Harnessing the potential of solar PV power safely and effectively; IEC 62446 & the role of effective installation testing

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Introduction

Solar photovoltaic (PV) systems are being installed in ever increasing numbers throughout the world and are expected to safely and reliably produce electricity over several decades of operation.

However, many systems are not satisfactorily evaluated prior to being put into service and many have little, if any, scheduled maintenance or testing over their lifetime. Unfortunately this leads to unsafe and underperforming systems with reduced value to their owners.

Any electrical system can be tested to verify performance and to evaluate the condition of wiring systems and equipment. This is particularly important for PV installations which can be subjected to extreme environmental conditions and deteriorating effects of the elements over many years.

To help ensure the long term safe operation of these systems, quality PV installation and service contractors execute a thorough commissioning process followed by a regular periodic testing and maintenance programme. These practices can help to promote safety and optimise performance, and provide essential information to those who may need to effectively troubleshoot, diagnose and remedy any problems arising with the system.

In this way, all PV systems require testing for performance and safety verification. The level of testing required will depend on local regulators, customer requirements and the quality commitments of the installation and maintenance contractors.

A growing market

The almost exponential increase of global solar PV installations in the recent two decades have enabled both rooftop systems and utility-scale PV farms to become an increasingly important mainstream source of electricity.

As the sustainable energy benefits of solar PV attracts more support, and as the technology continues to evolve and reduce in cost, the global growth momentum behind photovoltaics is forecast to continue.

According to the Global Market Outlook for 2015-2018[2], published by recently created Solar Power Europe (the new name for the EPIA), it is reported that installed solar PV capacity has grown by a factor of 100 in only 14 years.

A record 40GW of solar PV systems were installed globally in 2014, up from 37 GW in 2013. China, Japan and the USA were the three top markets in 2014, but for the first time the UK led the development of solar power in Europe with 2.4GW of new capacity, ahead of France (1.9GW) and France (927MW).

Solar PV is now providing more than 7% of the electricity demand in Italy, Germany and Greece and it is anticipated that solar power capacity could grow in Europe by 80% by 2019.

Overall, the latest report forecasts that global solar PV capacity could reach 540GW in five years' time. In most countries, solar PV installation remains a policy-driven market and this range of growth possibilities forecast by the EPIA reflects the difficult-to-anticipate impacts of the introduction, modification or phasing out of national support schemes and subsidies in different countries.

Against this background, with all the indications pointing to sustained growth in the global solar PV installation market, there are clear opportunities for those involved in the provision of products and services to the sector.

The need for recognised installation standards

Because the solar PV industry has expanded so rapidly, electrical installation and safety standards have had to be revised in order to keep pace with the demands of the industry. However, in many cases it is recognised that the rate of growth of the industry has been at such a fast pace that standard-making organisations have found it difficult to keep up.

As a result, there have been concerns expressed in a number of countries over the safety and quality of the installation of some PV systems.

In some circles the concerns are that incorrectly installed PV systems are not working efficiently and can also be linked to safety problems, including the creation of fire hazards.

The latest example of these concerns comes from Australia. In 2015, the Government's environment minister Greg Hunt ordered an enquiry into the quality of rooftop solar system installations.

The move came after reports of rooftop solar PV panels failing long before their intended lifetime and concerns being expressed over the quality of components and products used in some installations.

In response, the minister asked the Clean Energy Council (CEC) to carry out investigations into the claims. In a letter to both the CEC and the Australian Solar Council, he stated that 'the poor installation of substandard solar PV has the potential to lead to fires with risks to property and human life'.

On the same matter, in an earlier survey by Australian consumer watchdog Choice[3], while more than 80% of solar owners were reported as being satisfied with their purchase, it was reported that a quarter of owners had problems with their systems and 32% had problems with their installer.
These reports followed a number of previous reports in Australia that highlighted similar concerns. Last year, for example, a Queensland company that sold allegedly faulty circuit breakers, that caused at least 70 fires in rooftop solar panel arrays, went into receivership. At the time, it was claimed that faulty isolators were responsible for a number of incidents in Queensland and New South Wales, with fires causing wall and ceiling damage.

