance, and which indicate consistency in quality of installation:

- Battery terminal torque – as per battery manufacturer instructions
- Battery fuse terminal connections
- Busbar connections
- Inverter DC CB connections
- Tightness of other connections and junctions.
- Check correct build technique has been applied to all lugs and crimps for optimal integrity of strength and compression.

7.5 Temperature measurements

At this stage, it is useful to focus mainly on ambient conditions that will indicate the need for equipment de-rating. Take measurements at noon.

- Cables in cable trays on array structure
- Control room internal environment
- Battery temperature.

8 SWITCH-ON SEQUENCE AND FUNCTIONALITY CHECKS

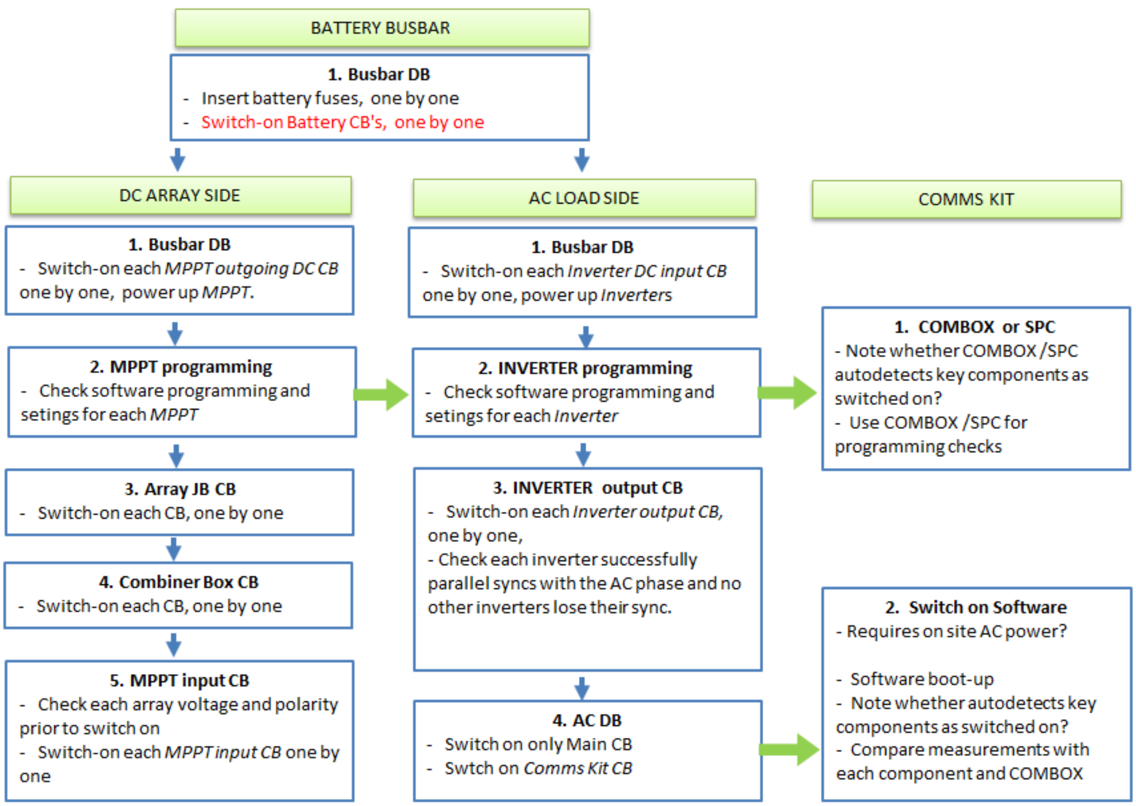
The switch on sequence is undertaken after satisfactory undertaking of the electrical safety tests and protection continuity tests. This sequence is undertaken methodically with the purpose of isolating faults, and confirming operation methodically and systematically.

8.1 Switch-on and switch-off sequences

8.1.1 Switch on sequence

The proposed switch on sequence is showing in Figure 2.

