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SUMMARY

The PVTRIN troubleshooting guide aims to present the actions should be taken in order to ensure a proper performance of a PV system. The maintenance and troubleshooting requirements are -in many cases- the same for stand-alone and grid connected PV systems, however it may be different depending on the circumstances.

This document deals with operational issues that can reduce the performance of the PV systems and provides the necessary documentation for operating and maintenance procedures to minimise those losses.

The Guide is not intended to be either exhaustive or definitive and cannot guarantee to cover all possible situations in depth. Technicians are advised to exercise their own professional judgment and to consult all current building regulations, health and safety codes, standards and other applicable guidelines, as well as the technical manual of the equipment used.
1. COMMON MISTAKES AND FAILURES

1.1. Introduction

As PV systems have now been in operation for many years, a store of useful information has been accumulated on their typical faults and problems.

1.1.1. Insulation failures

Over recent years, the quality of module connections has significantly improved since the widespread introduction of plug connectors. The use of cable ties or wiring that is not UV or temperature resistant has proven highly problematic. Insulation also needs to withstand mechanical loads. All insulation ages over the course of time. For electrical power supplies, the physical operating life of power cables is generally specified as 45 years. Insulation can also be damaged by UV radiation, excessive voltage and mechanically. Suitable protection for cables is readily available on the market. Any insulation fault – whatever the cause - on the DC side can result in arcing, which is a serious fire risk. In consequence, all wiring should be periodically checked for any mechanical or thermal damage. The best way to do this is to measure the insulation resistance.

Automatic insulation monitoring, as performed by many inverters, is therefore a very useful feature. It signals an insulation fault and the inverter then isolates the system from the grid. However, the illuminated PV array will still supply direct current to feed the arc. Consequently the fault cannot be isolated by the inverter. If an insulation fault is indicated, the cause of the fault should be traced as quickly as possible. In a system with one or two strings, wiring faults can be detected by checking the inverter.

1.1.2. Inverter failures

The most frequently reported faults according to a great many studies are inverter faults (63%). However, there have been considerable improvements in this sector over time. A common fault is incorrect dimensioning and/or incorrect cable or voltage matching with the PV array. Most PV installation firms have now overcome this problem, and simulation software programs and design tools from inverter manufacturers also provide support in this area. Other sources of inverter trouble are voltage surge effects caused by electrical storms or grid switching, ageing and thermal overload. Further failures are simply due to device faults (DGS, 2008).

1.1.3. Construction failures

A common failure regarding PV mounting systems is the distortion of the PV modules when they are installed on the roof, in order to form a flat array surface mechanically. Under the influence of temperature and wind, or over the course of time, the module glass may shatter. Typical faults in PV mounting systems are an absence of expansion joints between modules or too few roof hooks to take account of the wind load. Moreover, the wrong choice of materials can cause corrosion on the mounting frame and compatible materials should be used at all times (DGS, 2008).

1.2. Common mistakes

Mistakes in a PV installation can be minimized, by ensuring appropriate design, installation and maintenance. Usually, most mistakes occur in PV installations during installation. In this sub-section, the most frequent installation mistakes are listed (Brooks Engineering, 2010).
Common Installation Mistakes with Array Modules and Configurations:
- Changing the array wiring layout without changing the submitted electrical diagram.
- Changing the module type or manufacturer as a result of supply issues.
- Exceeding the inverter or module voltage due to improper array design.
- Putting too few modules in series for proper operation of the inverter during high summer array temperatures.
- Installing PV modules without taking account of the Impp of each module (grouping).

Common Installation Mistakes with Wire Management:
- Human mistakes regarding the wire connection during installation.
- Not enough supports to secure the cable properly.
- Conductors touching roof or other abrasive surfaces exposing them to physical damage.
- Not supporting raceways at proper intervals.
- Multiple cables entering a single conductor cable gland
- Not following support members with conductors.
- Pulling cable ties too tight or leaving them too loose.
- Not fully engaging plug connectors.
- Bending conductors too close to connectors.
- Plug connectors on non-locking connectors not fully engaged

Common Installation Mistakes with Electrical Boxes, Conduit Bodies, and Disconnecting Means:
- Installing disconnects rated for vertical installation in a non-vertical application.
- Installing incorrectly rated fuses in source combiners and fused disconnects.
- Covering boxes or conduit bodies leaving them almost inaccessible for service.
- Not following manufacturer’s instructions for wiring disconnect on the DC side.
- Installing dry wire nuts in wet locations and inside boxes that routinely get wet.
- Using improper fittings to bring conductors into exterior boxes.