In 2011, the NSW Government issued details of a survey of solar PV installations in western Sydney[4] that found that 18.5% of the installations had major defects. At that time, of the 658 systems inspected, 122 were found to have significant safety issues and a further 418 (63.5%) were found to have minor defects.

These findings mirror that of a similar survey a year earlier in France[5], when safety inspectors from the electrical safety certification agency Consuel found that 51% of all PV installations in the country posed a potential safety risk and did not conform to regulations.

In the UK, as the number of solar PV installations has increased, separate newspaper stories have detailed a number of examples of fires in residential premises, supermarkets and schools, where the cause was attributed to faults in the rooftop solar PV installation.

Elsewhere, in the USA, after a well-documented solar PV "thermal event" that occurred in Bakersfield, California, in April 2009, the cause was put down to an undetected fault-to-ground in a grounded current-carrying source circuit conductor at the site. A subsequent analysis of utility-owned and operated rooftop PV systems in North Carolina revealed the presence of undetected ground faults in approximately 10% of the systems surveyed.

Figure 1 - There have been concerns expressed in a number of countries over the safety and quality of the installation of some PV systems

Also in the USA, a report, prepared by the Fire Protection Research Foundation, entitled 'Fire Fighter Safety and Emergency Response for Solar Power Systems'[6], published in 2010, detailed several fires caused by PV systems. The believed causes included electrical malfunction, leaves and debris under the solar panels, electrical arcing and electrical faults in inverters.

Clearly all these cases highlight the fire risks that can be associated with PV systems and support the need for the maintenance of rigorous installation and inspection standards.

Safety and fitness for purpose

Given the political and financial support being given to solar PV around the world, the universal priority for governments, industry and regulators is to ensure that the integrity, safety and quality of solar PV installations is maintained at the highest standards.

The owners of solar panel installations need to have confidence that the system they have purchased will function correctly and will avoid any potential hazard throughout its usable lifetime.

This is particularly important for installers working on ‘roof rental’ schemes were the installation is provided free of charge in return for receipt of rebates or feed-in tariff payments. Similar financial performance considerations are also vital for the investors and operators of utility-scale solar farms.

Manufacturers of PV cells, inverters and components, should equally be concerned that their reputations can be held to account as, in the event of a system failure from poor installation practices, the supplier and their products might then be regarded as being inferior and contributing to the hazard.

The buildings insurance industry also has a vested interest in all of this by ensuring that installations are properly installed, and are not the basis of subsequent compensation claims.

Last, though not least, the fire and rescue services that may need to deal with any incidents involving a rooftop PV installation need to be sure that they are not being exposed to a hazardous environment.

As a result of all these considerations, verifying the proper installation, checking system performance and confirming the sustained energy output from a solar PV system are fundamental requirements.

In achieving these aims, it follows that the effective commissioning and periodic quality testing of the system is crucial - as well as being essential to comply with warranty and PV system guarantees.

Applying adequate test standards – IEC 62446

The installation of PV systems presents a unique combination of hazards linking the risk of electric shock with the implications of working at height.

PV arrays produce a DC voltage when exposed to sunlight. In the wiring system associated with PV panel installation, the DC current generated by the solar array is converted to AC by means of an inverter which then feeds into the AC mains supply of a building.

Most electrical installation standards focus on conventional AC installations and the advent of extensive DC systems in the form of photovoltaics installed outside an equipotential zone has required the introduction of revisions and amendments to existing national standards.

However, across the globe, the recognition of the need to implement specialist controls and guidance notes has varied. Indeed, until comparatively recently, only a handful of countries had documented a rigorous testing process to ensure that a PV installation had been properly tested, the results recorded to demonstrate that adequate precautions had been taken and that evidence was available to support periodic inspection.

What appears to have been overlooked in this situation is that an international standard already exists that, if properly incorporated in mandatory national documents, would significantly help to eliminate solar PV system safety and quality issues.

IEC 62446 defines the minimum requirements for solar PV system documentation, commissioning tests and inspection. As such, this standard not only specifies minimum testing and inspection requirements on newly installed systems, but equally importantly, how those inspection and test results are documented and supplied to the consumer after installation.

The standard recognises that subsequent building or electrical works in the vicinity of the PV array may be likely and that the ownership of a system may also change. As a result, the standard recognises that only through the provision of adequate documentation at the outset can the long term performance and safety of the PV system be ensured.

