Short-Course

Solar PV System Installation and Maintenance

NTQF Level III

Learning Guide -20

Unit of Competence	**Diagnose, Repair and Maintain PV System**
Module Title	**Diagnose, Repair and Maintaining PV System**
LG Code	**EIS PIM3 M15 0120 LO2-LG20**
TTLM Code	**EIS PIM3 TTLM 0120v1**

LO 2:- Find the fault-20

Instruction Sheet	Learning Guide-20

This learning guide is developed to provide you with the necessary information, knowledge, skills and attitude regarding the following content coverage and topics:

- Confirming required isolations with site requirements
- Diagnosing and maintaining Solar PV system
- Carrying out fault finding with job requirements
- Inspecting equipment components, wires, cables, terminations, and support fixings
- Identifying all appropriate fault finding/diagnostic techniques
- Disconnecting all appropriate components for accurate test measurements
- Using test and measurement instruments

This guide will also assist you to attain the learning outcome stated in the cover page. Specifically, upon completion of this Learning Guide, you will be able to:

- Confirm required isolations with site requirements
- Diagnose and maintain Solar PV system
- Carry out fault finding with job requirements
- Inspect equipment components, wires, cables, terminations, and support fixings
- Identify all appropriate fault finding/diagnostic techniques
- Disconnect all appropriate components for accurate test measurements
- Use test and measurement instruments

Learning Instructions:

1. Read the specific objectives of this Learning Guide.
2. Follow the instructions described below:
3. Read the information written in the information Sheet 1 (page: 30), Sheet 2 (page:32), Sheet 3 (page: 36), Sheet 4 (page:39), Sheet 5 (page:45), Sheet 6 (page:48), Sheet 7 (page: 51),
4. Accomplish the Self-Check 1 (page: 31), Self-Check 2 (page:35), Self-Check 3 (page: 38), Self-Check 4 (page:44), Self-Check 5 (page:47), Self-Check 6 (page:50), Self-Check 7 (page: 59),

LO2. Find the fault

Information Sheet 1	Confirming required isolations with site requirements

1 Confirming required isolations with site requirements

Before starting any measurements, familiarise yourself with the installation drawings and identify the following safety and disconnect devices:

- All fuses e.g.:
  - Between PV modules and combiner box;
  - Between Combiner box and Charge Controller;
  - Between Charge Controller and Battery;
  - Between Battery and inverter;
- All disconnect switches and circuit breakers:
  - DC Disconnect switches between PV string(s), Combiner box and Charge Controller.

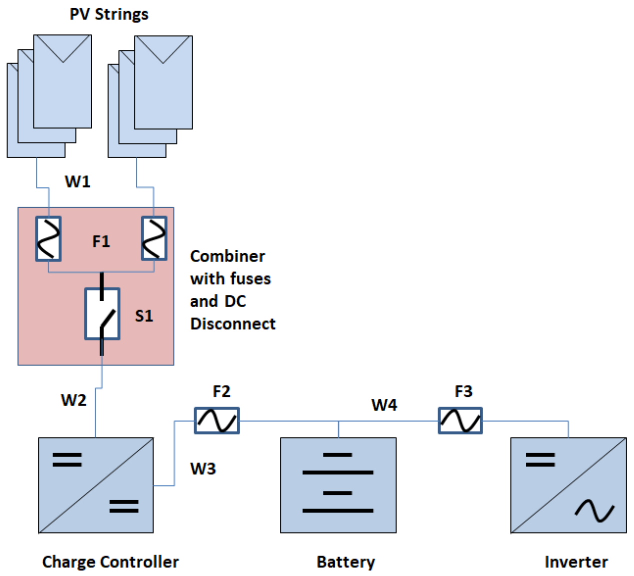

Figure 10 – Possible points for isolation

Self-Check - 1	Written Test

Instruction: Follow the below selected instruction

Answer all the questions listed below

N°	Questions and answers
1	**Name 3 isolation points in an off-grid PV system (3)**

Note: the satisfactory rating is as followed

Satisfactory	2 points
Unsatisfactory	Below 2 points

Answer Sheet

Score = ___________

Rating: ____________

Name

Date

Information Sheet 2	Diagnosing and mantling Solar PV system

2 Diagnosing and mantling Solar PV system

The following paragraphs were taken/adapted from (Sinovoltaics.com, 2015)

Quality solar panels are built and guaranteed to produce power for 25 years.

For that reason, it is most likely that a problem is caused by a defect in system components other than the panels, such as the solar inverter, charge controller, wiring or batteries. However, nearly every PV manufacturer has seen defects in solar panels over the past years.

There are two failure modes which a PV system might experience i.e.:

- No power or
- Low power

2.1 Troubleshooting: No Power

Zero output is a common problem and in nine out of ten cases, it is due to a faulty inverter or charge controller.

It is also possible that one solar panel in your PV array failed. If the PV modules are connected in series, one failing PV module will shut down the entire system.

No power may also be caused by tripped breakers or blown fuses, as well as faulty batteries.

2.2 Troubleshooting: Low Power

If your solar system is not delivering sufficient power for which it is rated for, the resulting situation is called a low power situation. It is easy to tell that there is a fault if the system is not working at all. But errors not always occur that obvious. Also, low power output or low charging rate of the battery is a malfunction and needs to be identified.