Common Installation Mistakes with Module and Array Grounding:
- Not installing a grounding conductor on the array at all.
- Not connecting the different parts of the modules together to achieve equal potential grounding
- Using indoor-rated grounding lugs on PV modules and support structures.
- Assuming that simply bolting aluminium frames to support structures provides effective grounding.
- Installing an undersized conductor for grounding
- Not installing lightning protection properly

Common Installation Mistakes with Mounting Systems:
- Not using supplied or specified hardware with the mounting systems.
- Not installing flashings properly.
- Not using the correct roof adhesives for the specific type of roof.
- Not attaching proper lag screws to roofing members.
- Not drilling proper pilot holes for lag screws and missing or splitting roofing members.
1.3. Troubleshooting

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.

The measurements required to find faults in grid-connected systems are essentially the same as those required for commissioning. Today, increasingly, remote diagnostics via a modem and PC are also possible with more modern inverters.

The step-by-step troubleshooting procedure is described in the following paragraphs:

Step 1: Inverter and PV combiner/junction box
Firstly, the measurement check of the inverter and the PV combiner/junction box should start with the respective connecting wires. Test the inverter operating data, by checking the LED or error code, or by using remote software and a laptop. The inverter’s operating data records can give useful information for the localization of the faults. For the measurement check, test the AC side and then the DC side at the inverter. Then, 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 2MΩhm.

Step 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.

Step 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.

Step 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.

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 (DGS, 2008).

In the Annex, a troubleshooting tree (F.Y Dadzie, 2008) is presented regarding a grid connected PV system with backup system.
<table>
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<tr>
<th>Typical failures</th>
<th>Corrective measures and troubleshooting</th>
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<tbody>
<tr>
<td>Failure in any PV system component</td>
<td>Try to get as much information from the customer as possible</td>
</tr>
<tr>
<td></td>
<td>Get as much information, such as prints, outputs and wiring diagrams, as possible</td>
</tr>
<tr>
<td></td>
<td>Follow the manufacturer’s instructions regarding malfunction</td>
</tr>
<tr>
<td>Entire PV system is down</td>
<td>Prior to getting on the roof, check and record the inverter’s input voltage and current level from the array</td>
</tr>
<tr>
<td>No current from array</td>
<td>Switches, fuses, or circuit breakers open, blown, tripped, wiring broken or corroded</td>
</tr>
<tr>
<td>Array current is low</td>
<td>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.</td>
</tr>
<tr>
<td>Output voltage is low</td>
<td>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.</td>
</tr>
<tr>
<td>Battery is not charging (autonomous systems)</td>
<td>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.</td>
</tr>
<tr>
<td>Battery is always at a low state of charge (autonomous systems)</td>
<td>Reduce load size or increase system size. (Sandia National Laboratories, 1991)</td>
</tr>
<tr>
<td>Typical failures</td>
<td>Corrective measures and troubleshooting</td>
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<tr>
<td>---------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Battery voltage loss overnight even when no loads are on (autonomous systems)</td>
<td>Replace or add diode, or repair or replace series relay charge controller. (Sandia National Laboratories, 1991)</td>
</tr>
<tr>
<td>Load not operating properly</td>
<td>Check that no fuses are defective or circuit breakers have been tripped. Check the system’s voltage at the load’s connection.</td>
</tr>
<tr>
<td></td>
<td>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. (Pennsylvania Weatherization Providers)</td>
</tr>
<tr>
<td>Low voltage shutdown</td>
<td>Shorten cables or use heavier cables, recharge battery, allow unit to cool, improve air circulation, locate unit to cooler environment.</td>
</tr>
<tr>
<td>Fault light on, AC load not working</td>
<td>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.</td>
</tr>
<tr>
<td>Reverse Polarity connection on inverter (autonomous systems)</td>
<td>Check connection to battery, the inverter has likely been damaged and needs to be replaced.</td>
</tr>
<tr>
<td>Loads disconnecting improperly</td>
<td>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,</td>
</tr>
<tr>
<td>Array fuse blows</td>
<td>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.</td>
</tr>
<tr>
<td>Loads disconnecting improperly</td>
<td>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</td>
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<tr>
<td><strong>Array fuse blows</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>No output from inverter</strong></td>
<td>Switch, fuse or circuit breaker open, blown or tripped. Wiring broken or corroded. Low voltage disconnect on inverter or charge controller circuit is open. High battery voltage. The load on the inverter may have too high of a current demand. Reduce the loads or replace the inverter with one with a larger output. Many PV inverters have LED displays as indicators. Check that the appropriate LEDs are lit up to indicate proper inverter operation. With the power off, check for and repair any ground faults before starting the inverter again.</td>
</tr>
<tr>
<td><strong>Corrosion of Structural components</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>Fire during the operation of photovoltaic</strong></td>
<td>Stay away from the PV system during and after a fire. Inform the fire brigade about the particular hazards from the PV system. After the fire, have your installer bring the PV system in a safe mode. (Mitsubishi)</td>
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2. DIAGNOSTIC PROCEDURES

