Of the many tools you use to install and maintain a PV system, electrical test equipment may not be your first priority. But a PV system is only as good as the electrical energy it produces.

Electrical Test Equipment

By Blake Gleason

How do you know all circuits are working? How do you know the system is safe against shock hazards and fire? How can you be confident the system will continue working until the next scheduled maintenance? How can you find the problem when some part of the system stops working or when you are not sure whether it is working as well as it could be?

The answers to these questions can be found with electrical test equipment, which is essentially a set of measuring tools. The quantities that can be measured include voltage, current, resistance, capacitance, power, energy, frequency, power factor, phase angle and temperature. Many of these quantities can be measured in both ac and dc, and most can be logged over time. They can be measured with highly accurate equipment or with a simple tool that reports only presence or absence.

Perhaps your old analog voltmeter will do just fine. But here is a look at what this category of equipment could and should be doing for you, including examples of specific tools, what to look for, how and when to use them on PV systems and some idea of cost.

SAFETY IN TESTING

The first consideration when choosing and using electrical test equipment is technician safety. All those burdensome working clearance requirements in *NEC* 110.26 were designed to help make testing and maintaining energized equipment a relatively safe endeavor. Proper tools, procedures—such as lockout-tagout—and personal protective equipment are necessary as well. Read and follow NFPA-70E, *Electrical Safety in the Workplace*, for more safety details (see Resources).

Be sure to read the test equipment manual thoroughly, both for safety and proper use guidelines, and for ideas for new and better ways to use the equipment. Also make sure your test equipment is appropriate for the application. ANSI/ISA-S82 defines four categories of electrical test equipment user risk. The higher the available voltage and fault current in a given test location, the higher the category. In general, Category I is low-power electronics; Category II is branch circuits; Category III includes feeders and panelboards; and Category IV covers service entrances. All professional-grade, power electrical test equipment should be certified and marked on the device for 1000 V Cat III or 600 V Cat IV.

Courtesy greenlee.com

Safety first When using electrical test equipment, like this Greenlee GT-95 voltage tester, personal protection equipment should include appropriately rated insulating gloves.

QUALITY EQUIPMENT

As with most tools, you tend to get what you pay for with electrical test equipment. Most high quality electrical test equipment is available through your usual electrical

supply wholesaler. Almost everything is available for purchase online. Just beware of too-good-to-be-true prices. About five years ago, I monitored eBay for two months before finally snapping up a "new, in the box" Fluke 337 clamp meter for half of its retail price. It has worked at least as well as my other test equipment since then, but it felt like a gamble at the time. I could have wound up with a low quality knockoff or a genuine but refurbished brand-name product, out of warranty or out of calibration.

If you decide that your needs will be met by lower cost, consumer grade equipment, you can find these at the local hardware store or Radio Shack. Just do not expect consumer grade equipment to perform like a professional tool, out of the box or over time. Even if both tools have the same feature list, the professional tool offers extra value.

Durability. Test equipment almost always includes complicated, sensitive electronics, and it will not serve any purpose if those are damaged. A professional tool is designed to survive years of daily use and abuse, including being dropped, shoved into your tool belt, left in the rain and bounced endlessly in the truck. It will have to work reliably over a wide range of job site temperatures. So avoid equipment designed for laboratory use where possible. A professional tool will have proper fusing and input protection to protect you and itself from the occasional incorrect use and surprising surges you subject it to.

Accuracy. Professional equipment should have very high accuracy, repeatability and resolution (see sidebar, p. 41). Even though a low quality meter might show three digits to the right of the decimal place for a voltage measurement, likely it is not very accurate in the millivolt range. High quality equipment will be backed by specifications, certifications and warranties that give you confidence in your measurements and the decisions you make based on those measurements.

Support. Professional equipment will come with good support from the manufacturer. You can be sure your equipment was calibrated to a high standard, and you can have it recalibrated as necessary. Manuals, technical and application notes and other documentation will be thorough and informative. The warranty period will be meaningful.

Interestingly, the first three PV installer foremen I asked selected a different favorite brand for their primary meter—Fluke, Greenlee and Ideal—but all of them chose high quality products and manufacturers, despite their initial high cost. All of the example models cited below for the various test equipment categories come from reliable manufacturers.

TEST EQUIPMENT CATEGORIES

The following 10 categories of test equipment are arranged in order from more common tools to highly specialized instruments. Tools at the beginning of the list probably have permanent places in most installers' tool belts or at least on every truck in the fleet. Tools toward the end of the list might live in the shop or might even be rented as needed from an electrical tool supplier.