This is the most common type of problem and a few, quick, troubleshooting steps will help you find the source of the problem. The factors that could contribute to a low power problem are:

- Shading
    - This is a common cause of low voltage. Ensure that there are no trees around and that the solar panels are not blocked by shadow at any time during the day.
    - Keep in mind that a solar system lasts for more than 25 years and trees grow over time. Conducting a bi-annual survey of the installation site is a good idea.
- Temperature

    - If shading is not an issue, it may be the higher than normal operating temperature of the solar panels. PV module voltages drop with rises in temperature. The higher the temperature, the lower will be the power output.
    - Adding more modules in series, and therefore increasing the string voltage, will eliminate this problem. This is however a factor that will be eliminated with a proper design, taking into account local conditions.
    - Also make sure that there's sufficient air circulation beneath the panels and that this open space is not blocked in any way.
- Bad Connections
    - Bad connections can cause excessive voltage drops. If the modules are not overheated, the best bet for you will be to check for a bad connection.
    - You can use a multi-meter to check the voltage levels at various points to find out the point beyond which the problem of low voltage begins.
    - If your system was professionally wired, chances are that you may not experience this problem, but it is worth checking for.
- Solar panel defects
    - It's uncommon for a solar panel to fail as they're meant to last 25 years in the field. However nearly all large PV manufacturers have seen product recalls over the past years, and therefore you may come across failing solar panels when you troubleshoot a solar system.
    - Hotspots - The series resistance of the solar cells in a panel could have increased overtime. This may be the result of hotspot that may occur when micro cracks appear in the cells. The result is a lower voltage in the panel, which will bring the overall voltage of the solar array down.
    - Junction box - An increase in resistance is also likely to happen in a junction box that may be exposed to moisture. Nowadays quality junction boxes are IP67 certified, which means they're completely water proof.
    - Delamination- Delamination is another common defect. You should be able to see delamination with your eyes. When delamination occurs, moisture can enter the electrical circuit of the panel, which may create a current leak or a short.
    - Other solar panel defects are PID (Potential Induced Degradation), micro cracks, UV discolouring.
- Excessive power usage
    - This is the most common reason for solar electric systems failing, where the original investigations underestimated the amount of power that was required. If you have identified that you are using more power than you were originally anticipating, you have three choices: Reduce your power load, increase the size of your solar array or add another power source (such as a fuel cell, wind turbine or generator) to top up your solar electric system when necessary.
- Insufficient power generation
    - If you have done your homework correctly, you should not have a problem with insufficient power generation when the system is relatively new.

However, over a period of a few years, the solar panels and batteries will degrade in their performance (batteries more so than the solar panels).

- Reduce your power load, increase the size of your solar array, add another power source (such as a fuel cell, wind turbine or generator) to top up your solar electric system when necessary

Self-Check - 2	Written Test

Instruction: Follow the below selected instruction

The following are true or false items, write true if the statement is true and write false if the statement is false.

N°	Questions and answers
1	**The 2 main types of faults are 'No power' and 'Low power':**
	True or false:
2	**When delamination occurs on a PV module, moisture can enter the electrical circuit of the panel, which may create a current leak or a short.**
	True or false:

Note: the satisfactory rating is as followed

Satisfactory	2 points
Unsatisfactory	Below 2 points

Answer Sheet

Score = ___________

Rating: ____________

Name

Date

Information Sheet 3	Carrying out fault finding with job requirements

3 Carrying out fault finding with job requirements

Follow a systematic approach to identify the source of the problem:

- Verify the problem;
- Identify the symptoms;
- Analyse the symptoms;
- Use analysis to isolate the problem
- Rectify the problem;
- Check that the system is operational.

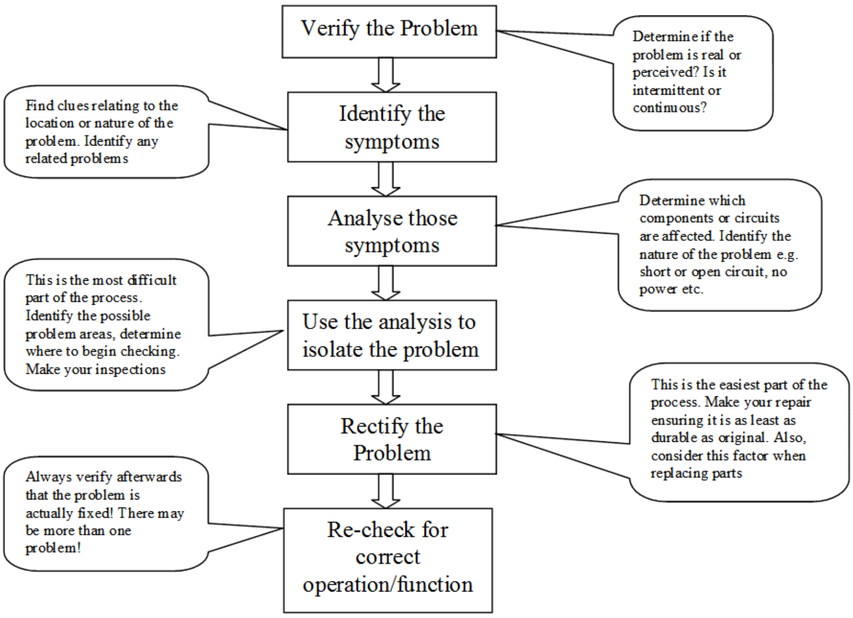

Figure 11: Fault Finding Procedure (http://autoelexblog.blogspot.com/)