2.1. Visual inspection procedures

The mechanical problems are generally evident by something being loose or bent or broken or corroded, can generally be found with a visual check. To perform an inspection the weather should be good and all inspections must completed through a clear, sunny day. (Rudkin E. & Thornycroft J., 2008)

2.1.1. Array Inspection

The PV array is the first item that needs inspection as PV arrays can influence the performance of the PV system. This can be a difficult procedure if the array is placed on multiple roof faces of the building and the visual inspection of the array cannot be carried out. Sometimes, the array inspection cannot take place as the inspector is unable to get on the roof. In such situations using a lift or a secured ladder at the time of inspection is recommended.

Once the inspector has either gained access to the roof or has a clear view of the roof, the number of PV modules of the system must be counted. It is important that the number of modules matches that of the plans and a comparison should take place.

At the back of the modules, there is a label listing all the characteristics of the PV module. During the visual inspection, the label should be checked so as to confirm the model number of a module. A photo of the label is a good option if there is a difficulty to view the back side. Otherwise, if possible the module should be moved, so as the inspection is completed successfully.

Also, an inspection should include a check of the physical condition of the photovoltaic array as some can become distorted or settled under stress. This may crack the glass on the front and the module must be replaced. Futhermore, under temperature and wind influences, the PV modules may shatter. Additionally, an inspector may check for any signs of corrosion on the mounting frame. This can appear due to the wrong choice of material. Poor system conditions may lead to losses in output power. (DTI,2006)
(The German Energy Society, 2008)
(Brooks Engineering, 2010)
(Rudkin E. & Thornycroft J., 2008)

2.1.2. Wire Inspection

The inspector must get near the PV array and inspect under the modules array. Conductors must not lie on the roof or come in contact with sharp surfaces that may cause them physical damage. Also the inspector should check if the connectors are fully engaged. The wiring should be checked often for any mechanical and termal damage. A simple way of doing this is to measure the insulation resistance. Attention should be taken to minimise cable lengths, and to ensure that all connections are made in the correct way and are protected. A poor connection may reduce the performance of the system in the long term. It is better to ensure the quality of the connections during the installation. This can save time at the inspection, as the inspector will not have to identity and localize the poor connections. (DTI,2006)
The German Energy Society, 2008
(Brooks Engineering, 2010)

2.1.3. Inverter Inspection

Output reductions are observed when the inverter shows operational problems. The inverter may shut down, present a fault, or failed to restart automatically due to a grid fault. Faults with inverters may not be noticed for a long period of time. So, it is
2.1.4. Inspection of Module and Array Grounding