IEC 62446 therefore sets out the testing, information and documentation that should be provided to the customer following the installation of a solar panel system and also the initial (and periodic) electrical inspection and testing required.

In short, the standard sets out measures to ensure that:

- The PV panels and electrical supply connections have been wired up correctly
- The electrical insulation is good
- The protective earth connection is as it should be
- There has been no damage to cables during installation

In addition, the standard sets out specific requirements for a range of electrical tests and functional testing of the system as part of its commissioning. In doing so, the system documentation required by IEC 62446 therefore not only provides evidence to the consumer that the work has been performed correctly, but it also acts as a best practice guide to the contractor to ensure that recommended procedures have been followed and that installed system performance is as it should be.

IEC 62446 was published in March 2009 and when voting was taken on this standard, all member countries voted in favour. Although it is not mandatory, various countries have already adopted the principles of IEC 62446 in their national accreditation schemes.

For example, it has been adopted as an EN standard in many of the European member states and is generally regarded as making a significant contribution to improving the quality and safety of PV systems.

In the USA, similar requirements for compliance with IEC 62446 are being listed in procurement contracts for new projects and many of the testing procedures listed in the standard correlate directly with NEC requirements for verification of electrical system safety.

In such countries, for all new solar systems, equivalent documentation and forms described in IEC 62446 are required in addition to any specialist information and paperwork required by each country's domestic electrical installation standards.

Furthermore, it is effectively enforced because in most countries no feed-in-tariff or electricity rebate will be paid to a consumer unless the installation has been installed by a formally accredited installer with the proven capability of carrying out the quality of work required – and who follows the necessary procedures needed to comply with the regulations.

Following the core principles of IEC 62446 would therefore not only help safeguard the future integrity of solar PV installations – it would significantly help to allay the various quality concerns that have been raised over the proficiency of PV installers and the system components they are using.

Figure 2 - IEC 62446 defines the minimum requirements for PV system documentation

Solar PV test instrumentation

After a PV system has been installed, simple electrical faults or wiring failures can cause a serious inefficiency in the ability of the panel to produce power and perhaps cause fire and other safety risks.

In such circumstances, although proper metering will usually give an indication of system performance, visual inspections on their own will not be enough to determine what ‘invisible’ system faults or problems may exist.

In response, advanced multi-function test instrumentation has been developed to ensure that solar PV installers can meet this requirement efficiently and cost-effectively – and that important tests and system checks are not overlooked. System data, collected by such testers, can be transferred to customer documentation packs and templates at the push of a button.

Of course there are many instruments available that are sold under the title of ‘solar testers’ so it is vital to ensure that the instruments selected are capable of performing all of the tests required by the various compliance requirements.

The absolute minimum testing that should be undertaken involves continuity measurements, open circuit voltage, short circuit current, insulation and irradiance.

To meet the electrical test needs, some contractors have used multiple instruments that typically include an earth continuity and insulation resistance tester, a multimeter, and a DC clamp meter along with various associated connectors and leads.

However, the danger with such ‘homemade kits’ is that not all of the tests required by IEC 62446 will be covered and, with different PV system electrical tests potentially requiring the use of different testers, using such an array of instruments can be cumbersome and time consuming.

This sort of consideration has led to the introduction of a new generation of dedicated multi-function solar PV electrical testers, such as the Seaward Solar PV150, that are capable of carrying out all electrical tests required by IEC 62446 on grid connected PV systems.

With the push of a single button, the combination tester automatically carries out the required sequence of electrical tests in a safe and controlled manner. Testing can be conducted quickly and easily with the PV150 being pre-programmed to run a test sequence of required tests and using specially designed PV test leads which quickly connect and disconnect from the installation circuit. This also avoids the risk of contact with exposed live DC conductors.

For a comprehensive approach, alongside electrical testing, an irradiance meter is also required to measure how much solar power is available at any particular location.

The most accurate solar readings are produced from irradiance meters which use sensors similar to the technology utilised in the panels themselves. The ideal solution is an irradiance meter which uses a photovoltaic cell as its sensor rather than a pin diode which will not necessarily have the same response to sunlight as the PV cell itself.