Figure 2: System switch-on sequence



8.1.2 Switch-off sequence

- DC array side
    - MPPT input CB (array)
        - Array JB CB (optional)
        - Combiner CB (optional)
- Busbar DB: MPPT output DC CB
- AC load side
    - Communications-kit switch off
    - AC DB (optional)

  - Inverter AC CB
  - Busbar DB: Inverter DC input CB
- Complete system switch-off after DC array and AC loads switched off
  - Busbar DB (battery) fuse and CB's

8.2 Software programming set-up tests

8.2.1 MPPT programming

These checks are done immediately after the MPPT is powered up in the switch on sequence, but before array power is connected. The programming is usually done via the COMBOX / SPC.

It is important to check key MPPT settings and programming, for general safety and protection, and for compatibility with the type of batteries used. Programme settings to be checked at a minimum:

- Check Multi-unit set-up and programming (i.e. Xanbus common, and check each MPPT device Number on Network). Ref "Commissioning Units using a System Control Panel"
- MPPT set for GEL not flooded battery charging
- Check battery voltage (V) and capacity setting (Ah) and charge limit settings (A)

  If battery is set to GEL these settings may be automatically set:

- Check charge cycle (3 stage or 2 stage)
- Equalisation enabled / disabled
- Check charge settings
  - Equalisation / Bulk / Absorption / Float / Recharge voltages
- Check Absorption time
- Check battery temperature compensation of charging voltage (BTS) unit, or set to (Cold / Warm / Hot?)
- Check configuration and operation of Earth Insulation Resistance protection (Ground Fault Protection - GFP)
- Check configuration and operation of Array Residual Current Monitoring detection (GFP)
- Compare MPPT battery remote voltage measurement reading with actual.

8.2.2 Inverter programming

These test/checks are done immediately after the Inverter is powered up in the switch on sequence, but before array power is connected. The programming is usually done via the COMBOX /SPC.

It is important to check key Inverter settings and programming, for general safety and protection, and for compatibility with the type of batteries used. Programme settings to be checked at a minimum:

- Check Multi-unit set-up and programming (i.e Xanbus common, and check each INV device Number on Network). Ref "Commissioning Units using a System Control Panel"
- Identify Master Unit. Master unit will ensure that the slave are programmed for
  - Check programming for load-sharing
  - parallel AC phase syncing.
- Inverter set for GEL not flooded battery charging

- Check Battery voltage (V) and capacity setting (Ah) and charge limit settings (A)
- Check equalise / boost / absorption / float settings and times (if charger mode used from generator or grid)
- Check load-shed disconnect and reconnect voltages.
- Check low voltage alarm settings.
- Adjust load limiter rating and throttle load (test that load is throttled).
- Compare Inverter battery remote voltage measurement with actual

8.2.3 Load limiter programming

The load limiter and timer is a stand-alone device between the output of the inverters and the AC distribution board. It is large programmable contactor that has two functions:

a) allowing time of use of load by means of a timer
b) tripping on load overload (which appears to be programmable)

Programme settings to be checked at a minimum:

- Check programming for 7 day timer, both weekdays and weekends
- Check programming for overcurrent.

If load limiter programming is overridden for the functional tests, then the load limiter must be reset to its required settings for normal operation after the completion of the tests.

8.3 Functional tests

After the switch on sequence has been successfully completed, then ad-hoc functional tests can be done to confirm system operation. These would include checks of MPPT and inverters, and basic load functionality.

If load limiter programming is overridden for the functional tests, then the load limiter must be reset to its required settings for normal operation after the completion of the tests.

8.3.1 AC load functionality

Confirm that the PV system can supply an AC load in short term operation, by switching on a substantial AC load of power similar to continuous rated power output. Check and confirm AC DB functionality.

- Measure AC voltage at AC DB with no load
- Switch on load equivalent to at least 50% of rated output power as per table 1
- Measure AC voltage in AC DB, and use clamp meter to measure load current.
- Check and confirm AC DB functionality,
- Confirm ELP operation by shorting L-E in the DB. This step may be simplified if the ELP test button actually does this safety test.