Each category includes a brief description of the tool and what it can measure, some available features and possible applications, and some examples of particular models. Where cost information is given, it is the approximate list price at press time.

Voltage detector. A voltage detector lets you know whether there is voltage present in the area being tested. This minimal yes-or-no information is most often useful when checking for the absence of voltage for safety reasons or the presence of voltage for troubleshooting reasons. The tool usually works for ac voltages by induction and does not require contact with exposed terminals or other conductive parts. It needs only to be within about 0.25 inch to a few inches of a conductor to detect live voltage. The voltage detector is just that—a tool that detects voltage. It does not need to have current flowing, or even to have a complete circuit, to sense the presence of voltage. Most models are designed primarily for 120 and 240 Vac detection, but many will detect ac from 12 V all the way up to 600 V.

Courtesy greenlee.com

Warning for PV installers! Most noncontact voltage detectors, like the Greenlee GT-11 shown here, will not detect dc voltage; do not rely on them completely for electrical safety, especially on the roof.

The voltage detector is a small, low-cost tool that should always be within reach. Many models are designed in the form of a large pen and often have a pocket clip. These can find a permanent home in your shirt or overalls pocket or one of the crayon slots in your tool belt. Common uses

include checking whether a particular receptacle or circuit is live, checking whether you have power at the far end of an extension cord, checking for ac voltage in a wall before drilling, checking for ac voltage in a panel before working on it and tracing a wire or cable on a broken circuit to find the break.

There are many off-brand voltage detectors available for as little as a few dollars. For something that will last a long time and be reliable, I recommend a model from a quality manufacturer, such as the Fluke 1AC-II ($27) or the Greenlee GT-11 ($15).

Courtesy fluke.com (2)

Size matters Voltage testers like this Fluke T+Pro are a good fit for measuring string voltages on rooftops due to their compact size.

Voltage tester. A voltage tester does one job, and it should do it well. It identifies whether there is voltage present at the points being tested and indicates the nominal voltage level and the actual voltage. This tool is somewhat redundant if you already have a good multi-meter (see below), which has more functionality and better accuracy over a wider range of voltages. However, if your multi-meter is oversized, small voltage testers like the Greenlee GT-95 ($91) and Fluke T+Pro ($92) could be more convenient: They fit easily into a tool pouch and can tell you at the dc disconnect or combiner box whether you plugged the right number of modules into each string.

Digital multi-meter. If you have only one piece of electrical test equipment, it has to be a multi-meter. Almost all of these tools are now digital—thus the term *digital multi-meter* (DMM)—with LCD screens. A DMM is several different meters in one package, as the name implies. At a bare minimum, all DMMs measure voltage and current. Many will measure both ac and dc voltage over a wide range (0–600 V or more), as well as ac and dc current up to about 10 A. Another very common feature is the ability to measure resistance, including a threshold below which continuity is announced, often by a tone. This feature proves extremely useful when checking multiple wires for continuity. It allows you to look at the wires while listening for the continuity tone, rather than looking back and forth between the wires and a display screen.

For general use with PV systems, the DMM must be able to measure up to 600 Vdc for higher voltage, grid-tied string inverter systems, and 600 Vac for electrical services up to 480 V. For battery systems, the DMM must have low voltage dc ranges, such as 0–5 V with millivolt resolution for individual battery cells and charge controller set points, and 0–60 V for typical 48 V battery banks. These ranges can be auto-ranging or set manually. Beware of buying a DMM intended for higher voltage work, which might only have the 0–600 V range. If this is the case, it will have poor accuracy at low voltage levels.

DMMs commonly include many additional features. In my experience, low cost, low quality multi-meters often have ten or more additional features, only two of which could realistically be useful, and only one of which actually works most of the time. On higher quality, moderate cost DMMs, the extra features are usually limited, so you need to know which ones you want. Besides the standard multiple-range voltage, current and resistance (continuity) settings, I find these additional features useful on occasion: capacitance, temperature, frequency, diode checker and LCD backlight.

Capacitance is mostly used to check a given capacitor to determine whether it is damaged. Temperature usually requires a separate thermocouple and is probably better measured with a dedicated instrument. Frequency is useful to verify that the grid is within specified tolerances, or that an engine generator is producing a frequency that is compatible with a battery-based inverter. A diode checker is used to verify suspect blocking and bypass diodes in PV circuits. Finally, make sure that the LCD screen has a backlight you can turn on in low light. Both the Fluke 87V ($392) and the Greenlee DM-860 ($366) have all of these features.