- The first step is to verify that there is really a problem with the system. It may be a user caused fault and operation of the system outside the designed specifications e.g. added loads that drain the batteries quicker.
- It is important to understand the symptoms of the problem:
  - Does it only happen certain times of the day or when it rains or when it is very hot?
  - Does it happen when you switch on a certain appliance?
  - Is it seasonal e.g. only in winter?
  - Does a circuit breaker trip regularly?
  - Does a fuse blow regularly?

- Analyse the symptoms based on the design specifications and layout of the system.

- In (Hankins, 2010) chapter 10, the author also recommends that system record be analysed (if kept). System managers should check the following on a monthly basis:
  - Daily battery state-of-charge log. This will indicate whether the battery has been in a low or full state of charge, and whether this continued for a long time.
  - Records of any recent repairs or problems with the system.
  - Some charge regulators and amp-hour meters store detailed records of battery state of charge, daily energy use and solar charge (a few of these enable the information to be downloaded on to memory sticks or laptops).
  - Always review this data to see how the system has been performing, and how much energy has been collected and utilized.
- Based on your analysis of the symptoms, try to isolate the area where to start your inspection.

Self-Check - 3	Written Test

Instruction: Follow the below selected instruction

Answer all the questions listed below

N°	Questions and answers
1	**Name the six steps of fault finding: (6)**

Note: the satisfactory rating is as followed

Satisfactory	5 points
Unsatisfactory	Below 4 points

Answer Sheet

Score = ___________

Rating: ____________

Name

Date

Information Sheet 4	Inspecting equipment components, wires, cables, terminations and support fixings

4 Inspecting equipment components, wires, cables, terminations and support fixings

A typical fault-finding chart can be seen in Figure 12. The specific chart to use will depend on the type of PV System, but the principle of elimination stays the same.