8.3.2 Inverter functionality

If the AC load is operational from the AC load test above, then the inverter(s) are also operational. If there is more than one inverter present, then basic functional tests would include the following:

- Check inverter CB operation and correspondence

- Confirm inverter load sharing from the inverter panel meters. Depending on programming, they may be in power sharing mode, or master-slave mode. (Record $P_{INV1,}$ $P_{INV2,}$ $P_{INV3,}$ P_{INV4})
- Check Battery voltage drops are within the anticipated range for the measured power draw (Record $Vdrop_{INV}$)
- Extrapolate for maximum current draw in relation to minimum operating voltage of inverter. (Rec Vdropmax = $Vdrop_{INV}$ x Pmax/P_{INV}) where Pmax is Inverter rating.
- If the system has been operational for some days, then Inverter front panel should enable access to log-files of daily kWh/day readings, and total kWh readings/ these can be compared between Inverters on site. (Record E_{INV})

8.3.3 MPPT functionality

The MPPT checks will identify that the PV system is charging and that all arrays are operational. If the test is done between 10h00 and 15h00 then there should be sufficient solar energy to conduct

- Check MPPT CB operation and correspondence
- Confirm MPPT and array operation - MPPT front panel display for each of same array type should be identical input power, input voltage, and output power to the battery busbar (Record $P_{MPPT,}$ Vpv_{MPPT}, Ipv_{MPPT}, $Ibat_{MPPT}$)
- Check MPPT –Battery voltage rises are within range for the measured power supplied ($Vdrop_{MPPT)}$
- Extrapolate for maximum array output expected; Vdropmax = $Vdrop_{MPPT}$ x Pmax/$P_{MPPT)}$ where Pmax is Array rating
- If the system has been operational for some days, then MPPT front panel should enable access to log-files of daily kWh/day readings, and total kWh readings/ these can be compared between MPPTs on site with similar or known array sizes. (Record E_{MPPT})

8.3.4 Communications kit functionality

The SCP does not require AC power, so this can be used to configure and check programming of each Schneider component. The ComBox may also not require power.

However, the Communications kit may indeed require AC power to operate. If this is the case, the AC Load switch-on will be needed. sCommunication with the Kaduna Clinics Project control room also must be checked and confirmed.

- Some short term tests can be done to confirm validation of key variables logged with actuals, in real time.
- Remote display and programming at COMBOX.
- Programming tests to override certain equipment (i.e. aux, LV alarms, etc.).

9 ANNEX

9.1 Annex 1: Main References

AC side of the facility installation (LV and MV): visual inspections, tests and standards:

- Nigerian standards: Electrical Installation Standards
- IEC 60364

DC side of PV installation: visual inspections and standards:

- IEC 62548 Ed.1: Installation and safety requirements for photovoltaic (PV) generators
- IEC 60364-7-712 Electrical installations of buildings – Part 7-712: Requirements for special installations or locations – Solar photovoltaic (PV) power supply systems
- IEC 60364-9-1: Low-voltage electrical installations - Part 9-1: installation, design and safety requirements for photovoltaic systems (PV).
    - Once published IEC 60364-9-1 Ed.1.0 will replace IEC 60364-7-712 Ed.1.0. and IEC 62548 Ed.1.0).
    - IEC 60364-9-1 is a combination of IEC TS 62548, and IEC 60364-7-712. 60364-7-7xx series of documents give the requirements which supplement, modify or replaced certain of the general requirements contained in parts 1-6 of IEC 60364 whereas this document makes specific references to certain general requirements contained in parts 1-6 of IEC 60364. While this document assumes a good knowledge of the IEC 60364 series of documents, it is designed to be readable without constant cross referencing to clauses within the IEC 60364 series. The area of photovoltaic systems is rapidly developing and with that there will be a need to keep this document under constant review hence a short maintenance cycle enabling it to keep pace with developments in the industry and to maintain the highest level of safety of these systems.

System commissioning: documentation, insulation tests, array string performance tests:

- IEC 62446: Grid connected PV systems - Minimum requirements for system documentation, commissioning tests and inspection

Rating of the PV system facility:

- IEC 61724 Ed 1: PV System Performance Monitoring Guidelines for measurement, data exchange and analysis (to be superseded by Ed 2). This is a modified performance ratio test.