Select features Higher quality digital multi-meters offer very specific feature sets from product to product. Some, like this Fluke 87V, will be better suited for PV applications than others.

If your DMM comes equipped with straight-tip probe leads only, you should buy at least one clamp-style tip—commonly referred to as an *alligator clip*—for your test leads. This clamp is quite useful when you are making many measurements with one lead on the same point. For example, when measuring open-circuit string voltages in a 36-string combiner box, you can clip one lead to the grounded busbar, and then use one hand to probe each string and the other hand to write down the voltages. The alligator clip works a lot better than trying to balance, wedge or tape the straight-tip probe against a grounded busbar.

Clamp meter. A clamp meter is an important variation of a multi-meter that specializes in quick and easy measurement of current. CONTINUED ON PAGE 38

Standard DMMs can measure current only by interrupting the circuit being measured and inserting the meter into the circuit. Clamp meters, on the other hand, do not require contact with any conductive element in order to measure the current in a wire or busbar. Most importantly, a clamp meter does not require interrupting the measured circuit at all. While standard DMMs are usually limited by internal fuses to measuring a maximum of 10 A, for example, clamp meters can measure hundreds or even thousands of amps. These meters measure ac current by induction and dc current by the Hall effect.

Do you need to pay extra for a clamp meter to be able to measure true rms current for PV work? In general, you can assume that the dc current on PV circuits should be close to flat dc, and the ac current on inverter output circuits should be very close to sine-wave ac, which means that a true rms meter will give the same reading as a "non-true" meter. If you are troubleshooting because something has gone wrong, however, that assumption may be false. Perhaps the inverter is malfunctioning, and there is a lot of ripple on the dc or distortion on the ac.

Courtesy idealindustries.com

Get current Working with a clamp meter deep inside a live panel can make reading the display difficult. This Ideal 61-774 clamp meter comes with a secondary LCD screen in addition to a data hold function that captures and holds readings taken in tight spaces.

A handy feature of clamp meters is that even when the meter is measuring voltage, hanging the device from its clamp allows for two-handed operation of test leads. But these tools offer many more important functions as well. For example, many DMMs and clamp meters, such as the Ideal 61-774 ($246) and the Fluke 337 ($386), will include these features: Max/Min/Avg, inrush or peak current capture and data hold.

Max/Min/Avg is a quick and easy way to do very basic datalogging. This function continuously monitors voltage or current and reports the maximum value and minimum value for the time period measured. If you would like to know how high the open-circuit dc voltage on your PV array gets on a cold morning before the inverter turns on, you could set up your DMM to monitor the voltage and come back after the inverter turns on to read the Max voltage. Similarly, if you are evaluating a site for PV, it might be interesting to record both the Max and Min ac voltage at the main panel or at the location of your proposed intertie. These values can identify a soft grid—meaning the difference between Max and Min is large—or whether the voltage tends to be unusually high or low, at least during the monitoring period. This simple procedure will not solve grid problems, but it might alert you early in the planning process to potential interconnection issues and trigger the use of more sophisticated tools and methods, or at least a call to the local utility. Using the Max/Min function while measuring dc PV source-circuit current or voltage will provide a sense of how much the particular inverter MPPT algorithm varies these values. Applying the Max/Min/Avg function to the inverter output current during a part of the day when clouds are passing shows how severe the worst drop in PV production is relative to the best times. It might even give you a glimpse of the elusive edge-of-cloud effect, which would reveal itself as a Max value well above the expected output.

Inrush, or peak, monitoring is similar to the Max function, but it is specifically intended for measuring very brief surges in current, such as the inrush current to a motor at startup. This function can also be used to measure the highly variable inrush current for an isolation transformer. When large central inverters used to leave their accompanying isolation transformers connected at night, grid energy was wasted to keep the transformer energized all night. A solution employed by integrators and supported by manufacturers was to install a contactor on a timer between the transformer and the interconnection circuit breaker to disconnect the transformer from the grid at night. In the morning, when this contactor would suddenly connect the transformer, if the grid happened to be in just the right part of the cycle relative to the magnetics of the transformer, the extraordinarily high inrush current to the transformer would intermittently trip the overcurrent protection on the grid side of the transformer. Sun Light and Power learned this lesson the hard way. The inrush function on my clamp meter was the tool I used to capture this fleeting phenomenon.