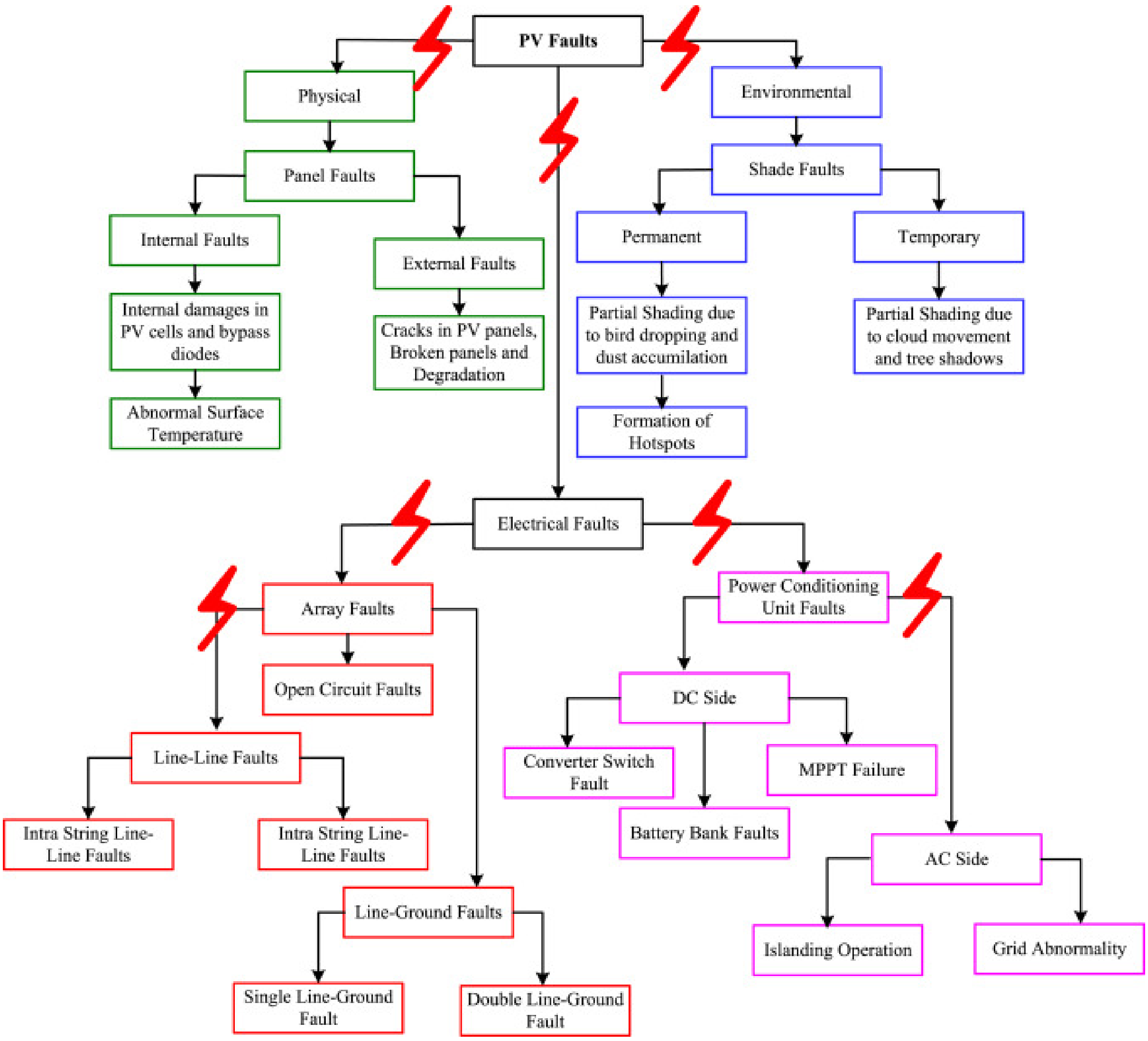

Figure 12: Fault Finding Chart (sciencedirect.com)

The following paragraphs were taken and/or adapted from (www.pvtrin.eu)

The fault correction method depends upon the type of fault and the type of PV system. First, customers should be asked when and how the fault came to their attention. Circuit diagrams and a technical description of the system are very helpful. Before taking measurements, a visual check of the PV system should be carried out – in particular, of the PV array – to check for mechanical damage and soiling. Wiring and electrical connections should also be checked.

4.1 Charge Controller and PV combiner/junction box

Firstly, the measurement check of the charge Controller and the PV combiner/junction box should start with the respective connecting wires. Test the charge controller operating data, by checking the LED or error code, or by using remote software and a laptop. The charge controller operating data records can give useful information for the localization of the faults. Check the DC cable and the DC main disconnect/isolator switch. When measuring the insulation resistance, the resistance to the ground potential should be at least 2MOhm.

4.2 Ground and short-circuit faults

Ground and short-circuit faults can be detected by following the troubleshooting procedure, but the PV strings should first be separated and measured individually. To do this, first switch off the inverter and, if present, switch off the DC switch or DC switches. Then one module per string should be completely darkened by covering it from sunlight. Now the strings can be separated without the danger of arcing and measurement can begin.

4.3 String fuses/diodes/modules

The voltage at the string fuses and diodes can be measured during operation by using a voltmeter in parallel. If excessive differences are present in the individual string voltages and/or string short-circuit currents, this is either an indication of excessively high mismatching in the generator or an indication of an electrical fault in one or more strings. It may therefore be necessary to take individual measurements at the modules of the corresponding string. For longer strings, divide the string in half and find out which is the faulty half of the string. Then, use the same method on the faulty half of the string to identify the faulty module. The module connections and bypass diodes should also be tested.

4.4 Open-circuit voltage and short-circuit current

Measurement of the open-circuit voltage and the short-circuit current is very important for monitoring the operation of the system but the current irradiance of the area should also be recorded.

4.5 Other typical faults

Some typical failures which are encountered in PV installations are listed in Table 1 below. On the right-side column, the possible reasons for these failures are reported alongside corrective measures in order to troubleshoot the problem and put the system back in operation.

Table 1: Typical Failures and corrective measures

Typical Failures	Corrective measures and troubleshooting
Failure in any PV system component	Try to get as much information from the customer as possible. Get as much information, such as prints, outputs and wiring diagrams, as possible. Follow the manufacturer's instructions regarding malfunction.
Entire PV system is down	Prior to getting on the roof, check and record the inverter's input voltage and current level from the array.
No current from array	Switches, fuses, or circuit breakers open, blown, tripped, wiring broken or corroded.
Array current is low	Cloudy conditions, a defective blocking or bypass diode, a damaged module, one or more parallel connection between modules in the string is broken, loose, or dirty. Replace a damaged module or one with internal parallel connection problems. Replace defective diodes and clean and tighten all connections. Some of the array may be shaded, significantly reducing the array's current output. Remove the shade source to regain the string's full current output. Dirty modules also could cause reduced current output. Wash the modules to restore the array's current output, read module manual to prevent further damage through wrong washing.
Output voltage is low	Some modules in the series string are defective or disconnected and need to be replaced. Defective blocking or bypass diodes in the modules may need to be replaced. Low voltage also could be caused by the wrong wiring connecting the modules in the string to the junction box or combiner box or the inverter. The wiring could be either sized too small or the wire run is too long for the string's output current level. Upgrading the wire size for the current level should correct this problem.
Battery is not charging (autonomous systems)	Measure PV array open circuit voltage and confirm it is within normal limits. If voltage is low or zero, check the connections at the PV array itself. Disconnect the PV from the controller when working on the PV system. Measure PV voltage and battery voltage at charge controller