In addition, some irradiance meters are themselves 'multi-function' and incorporate other useful features such as a digital compass, a digital tilt meter and a dual channel precision thermometer.

In this respect, and intended for maximum operational efficiencies, special solar PV test kits have been introduced to help installers to work faster and more effectively without reducing the integrity of testing.

As an example of this approach, the Solarlink Test Kit includes all the necessary test equipment and datalogging capabilities needed to perform pre-installation site surveys and measure the electrical safety and performance of PV systems in line with IEC 62446.

The kit combines the comprehensive electrical commissioning test capabilities of the PV150 hand-held solar installation tester with the advanced Solar Survey 200R multi-function PV survey meter.

Special wireless Solarlink connectivity between the two instruments enables real-time irradiance to be displayed and measured at the same time as electrical testing is being undertaken. This means that irradiance, module and ambient temperature can be recorded in real time, within the PV150, as the electrical tests are conducted.

Once testing is completed, the USB download of time and date stamped test results, irradiance and temperature measurements provides full traceability and speeds up the completion of PV system documentation and customer handover packs.

In addition to solar PV system installation and commissioning, the Solarlink Test Kit is ideal for conducting site surveys of potential installations, by quickly providing the information needed to calculate estimated annual solar irradiation and system yields of PV and solar thermal systems.

In terms of working more efficiently, multi-function PV testers and dedicated test kits can also record and provide results in a format that can easily be accommodated in comprehensive system information folders for use in customer test certificates and system commissioning packs.

Figure 4 - Advanced multi-function test instrumentation is available to help solar PV installers to meet the requirements of IEC 62446

Case Study 1 – OCS Energy Inc, California, USA

PV test instrumentation cuts test times on major new California solar installation

Advanced test instrumentation from Seaward has enabled the installation and commissioning of a large new solar PV installation in the California Central Valley to be completed, in record time – and safely, in compliance with all required standards.

Renewable energy design and integration company OCS Energy Inc., specified the use of the Seaward Solar PV150 tester and Seaward Survey 200R irradiance meter for the installation of a new 20MW 'behind the fence' system in Fresno, California.

The system is comprised of 113,280 Sharp 240W and 235W panels arranged in a high voltage configuration of 24 panels in series mounted on single axis trackers, with Advanced Energy Solaron 500 1kV utility inverters with AC/DC switchgear and optional VRT.

With a tight construction schedule, OCS Energy calculated that the 4,720 circuits to be tested as part of the commissioning documentation would take approx. 3.5 minutes per test with manual irradiance and temperature measurements recorded every 15 minutes.

Another factor was safety, with NFPA 70E imposing strict procedures for protecting employees working on or around systems rated over 600 volts.

In this situation, OCS and the installation contractor devised a 'commission during build' schedule utilizing advanced solar PV instrumentation provided by Seaward. The strategy was to have OCS Energy "dove tail" the installation and construction crews, to verify and document that the system was built to NEC code compliance and identify any problems or issues early on so that corrective action could take place during the build.

This meant that, once the substation was connected to the utility grid, final commissioning of the inverters, medium voltage switchgear and the substation followed in sequence.

The Seaward Solar PV150 is a dedicated multi-function PV electrical tester designed specifically for solar panel system installation. It performs open circuit voltage measurements (Voc), short circuit current measurements (Isc), earth continuity, insulation resistance, operating current (via AC/DC current clamp). Results can be recorded and stored in the tester for subsequent USB downloading to a PC.

With the push of a single button the new combination tester carries out the required sequence of electrical tests in a safe and controlled manner, avoiding the risk of contact with exposed live DC conductors.

As a result, it eliminated the need for multiple test instruments for PV panel electrical installation, commissioning and connection testing.

In the California Central Valley installation, the use of the PV150 tester was accompanied by the Seaward Survey 200R irradiance meter. This unit also incorporates a compass, tilt measurement meter and ambient temperature monitor, with time and date data logging features.

Uniquely, it also incorporates 'solarlink' wireless connectivity to the PV150 so that all data can be recorded, in real time, within the PV150, as the electrical tests are conducted.

With OCS Energy outfitted in the field with the means to run a laptop for the downloading of results into separate folders for each combiner box, the net result was that test crews were able to test three combiner boxes simultaneously – representing 36 circuits in approximately 3 minutes in total. This represents a considerable time saving in labor hours compared to other projects, where similar testing could take nearly 2 hours.