The data hold function on a clamp meter allows you to capture and hold a reading on the display. When you measure current by clamping onto a hard-to-reach wire in the back of a live panel, it can be useful to push the hold button and then remove the meter from the panel to read the display.

Infrared thermometer. An infrared thermometer allows quick surface temperature measurements without touching the object being measured. This can be very useful for identifying wire terminations, fuse holders and circuit breakers that are operating at higher temperatures than normal. These hot spots indicate an overload condition, a malfunctioning device or a high-resistance connection, any one of which could soon be a major safety or PV production issue. Use an infrared thermometer to scan all CONTINUED ON PAGE 40

Courtesy extech.com

Avoid surface glare Infrared thermometers, like the Extech 42512, work by measuring the black-body radiation of the surface being measured, so they can be tripped up by surfaces with high emissivity like shiny metal conduit or aluminum busbars. Either adjust the emissivity setting, if your model has one, or temporarily apply a piece of non-shiny tape to the metal.

of the fuse holders in a dc combiner box or all of the circuit breakers in an ac accumulation panel. If any of the overcurrent devices are hotter than the others, you immediately know you have a problem. You can also use an infrared thermometer to quickly scan other parts of the system to help identify performance concerns. Scan a few module cell temperatures, rooftop conduits, inverter bodies and heat sinks. Are they within expected range? Are they within their specified operating range? Are they in the same range as they were last week when everything was working perfectly? Products like the Fluke 62 ($100) and the Extech 42512 ($156) will help you find out.

Circuit tracer. A circuit tracer can be used to easily identify which wires, receptacles and loads go with which circuit. When wires are covered in walls or buried underground, the circuit tracer quickly maps everything out without interrupting power or requiring you to uncover anything. It typically uses two units: a transmitter and a receiver. The transmitter plugs into a receptacle or uses induction for noncontact injection of a signal into the circuit, which the receiver detects at a panelboard or other location.

There are a few common uses of a circuit tracer in PV work. In battery backup retrofit projects, the customer will want particular outlets, both lighting fixtures and receptacles, to be moved into a new, dedicated load subpanel. A circuit tracer makes quick work of identifying both the hot and neutral wires of these circuits in the existing breaker panel. Next, if on a commercial project you somehow end up with 40 strings worth of unlabeled homerun wires at the combiner box, you can use the tracer to efficiently identify which is which, without doing tedious continuity tests. Finally, the circuit tracer is an excellent tool for quickly determining the exact location of an unintended open circuit or fault. Each of these tasks could be accomplished by other means, but

Circuit identification A circuit tracer, like the Ideal 61-956, is useful when separating out circuits for battery backup. It can turn a two-person project into a one-person task.

Courtesy idealindustries.com

a circuit tracer can save a lot of time. In addition, it can be safely used on live circuits. Check out the Amprobe AT-4004 CON ($945), which works up to 4 miles, and the Ideal 61-956 ($737), which uses direct coupling and is effective up to 15 feet underground.

Datalogger. There are many times when instantaneous measurement of an electrical value does not provide enough information to accurately diagnose a problem or confirm that a PV system is working as it should. This type of spot measurement will not divulge peak values, minimum values, trends or averages. To measure these and other time-dependent quantities, you need a datalogger. Datalogging can be accomplished with a wide variety of equipment. The diverse categories of equipment offer a correspondingly wide variety of features, accuracy, complication and cost.

At the low end of the technology, residential customers can write down the total accumulated production from their inverters every day on a clipboard hanging in the garage. At the high end, $150,000 might buy you hundreds of distributed sensors with live connections to several dedicated industrial PCs running custom analysis software and a full-time plant manager to operate the whole thing.

In between, there are several options. DMMs and clamp meters that have Min/Max/Avg functions can be used for very basic, short-term logging. There are also advanced logging DMMs, such as the Fluke 287 ($525), which can log for hundreds of hours. The data can be displayed on the LCD screen or uploaded to a PC for further analysis. Of course, you have to

Courtesy fluke.com

Hard to part with Advanced logging digital multi-meters, like the Fluke 287, can log data for hundreds of hours and upload to a PC later, but this requires leaving the meter behind at the site.