	terminals if voltage at the terminals is the same the PV array is charging the battery. If PV voltage is close to open circuit voltage of the panels and the battery voltage is low, the controller is not charging the batteries and may be damaged.
Battery is always at a low state of charge (autonomous systems)	Reduce load size or increase system size.
Battery voltage loss overnight even when no loads are on (autonomous systems)	Replace or add diode, or repair or replace series relay charge controller.
Load not operating properly	Check that no fuses are defective, or circuit breakers have been tripped. Check the system's voltage at the load's connection. The load also could be too large for the wire size in the circuit. Reduce the load on the circuit or run larger wire that is sized for the current load.
Low voltage shutdown	Shorten cables or use heavier cables, recharge battery, allow unit to cool, improve air circulation, locate unit to cooler environment.
Fault light on, AC load not working	AC products connected are rated at more than the inverters power rating; overload shutdown has occurred The AC products connected are rated at less than the inverters continuous power rating. The product exceeds the inverters surge capacity.
Reverse Polarity connection on inverter (autonomous systems)	Check connection to battery, the inverter has likely been damaged and needs to be replaced.
Loads disconnecting improperly	Controller not receiving proper battery voltage, check battery connection. Adjustable low voltage disconnect is set too high. Reset adjustable low voltage disconnects using a variable power supply.
Array fuse blows	Array short circuit test performed with battery connected. Disconnect battery to perform test. Array exceeds rating of controller, add another controller in parallel if appropriate or replace with controller of higher capacity.
Loads disconnecting improperly	Controller not receiving proper battery voltage, check battery connection. Adjustable low voltage disconnect is set too high. Reset Adjustable low voltage disconnect using a variable power supply.

Array fuse blows	Array short circuit test performed with battery connected. Disconnect battery to perform test. Array exceeds rating of controller, add another controller in parallel if appropriate or replace with controller of greater capacity.
No output from inverter	Switch, fuse or circuit breaker open, blown or tripped. Wiring broken or corroded. Low voltage disconnects on inverter or charge controller circuit is open, High battery voltage. The load on the inverter may be too high of a current demand. Reduce the loads or replace the inverter with one with a larger output. With the power off, check for and repair any ground faults before starting the inverter again.
Corrosion of Structural components	Loose components or fasteners should be re-secured or tightened, and special attention paid to galvanic corrosion of fasteners. Repair or replace any bent, corroded, or otherwise damaged mounting components. Check and tighten all mounting system fasteners.
Fire during the operation of photovoltaic	Stay away from the PV system during and after a fire. Inform the fire brigade about the particular hazard from the PV system. After the fire, have your installer bring the PV system in a safe mode.

Self-Check - 4	Written Test

Instruction: Follow the below selected instruction

Answer all the questions listed below

N°	Questions and answers
1	**What should be done when a battery is always at a low state of charge? (2)**
2	**What could be the problem if on the inverter, the fault light on and AC loads are not working (3)**

Note: the satisfactory rating is as followed

Satisfactory	4 points
Unsatisfactory	Below 3 points

Answer Sheet

Score = ____________

Rating: _____________

Name

Date

Information Sheet 5	Identifying all appropriate fault finding/diagnostic techniques

5 Identifying all appropriate fault finding/diagnostic techniques

The following techniques can be used to find the source of the problem:

- Interview users – Try to understand when and under what conditions the fault occur, and what the symptoms are;
- Optical Inspection – Before any measurements, visually inspect all the components. Look for physical damage or issues on the PV modules, the cables, switchgear and protective devices, Charge controller, Inverter and batteries. See Information Sheet 2. An optical scanner can also be used at this stage to indicate hot-spots in wiring or on panels;
- Check for error codes or LED indication on devices. Some devices have a port or Bluetooth/Wi-Fi connection from where certain information on the device can be viewed or diagnostics can be performed. Other systems have dedicated displays that indicate the system status and operation (see Figure 13 & Figure 14);
- If there is a monitoring system, fault information can be obtained on-site or even remotely. Information like daily PV generation curves can indicate if there are problems with the PV modules. Some Lithium battery management systems can also provide data on the state of the batteries. Meters can indicate if the load applied by the customer is higher than what the system is designed for etc.;
- Once you have a good idea in which area the fault lies, start with targeted measurements. Typical measurements will be the PV string open circuit voltages, String short circuit currents, battery voltage, inverter output voltage, cable voltage drops etc. See Information Sheet 6.

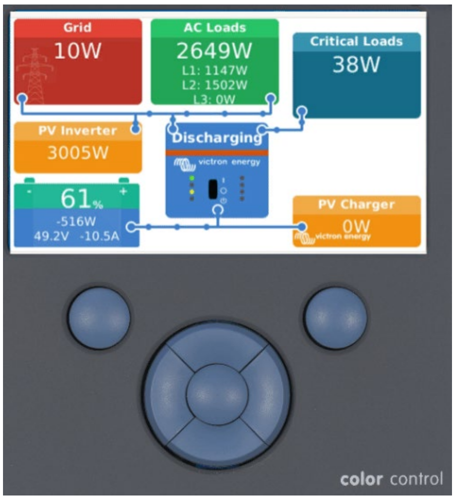

Figure 13: System Status Display

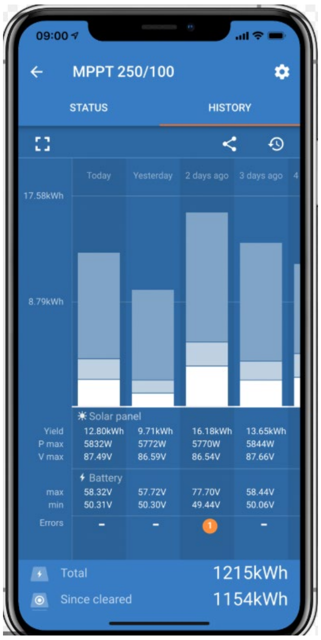

Figure 14: Cell phone link to Charge Controller

Self-Check - 5	Written Test

Instruction: Follow the below selected instruction

Answer all the questions listed below.