Richard O'Connell, CEO of OCS Energy Inc., said: "Typically, most construction projects have 'punch lists' that occur at the end or near the end of a project to allow the owners and contractors to walk the job and identify issues to be addressed later.

"In the case of this project, the completion date did not leave any room for construction defects. Nevertheless, the testing schedule using the PV150 and 200R enabled us to meet our target project milestones and demonstrate compliance with all standards almost immediately.

"The commissioning of industrial photovoltaic systems requires attention to detail and an ironclad protocol to demonstrate to owners that they got what they paid for.

"In this circumstance, I cannot over-stress how difficult it can be to obtain accurate and meaningful data collection on an industrial PV array while the temperature of the project is in the 90 degree or higher range. When technicians are in extreme heat the risk of poor data collection is almost a certainty, so minimizing these errors is not an easy task.

"However, using the new test technology ensured that we were able to overcome these challenges and meet all the requirements of the project safely, effectively and cost efficiently."

With over thirty years' experience in the electrical industry, OCS Energy understands the importance of accurate data collection for the owners and operators of these power plants, and recognizes the crucial contribution made by the new Seaward Solar PV150 and 200R instrumentation in the satisfactory commissioning of PV systems.

Case Study 2 - Lightsource Renewable Energy, UK

Advanced test technology helps solar farms to maintain maximum power generation performance

Seaward Solar test instrumentation is helping the UK's leading developer and operator of commercial solar photovoltaic (PV) plants ensure that its solar farms continue to operate at maximum performance levels.

Lightsource Renewable Energy has equipped its engineering maintenance teams with Seaward Solarlink PV test kits to enable them to fault check and verify the ongoing power generation efficiency of its portfolio of solar farms and large-scale rooftop installations in the UK.

In total, Lightsource owns and operates over 200 solar farms and large-scale roof mounted solar installations, as well as hundreds of smaller scale assets on schools and other properties - all supplying clean energy to the National Grid and direct to customers.

The development of large scale solar farms is only undertaken after careful consideration of the costs involved and the potential return on investment provided by FIT (Feed-in Tariff) and power purchase agreements. As a result, the day-to-day maintenance of optimum PV performance from the panels is essential.

At Lightsource, after installation and commissioning of each solar PV site, the company uses the latest technology to undertake real time data-monitoring of the solar power output at all of its locations.

Detailed electrical supply information is provided for each solar site, down to individual solar PV string level, to provide the monitoring team with an early indication of any faults, under performance or other potential problems at the installation.

If any problems are identified, the company's 30-strong operation & maintenance team can then be alerted to enable an on-site assessment to be made and any corrective action to be taken, with the Seaward Solarlink PV test kit proving to be an essential tool in identifying the fault and making the necessary repairs.

The Solarlink kit combines the comprehensive electrical test and data-logging capabilities of the PV150 hand-held solar tester with the advanced Solar Survey 200R PV survey meter.

With the push of a single button, the combination tester carries out the required sequence of electrical tests in a safe and controlled manner, avoiding the risk of contact with exposed live DC conductors.

Special wireless Solarlink connectivity between the PV150 and the high performance Solar Survey 200R meter enables irradiance, module and ambient temperature to be recorded, simultaneously, within the PV150, as the electrical tests are conducted.

This enables the tester to be used for the assessment of solar PV performance, the diagnosis of electrical faults and the effective operation of the system after any remedial works have been undertaken.

It is this all-round combined capability that is proving to be essential to the Lightsource engineering team and its work at large-scale solar farms around the country.

Richard Ellis, Lightsource O&M Regional manager for Central Region, said: “The test kit has become an essential part of our on-site tool kit, with the multi-function PV150 unit eliminating the need for engineers to carry separate meters for different tasks.

“The ability to take one combined measurement instead of many separate ones greatly improves operator efficiency and accuracy, helping to identify any faults within DC Strings and getting them back on stream quickly and safely - which is the key requirement of our maintenance work.”

In this way, the combination of advanced remote monitoring technology with the latest in on-site solar PV test instrumentation is enabling Lightsource to ensure that its expanding solar generation portfolio continues to perform at maximum power efficiency.