PV module and array grounding is one of the most important safety issues in a PV installation. For module grounding, an electrical connection is created between the module frame and the equipment grounding conductor. This connection requires all the modules array to have additional array grounding which is important for lightning and surge grounding. (Brooks Engineering, 2010)

2.2. Performance monitoring

2.2.1. User feedback

User feedback is one of the most important factors for ensuring good performance and operation of the PV system. Users can check the inverter operation, output power levels, shading problems or obvious damage to the system. This can range from a simple LED on the inverter lid or a user display in a domestic corridor, to a large interactive wall display in the entrance hall of a corporate building. All displays provide the users an indication that the system is functioning. A clear display gives much added value to the system, especially if combined with some graphic or text explaining the concepts. When a problem occurs, the users may call the specialists to resolve and fix the problem. It is important that the user understands how to make the necessary checks - the system installer is responsible to provide this information to the user. (DTI, 2006)

2.2.2. Performance verification

A system may have been financed on the basis of its output through support schemes (Feed-in Tariffs), and so the user is good to measure the output and compare to the claims for the system. The complexity and expense of such metering is determined by the number and accuracy of the measurements to be made. A display is the interface between the user and the system and is the main source of information on the system performance. (DTI, 2006)

FIGURE 1.
MEASUREMENTS ON A ROOF GRID CONNECTED PV SYSTEM
(Source: Conercon Ltd)

2.2.3. Displays

Displays are the backbone of monitoring. With a display unit, the user is able to see the output power of the PV system. Some displays, may also include information on the consumption of the building, giving an estimate of the amount of electricity generated. The displayed values must be clear, easily understood and accessed. If the display is to be effective it must be in a place where it is visible and accessible in everyday activities. In some cases, displays were
installed in an open area (hallway), but either too high or too low to be easily viewed, thus difficult to read. It is also not recommended to place displays inside the meter cupboard, as they are not readily viewed.

Other kind of displays are remote displays which are easier to site, and may be provided with data from the inverter itself, or by a meter in the cabling from inverter to distribution board. A significant cost to installing this is the routing of the cabling to the display, but there are instruments on the market that avoid this by utilizing short-range radio transmission.

The easiest to fit is a simple indication as part of the inverter. Most PV inverter manufacturers offer an optional display. However this can place severe constraints on the placing of the inverter, which would normally be in a roof void, electrical switch room, or some other secluded place.

If the display is to be effective it must be in a place where it is visible in everyday activities. Remote displays are easier to site, and may be provided with data from the inverter itself, or by a meter in the cabling from inverter to distribution board. A significant cost to installing this is the routing of the cabling to the display, but there are instruments on the market that avoid this by utilizing short-range radio transmission.

There are many different formats of data that can be displayed: the most popular are the instantaneous power being generated, and the total energy to date. However, large displays often include derived values that mean more to the public, such as numbers of lights that are being powered, or the amount of carbon production being offset. A computer-based monitoring system can often embed that information within a touch screen driven information point, or to have it displayed on the website for the building.

( DTI, 2006 )

2.2.4. Design Software

All system design programmes have assumptions embedded in program calculations. Therefore, the accuracy of the output depends on the accuracy of those assumptions that are appropriate for the case being considered.

The software is designed to be general. The user can modify the values of a number of operating parameters and built the software with the desired parameters.

Most of software packages have imported data from packages and provide meteorological information for many sites around the world. System designers should select a data site that is climatically matched to the installation site with similar latitude.

( DTI, 2006 )

2.2.5. Data Acquisition Systems

The main system tends to fall into two types: loggers and computers. The advantage of a logger is its simplicity and robust construction, but its disadvantage is its inflexibility and cost. A computer system, in contrast, may be slower to set up and commission, but has the advantage of a wider choice of operational modes and custom settings, while the cost may be less for a system based on a desktop PC. The choice between the types may well be dictated by the type of monitoring strategy.