N°	Questions and answers
1	**When doing an optical inspection, what should be checked for: (4)**

Note: the satisfactory rating is as followed

Satisfactory	3 points
Unsatisfactory	Below 2 points

Answer Sheet

Score = ___________

Rating: ____________

Name

Date

Information Sheet 6	Disconnecting all appropriate components for accurate test measurements

6 Disconnecting all appropriate components for accurate test measurements

Some measurements will be taken on a live system (e.g. string and battery voltages etc.). Always make sure that these measurements are taken by qualified personnel with the correct safety procedures and PPE.

It is important to disconnect and isolate the components for some measurements like checking the cables for insulation faults etc. The following needs to be considered:

- Never disconnect PV Modules when it is under load. Always disconnect the modules at the isolator switch.
- Remember that even if a PV module is disconnected, it will still produce a voltage.
- Make sure that lock-out procedures are followed to prevent someone from switching on the circuit while you are measuring.
- Before a wire is touched, always measure first to confirm that it is not live.

On site, notify the people on site that you will be working on the system. This will allow them to finish critical jobs and prevent them from switching on devices that you may have switched off.

One of the design considerations for electrical safety is to isolate the circuit. The use of isolation equipment to support preventive maintenance and repair for proper implementation of lockout/tag-out procedures is an essential provision for electrical safety.

Lockout devices are designed to keep energy-isolating devices in a safe or "off" position, preventing machines or equipment from becoming energized. These devices cannot be removed without a key or other verified unlocking mechanism or through extraordinary force by using bolt cutters or a similar tool. **Tagout devices** are warning tags attached to energy-isolating devices to warn employees not to turn on or re-energize the machine. Tagout devices are easier to remove and provide less protection. It is best practice to use the two together.	

Self-Check - 6	Written Test

Instruction: Follow the below selected instruction

The following are true or false items, write true if the statement is true and write false if the statement is false.

N°	Questions and answers
1	**PV modules can be disconnected under load:**
	True or false:
2	**Lockout devices are designed to keep energy-isolating devices in a safe or "off" position**
	True or false:

Note: the satisfactory rating is as followed

Satisfactory	2 points
Unsatisfactory	Below 2 points

Answer Sheet

Score = ____________

Rating: ______________

Name

Date

Information Sheet 7	Using test and measurement instruments

7 Using test and measurement instruments

An instrument which is used to measure or compare an unknown quantity with standard or prescribed quantity is called as 'Measurement Instrument'.

Current meters, Volt meters, resistance meter, and power meters are example of the electrical measuring instruments that we use on PV systems. Often, some of the functions are combined into one meter e.g. a multimeter (see Figure 15). These instruments calculate or measure the value of electrical quantities (current, voltage, resistance, electric power).

Figure 15: Multimeter

7.1 Multimeter

When using a multimeter, the following should be considered:

- Make sure that the correct unit is selected e.g. AC voltage or DC voltage. Selecting the wrong unit may give no or the wrong reading.
- Make sure that the meter is operational by measuring a known quantity.
- Make sure that the correct scale is selected. Try to get the scale selection always higher but as close as possible to the expected value.
- When measuring current, make sure that the meter can measure the expected current. If the current is higher than what the meter can read, the meter may be damaged or a fuse blown.
- If the current is too high for the meter, use a current clamp probe or meter (Figure 16).
- Some meters have a hold function where the last measurement is kept on the screen. Make sure that the hold function is off before measuring (back to zero) to avoid thinking that you read a value but in actual fact it is the old reading.

- If the low-battery indicator comes on, replace the battery immediately as the measurements may not be correct.

Figure 16: Current clamp meter

7.2 Specialised PV Test Equipment

There is also more specialised PV test equipment available. These types of instruments can test the following:

- Ground continuity measurement.
- PV string open circuit voltage.
- PV string short circuit current measurement.
- Tests individual PV modules or strings.
- Test irradiance (W/m2), ambient temperature & more.
- IV Curves;
- Tests in accordance with IEC/EN62446 guidelines

Figure 17: Seaward Test Kit

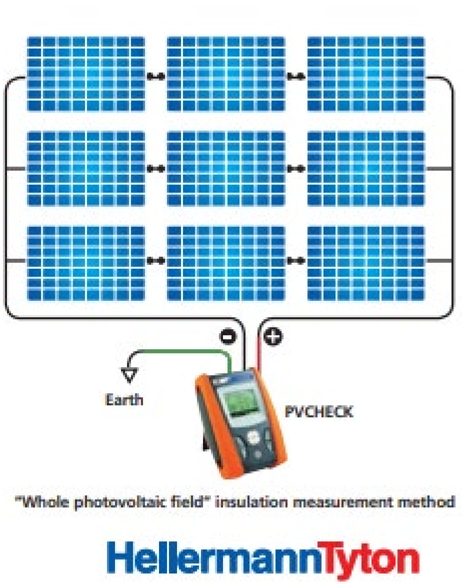

Figure 18: PV Check Instrument

7.3 Thermal Imager

The following was adapted from (Heijsman, 2018)

With a thermal imaging camera, potential problem areas can be detected and repaired before actual problems or failures occur. But not every thermal imaging camera is suited for solar cell inspection, and there are some rules and guidelines that need to be followed in order to perform efficient inspections and to ensure that you draw correct conclusions.