Accuracy, Repeatability and Resolution

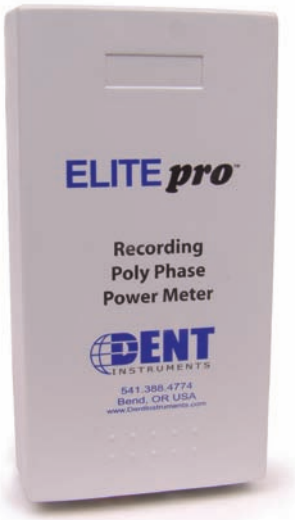
Depending on the intended use for the information gathered from a particular test, measurements may need high resolution, accuracy and repeatability—also known as *precision*—or all three. Resolution is the smallest increment that a tool can measure and display. Accuracy specifies the maximum difference between the actual value of the quantity being measured and the value read by the measuring tool. A measuring tool or measuring procedure has high repeatability or precision if duplicate measurements of the same quantity yield the same result.

For example, when you use a DMM to measure the operating voltage of a grid-tied PV string with an expected value of 450 Vdc, the DMM range might be 0–600 Vdc. If the display has four digits, it will probably have a resolution of 0.1 V, or 100 mV. Accuracy is typically a percentage of the measurement plus a floor, which is a minimum error due to problems such as drift and offset that is expressed as digits or counts of the least significant digit. For the 600 V range, the accuracy might be 2% plus 15 digits, which means 9 V (2% of 450 V) plus 1.5 V (15 counts of the least significant digit: 0.1 V), for a total accuracy for this measurement of 10.5 V. We would expect to read between 439.5 V and 460.5 V (450 +/- 10.5 V) if the true value being measured was indeed 450 V.

One consequence of the floor of accuracy is that a measurement taken in the low end of a range will have relatively low accuracy. For example, if we use the same 600 Vdc range tool to try to measure the voltage of a 2 V cell in a battery bank, we will be disappointed by both the resolution and the accuracy of the measurement. The resolution will still be 0.1 V, which is already 5% of the measurement value. The accuracy will be 40 mV (2% of 2 volts) plus 1.5 volts (15 counts of 0.1 volts), for a total of 1.54 V of uncertainty in a 2 V measurement. Clearly, we need a different tool with a lower range for this measurement.

The specified accuracy of a particular measurement device will be valid over a narrow temperature range only, usually around room temperature. Manufacturers can provide data that shows how reduced the accuracy will be at very hot or very cold temperatures. High quality DMMs typically have approximately twice the uncertainty at freezing temperatures as they do at room temperature.

Finally, the accuracy of a particular unit will tend to degrade over time, so your decade-old meter probably has much less accuracy than shown on the specification sheets. Manufacturers and metrology labs can recalibrate your test equipment using expensive, very high accuracy, high resolution equipment that has been calibrated by even higher accuracy, higher resolution equipment and so on back to the standard at the National Institute of Standards and Technology (NIST). This recalibration should be done often enough for you to have confidence that your equipment has the accuracy you need for your applications—annually is typical, but refer to the manufacturer's recommendation. ●



Courtesy dentinstruments.com

Courtesy onsetcomp.com

Detailed decision Datalogging tools, like the ELITEpro Logger from Dent Instruments and the HOBO U23-004 from Onset Computer Corporation, allow an in-depth look at the exact set of data you decide is most important for energy analysis, troubleshooting or system commissioning.

leave your fancy DMM at the site for hundreds of hours to acquire that data.

A better option is a dedicated datalogger. These can typically accept a large variety of inputs from several sensors so that, for example, you can log current and voltage on three phases as well as temperature and decibel level to evaluate the operating conditions of your large central inverter. They can also record more data points for longer periods and can be programmed to record at almost any interval. The data is uploaded to a PC for graphing and analysis.

When seeking out a datalogger, pay attention to how many and what type of data channels you wish to record, how much storage you need and what environment the logger will operate in. Onset Computer Corporation, maker of the popular HOBO line of dataloggers, has a broad selection of small, inexpensive, stand-alone logging devices for almost any application. If you and your co-workers cannot agree on the daily temperature profile right behind the module backsheet, for instance, you could deploy some HOBO U23-004 ($129) units behind a few arrays to find out for sure. A more industrial, very flexible model of datalogger is the Enernet K20 ($1,600 with display, without any sensors), which has many power, analog and digital channels. If you need to log only voltage and current for power and energy readings, the Dent Instruments ElitePro Logger ($1,000 without CTs) is a great, small package—about the size of a cell phone—with storage of up to 100,000 records and integrated software for the PC.