2.2.6. Sensors

There is no limit to the inputs that may be monitored for a PV System, but most systems will need to measure input and output energy, and some environmental and system variables.
2.3. Calibration and Recalibration

The system should be set up and calibrated preferably in situ. The need for recalibration should be determined whilst considering the length of time for the monitoring, and the accuracy required of the system. The reference cell is particularly critical, but often the most difficult item to access. If annual recalibration is not practical back in the laboratory, an on-site comparison with a reference device nearby may be adequate. The entire monitoring system can also benefit from a comparative calibration using hand-held reference devices (ambient temperature sensors, voltage and current meters, etc.).

2.4. Data Storage and Transmission

The data is generally stored in situ using RAM for a logger, or using a hard drive for a computer system. Loggers often include removable RAM cards, discs, or other magnetic media, as a form of storage/retrieval. PCs may use multiple drives, or daily downloads, as a backup storage method.

Having recorded the data, it may be transmitted back to the monitoring organization by many means. The simplest logging systems may have to be physically carried back to the laboratory and plugged into a special reader device, or a PC serial port.

Removable media allow the swapping of the storage medium on site allowing monitoring to continue uninterrupted. The only disadvantages are that the new media may not be inserted correctly, or the logger may not be restarted, and the loss of data will not be noticed until the next visit. Telephonic transmission is often used, as it allows frequent downloading of data (reducing the length of any ‘lost’ periods), and also the chance to ‘upload’ any changes to the logging schedule. The more sophisticated loggers can initiate a call to a fax or PC to report any faults or out of range signals immediately they are detected. The advent of the internet has allowed PCs to connect to a local portal via a local phone line, thus making downloading less expensive anywhere in the world. If a telephone line is not available at a remote site, a cellular phone connection can provide an equivalent facility.

2.4.1. Data Analysis

After collecting the PV system data, a detailed analysis should be conducted. In this way, the stored data can be a useful tool for system monitoring and evaluation. Monthly performance ratio values, array yields, etc. have become the normal way of defining the performance of a PV system and continued use of this method will make it easier to compare existing systems. Bar graphs can also be embellished with sub-categories of capture losses, system losses, etc. For example, keeping a bar graph record of daily and monthly energy output is a simple way to guarantee PV system performance and to analyze possible system failures (Source: Rudkin E. & Thornycroft J. 2008).

FIGURE 2. EXAMPLE OF A BAR GRAPH OF A 1KW PV SYSTEM
ANNEX

Troubleshooting process tree - Grid connected PV system with backup system (F.Y Dadzie, 2008)

System is not supplying power

Are all fuses and circuit breakers working?

Replace all failed fuses and circuit breakers

Is there a voltage output at the inlet to the service panel?

No

Yes

Is there an output from the AC disconnect?

No

Yes

Check service panel connections or replace service panel

Is power disconnected at AC disconnect?

No

Yes

Check cabling and tighten connections

Reconnect power at the AC disconnect switch

Check output from Inverter. Is there output from inverter?

No

Yes

Is there D.C. output from battery bank?

Check output connections and continuity of cable

No

Yes

Check wire connection to inverter and if not still working then inverter has failed

Check Battery bank
1. Check that the battery bank fuse is intact
2. Check that all terminal connections are tight and clean.
3. Measure the battery voltage for the whole bank at the output terminals with no load or inverter connected to it.
4. If the battery terminal voltage is as expected then the fault only appears under load.
5. The voltage of each battery is checked with a heavy load connected. If the battery voltage drops significantly on connections then it means one or more battery cells might have a short circuit which only appears under load.

Check Solar Array
1. Check for shading of the modules
2. Check for dirt on modules
3. Check for any loose wires
4. Check current output for each string and check if any of the strings give an unrealistic low figure.
5. If an under performing string is identified, identify the particular module by shading each module successively and checking the relative changes in the ammeter reading. The module that when shaded does not result in any change in ammeter reading is faulty.

Is system working?

End of troubleshooting

End of troubleshooting
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A great deal of additional information on the PVTRIN project is available on the web at: www.pvtrin.eu.

We would welcome feedback on this publication, if you have comments or questions please contact the project coordinator.

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# PVTRIN PARTNERS

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