To achieve sufficient thermal contrast when inspecting solar cells in the field, a solar irradiance of 500 W/m2 or higher is needed. For the maximum result, a solar irradiance of 700 W/m2 is advisable.

When solar cells are inspected from the front, a thermal imaging camera sees the heat distribution on the glass surface. Only indirectly can it see the heat distribution in the underlying cells. Therefore, the temperature differences that can be measured and seen on the solar panel's glass surface are small. In order for these differences to be visible, the thermal imaging camera used for these inspections needs a thermal sensitivity ≤0.08K. To clearly visualize small temperature differences in the thermal image, the camera should also allow manual adjustment of the level and span.

To avoid reflection of the thermal imaging camera and the operator in the glass, it should not be positioned perpendicularly to the module being inspected. However, emissivity is at its highest when the camera is perpendicular, and decreases with an increasing angle. A viewing angle of 5–60° is a good compromise (where 0° is perpendicular).

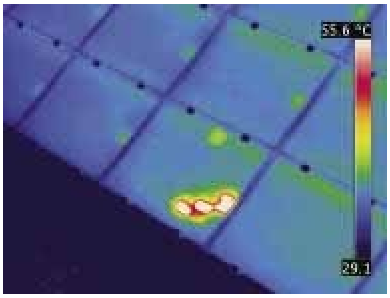

Figure 19: Hotspot image (FLIR P660 camera)

In most cases installed photovoltaic modules can also be inspected with a thermal imaging camera from the rear of a module. This method minimizes interfering reflections from the sun and the clouds. In addition, the temperatures obtained at the back may be higher, as the cell is being measured directly and not through the glass surface. Under normal circumstances the system should be inspected under standard operating conditions, namely under load.

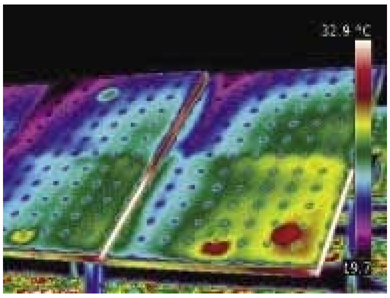

Figure 20: These red spots indicate modules that are consistently hotter than the rest, indicating faulty connections.

Thermal imaging cameras are primarily used to locate defects. Classification and assessment of the anomalies detected require a sound understanding of solar technology, knowledge of the system inspected, and additional electrical measurements. Proper documentation is, of course, a must, and should contain all inspection conditions, additional measurements, and other relevant information.

Figure 21: FLIR E4 Thermal imaging camera

Figure 22: Finding 'hot' wiring with a thermal imager

7.4 Battery testing

The following paragraphs were adapted from (Hankins, 2010) chapter 4

Just as one needs to monitor the amount of fuel left in a car's petrol tank, one needs to keep track of how much energy remains in the battery. The 'state of charge' (SoC) is a measure of the energy remaining in the battery. It tells you whether a battery is fully charged, half-charged or completely discharged. The cells of a fully charged battery have a 100 per cent state of charge, while those of a battery with one-quarter of its capacity removed are at a 75 per cent state of charge.

7.4.1 Measuring State of Charge

With lead-acid batteries (but not with most other types of batteries) the voltage of an open circuit cell varies with the battery state of charge. Thus, it is possible to roughly determine state of charge using a ‘multimeter’ (which measures the voltage of the battery and cells). Similarly, the density of a lead-acid battery electrolyte changes depending on the state of charge. A ‘hydrometer’ measures the thickness of sulphuric acid in each cell.

Good hydrometers are far more accurate for measuring state of charge than multimeters and can also to be used to detect dead cells. Nevertheless, multimeters are more convenient, versatile, less hazardous and easier to use.

When measuring state of charge, always check the electrolyte level in each cell to make sure that it has not fallen too low due to gassing. The level should be well above the plates – on better quality batteries the recommended level is indicated by a mark.

7.4.2 Measuring State of Charge with a Multimeter

As the state of charge of a lead-acid battery decreases, its voltage also decreases and this can be measured with a multimeter set to measure DC volts (a multimeter has several measuring functions and can act as a voltmeter). A typical solar battery at 100 per cent state of charge has a voltage of about 12.6V. When discharged to 50 per cent SoC its voltage will be about 12.1V and when completely empty (or dead) its voltage will be about 11.5V or lower (see Figure 23).

State of charge	12 Volt battery	Volts per cell	Specific gravity, grams/ litre at 25°C (77°F)
100%	12.7	2.12	1230
90%	12.5	2.08	1216
80%	12.42	2.07	1203
70%	12.32	2.05	1189
60%	12.20	2.03	1175
50%	12.06	2.01	1161
40%	11.9	1.98	1147
30%	11.75	1.96	1134
20%	11.58	1.93	1120
10%	11.31	1.89	n/a
0	10.5	1.75	n/a

Source: Manufacturer's data

Figure 23: State of charge for typical 12V SLI battery

The actual reading varies with the type of battery and the temperature – battery manufacturers should provide information about their battery state of charge parameters. A battery on charge (e.g. connected to a solar module during the day) will have a higher voltage and a battery connected to a load will have a lower voltage.