The most well known type of datalogging product for both solar thermal and PV systems is typically installed permanently and is known as the *monitoring system* or *data acquisition system* (DAS). These products range from simple inverter-integrated cards ($0–$100) to fully instrumented, weather station enabled, string (or even individual module) monitoring, building load analyzing arrangements ($3,000–$10,000+). Most monitoring systems eventually upload data to a Web-based display that can be used for monitoring, showing-off and triggering service calls. Five-year data plans range from free to many thousands of dollars for larger systems. The more portable types of electrical test equipment detailed in this article can be carried on your truck and put to good use verifying a PV system's DAS at commissioning or when the DAS produces questionable data.

Megohm-meter. A megohm-meter is essentially a device used for measuring high values of resistance, primarily for the purpose of testing electrical insulation. These are commonly referred to as Meggers or Megger testers, after the manufacturer, Megger, a full-range electric test equipment company best known for its line of insulation testers. What does this high resistance test have to do with PV? A good example is preventing one of the most common problems with dc wiring on PV systems large and small: ground faults.

A ground fault is basically an unintentional, low resistance path between current-carrying conductors and conductive equipment or equipment-grounding conductors. If a module frame has mistakenly been clamped CONTINUED ON PAGE 44

Courtesy fluke.com

Find faults before they happen Performing insulation tests with the Fluke 1550B at system commissioning and during periodic, preventative maintenance visits should allow you to identify insulation problems before they cause an unexpected system shutdown or worse, a fire or shock injury.

onto a module lead or homerun wire, there is a good chance the insulation on the wire is pinched so thoroughly that a very low resistance connection to the grounded frame or rack exists. This catastrophic fault is relatively simple to identify. However, as anyone who has tried to find the dreaded intermittent ground fault knows, an unintentional connection to ground is often not so obvious and might take several blown GFDI fuses or inverter faults and multiple site visits to finally solve.

With a standard DMM, you can check for continuity—resistance of less than about 30 Ohms—and moderate values of resistance. However, to properly characterize the insulation on conductors, you need a source of controlled high voltage dc and an accurate, very low range ammeter. The combination of these two functions yields an accurate high range ohmmeter, which in turn is the basic engine of an insulation tester such as the Megger MIT400 ($574).

Many more advanced features allow measurement of the various components of the undesirable current, including capacitive, polarization, leakage and conductive. These measurements can be performed by the Fluke 1550B ($3,518), and the results are useful for identifying both immediate isolated damage due to poor installation workmanship or trauma—such as a fire or an earthquake—and gradual deterioration due to poor manufacturing, improper specifications or environmental conditions.

Courtesy amprobe.com

Multitasking In addition to analyzing power quality, the Amprobe DM-III also tests insulation and measures ground resistance, making it a useful tool for the routine maintenance of PV systems.

Power quality analyzer. Power quality is a broad term. In general, ac power is of high quality when it stays at the nominal voltage under all load conditions and the waveform is very close to a perfect 60 Hz sine wave (in the US). A power quality analyzer is a sophisticated datalogging current and voltage meter that identifies and reports power quality issues on the circuits it is connected to. One of the typical uses for this tool is to determine the amount of higher-order harmonics present on the voltage waveform. The cause of these harmonics, which are a form of distortion, are often nonlinear loads such as lighting ballasts; variable-frequency motor drives; computer, printer and other office electronics; and uninterruptible power supplies. The harmonics, as well as spikes and sags in voltage, can cause errors and sudden shutdowns in PV inverters. Use a power quality analyzer to evaluate existing building loads and corresponding grid quality to identify potential compatibility issues with inverters or to troubleshoot ac error codes on large system inverters. Having a tool like the Amprobe DM-III ($3,295) in your truck when responding to a mysterious 225 kW inverter shutdown might help you identify the problem in one visit.

Courtesy daystarpv.com

Performance characterization The Daystar DS-100C I-V curve tracer can be used to verify the performance of the entire array—up to 50 kW—or to identify defective or damaged modules.

I-V curve tracer. An I-V curve tracer is a highly specialized piece of electrical test equipment suitable for characterizing a PV cell, module, string or entire array. By applying a varying load, the unit can calculate the peak power, internal series resistance and internal parallel resistance of the module or group of modules. This characterization can be useful for verifying a module or system and for identifying and proving defective or damaged modules for warranty claims. There are several European manufacturers of commercial-grade I-V tracers, such as PV-Engineering. New Mexico–based Daystar also makes an I-V curve tracer, the DS-100C ($23,250).

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Manufacturers

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Megger / 800.723.2861 / megger.com
Onset Computer Corporation / 800.564.4377 / onsetcomp.com
PV-Engineering / 49.2374.505096 / pv-engineering.de

Resources

National Fire Protection Association / nfpa.org (NFPA-70E safety standard)