Case study 3 – Comet Systems, Anguilla, Caribbean

Solar PV test instrumentation verifies module quality and system performance

Advanced Seaward Solar PV test instrumentation is helping a successful Caribbean-based reseller and installer of solar photovoltaic and thermal systems to verify the quality of PV modules and the performance of installations.

Comet Solar is an established solar installation company based in the British Overseas Territory of Anguilla. With some of the best beaches in the world, the local economy is largely focused on tourism and Comet has been successful in encouraging local hotels, resorts, property owners and businesses to invest in solar systems as a means of helping to offset the effects of the economic downturn on tourism levels and rising energy costs.

Chris Mason, owner of Comet, explains: “Cost is very important to our customers and so we tend to look for PV modules at bargain prices. Without any subsidies or incentives and facing aggressive resistance from the utilities, solar has been a difficult sell.”

Comet customers therefore tend to focus on price and return on investment, with aesthetics often being low on the list of purchasing factors. However, buying bargain priced solar PV modules brings its own challenges; second hand or refurbished modules are often used, but, in some cases, the life history of the modules or the original manufacturer is not always known.

Another issue is the lack of formal installation standards or regulations. For example, operating in a Caribbean jurisdiction means that Comet is not specifically required to perform the same tests that a UK or US-based installation company would be faced with.

However, in spite of this, in the interests of maintaining installation quality, Comet always aims to apply and meet the existing standards of the US NEC code and to perform to the best practices of the industry.

To help achieve this, the company has recently invested in a dedicated new Seaward Solar PV150 solar installation test kit, along with a 200R irradiance meter, to enable it to carry out effective quality control and customer reassurance testing on its products and installations.

Chris Mason, explained: “In order to ensure the quality of the products we sell to our customers, we feel it is important to carry out testing thoroughly and effectively.

“We owned standard test instruments and DC clamp meters but found that these manual methods were prone to error and were not particularly practical to use in the field. There is also no efficient way to record

the results. We therefore decided to find a portable but capable test system that would document the performance of each module in a recordable way."

Recently Comet was offered a container of 170W used monocrystalline solar panels and used them on a 12 kW commercial flat roof top system.

These PV units had been replaced on their original system due to yellowing of the backing but were in perfect electrical and mechanical condition. As the modules were used, Comet tested every unit prior to installation to make sure of the quality and safety of the modules and also to prevent any subsequent dismantling of the installation for any troubleshooting required.

To do this, Comet set up an improvised test bench at the installation site and tested every module as it came out of its packing. All testing was carried out during the middle of the day so as to make use of full sun for testing. Every one of the 66 modules were tested individually and no issues were found, with all units performing as expected with little variation between the modules and no ground faults or open circuits.

Importantly, the speed of the Seaward Solar test system allowed comet to perform full tests on each module without impairing the workflow of the installation crew.

The test data for each module was downloaded and given to the owner as a system spreadsheet to reassure him that testing had been carried out thoroughly to verify the quality of the modules and to confirm the anticipated performance levels of the system.

Comet's latest solar PV installation project is much larger and so requires a different test regime. The company is currently installing 500KW of Canadian Solar 240W modules, purchased directly from the manufacturer.

As these are Tier 1 Grade A modules, Comet won't be pre-testing every module, but will test each string at the combiner before installing fuses.

Working to US NEC requirements does not allow for easy testing of the installation in the way that typical UK systems do. The wiring is always in conduit and the combiner circuits are hard wired, so there is no easy way to test installed strings on larger systems.

For these larger projects, Comet will therefore be using Seaward's 1000V rated test leads with alligator clips.

Chris Mason said: "Using the PV150 system on an installation in front of the client gives a sense of security that the installers are professional and are doing the project properly.

"We are seeing the emergence of some less than professional installers in the region who perform poorly crafted installations, test nothing and do not give the customer any comfort that the work is being done properly."

“We invite our customers to witness the commissioning tests with the PV150 so they can see how much work goes into our quality assurance procedures. This is both a marketing tool to enhance word-of-mouth referrals and protection against liability from call-backs.

“Documenting system performance at commissioning gives us a baseline against which to retest in the case of a complaint or problem, both with customers and manufacturers. For this use alone, the test kit and reporting system is invaluable.”

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