To measure a battery’s state of charge with a voltmeter:

- Disconnect the battery from the load and solar charger. If the battery was being charged (or discharged), wait at least 20 minutes to allow the cell voltages to stabilize before taking a measurement. If you measure right away, the reading will be inaccurate.

- Connect the voltmeter's leads to the positive and negative terminals of the battery or cell. Read the voltage on the voltmeter and compare it to the reading on a state of charge table that is appropriate to your battery e.g. Figure 23.

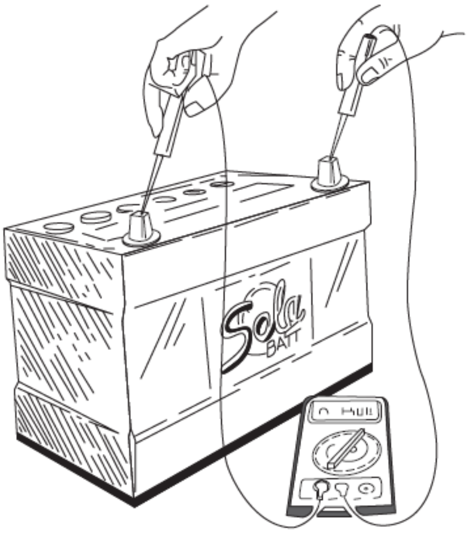

Figure 24: Measuring battery voltage

7.4.3 Measuring State of Charge with a Hydrometer

Hydrometers measure the 'density' (this is also called the 'specific gravity') of the sulphuric acid electrolyte in each cell, which is directly related to the state of charge of the battery. As lead-acid batteries are discharged, the sulphuric acid within each cell is converted to water, which has a lower density than sulphuric acid. Thus, discharged electrolyte becomes less dense as the battery's state of charge decreases. Hydrometers contain a floating scale with specific gravity readings that measure this density (see Figure 25).

Be aware that if the battery acid has 'stratified' (see below) this will give a false hydrometer reading. Be extremely careful when using hydrometers; wear protective goggles and always have supplies of water at hand to deal with acid spillages, clean hydrometers thoroughly after use and never leave them lying around.

Use the hydrometer as follows:

- Draw sulphuric acid up into the hydrometer from the battery cell by squeezing the bulb while the nozzle of the hydrometer is placed in the cell
- The scale floats at a level that varies according to the density of the acid and the state of charge of the cell.
- Read the specific gravity of the cell from the scale floating in the acid. Some hydrometer scales do not give the specific gravity, but only indicate whether the battery is in a low, medium or high state of charge – scales giving numbers are preferable.

- Consult a state of charge v. specific gravity table or graph to determine the SoC (i.e. see Figure 23).

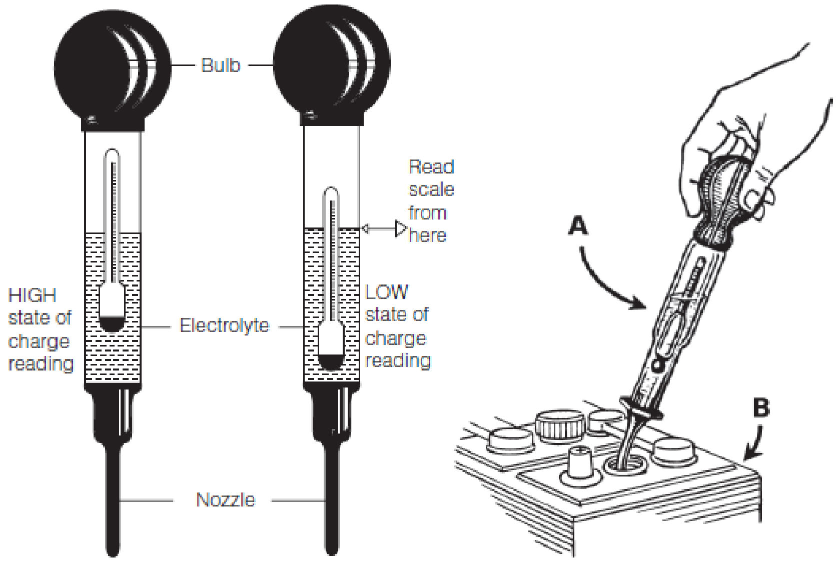

Figure 25: Hydrometer measurement

Self-Check - 7	Written Test

Instruction: Follow the below selected instruction

The following are true or false statements, write true if the statement is true and write false if the statement is false.

N°	Questions and answers
1	**All thermal imaging cameras are suited for solar cell inspection,**
	True or false:
2	**A PV tester can measure String Short Circuit current:**
	True or false:

Answer all the questions listed below

N°	Questions and answers
1	**Name 3 things to check before using a multimeter: (3)**

Note: the satisfactory rating is as followed

Satisfactory	4 points
Unsatisfactory	Below 4 points

Answer Sheet

Score = ____________

Rating: _____________

Name

Date