AMETEK® PROGRAMMABLE POWER

White Paper

Programmable Power Supplies and Loads Provide Comprehensive PV-Inverter Test

Effective solar-panel and grid simulation help propel renewable-energy rollout

Governments, private enterprises, utilities, and even homeowners are moving to adopt renewable energy sources. In July 2021, the U.S. Energy Information Administration (EIA) predicted that the share of generation from renewable sources would increase from 20% in 2020 to 21% in 2021 and 23% in 2022, with most of the increase coming from new solar and wind generating capacity in the electric power sector. And within the renewable-energy industry, solar is emerging as a key contender. The EIA forecasted that in 2022, large-scale solar capacity growth would exceed wind growth for the first time. The EIA further predicted that the electric power sector would add 16 G.W. of solar photovoltaic (PV) generating capacity in 2021 and an additional 17 G.W. in 2022, with small-scale PV capacity (primarily residential) increasing by about 5 G.W. in each of those years.

At the heart of a PV system is the solar inverter that connects PV panels' DC output to an AC load or the grid. In August 2020, Grand View Research Inc. forecasted that the PV inverter market would reach $13.0 billion by 2027, growing at a CAGR of 5.6%. The firm added that the central PV inverter segment occupied the largest market share in 2019, followed by the string inverter segment. Central inverters generally serve in large-scale power-generation systems, while string inverters typically accompany residential solar installations, where a single string inverter operates several rooftop solar panels.

PV Inverter Test Challenges

Microinverters represent another inverter configuration, with one microinverter for each panel. This configuration allows customers to add panels without replacing a string inverter with a larger model. Microinverters will boost total efficiency if one of several panels is in the shade. The drawbacks include cost, and repair requires a trip to the roof. But whatever the configuration, PV inverters pose significant test challenges. Early on in PV inverter testing, standard DC power supplies were used to simulate the power generated from solar panels. However, it was understood at that time that this method was not ideal and could not provide the variables of baseline irradiance, dust, shadows from trees and chimneys, temperature, cloud cover, and damage. Of course, actual PV panels serving as DC inputs to the inverters under test could be used, but it would be time consuming if not impossible to exercise an inverter with every condition mentioned that a panel might encounter during its operating life. In addition, it is not practical for developers to maintain banks of PV panels of various brands, ratings, and technologies, including monocrystalline, polysilicon, CdTe thin film, CIGS thin film, concentrated PV, or even a technology that has not been invented yet. Similarly, developers cannot hook up their untested and uncertified inverters up to the grid and see how they respond to various load conditions.

Consequently, simulation has a crucial role to play, with application-specific programmable DC power supplies acting as solar-array simulators (SAS), bi-directional AC sources providing grid simulation, and programmable loads simulating household or other AC loads. However, PV panels present significant simulation problems for programmable power-supply manufacturers vying to serve the solar-inverter simulation market. A standard DC supply is a "stiff" source—it maintains its programmed output voltage value regardless of load. In contrast, a solar cell is a soft source—its voltage drops as the load increases. Consequently, a power supply suitable for PV panel simulation must replicate the soft IV characteristic of

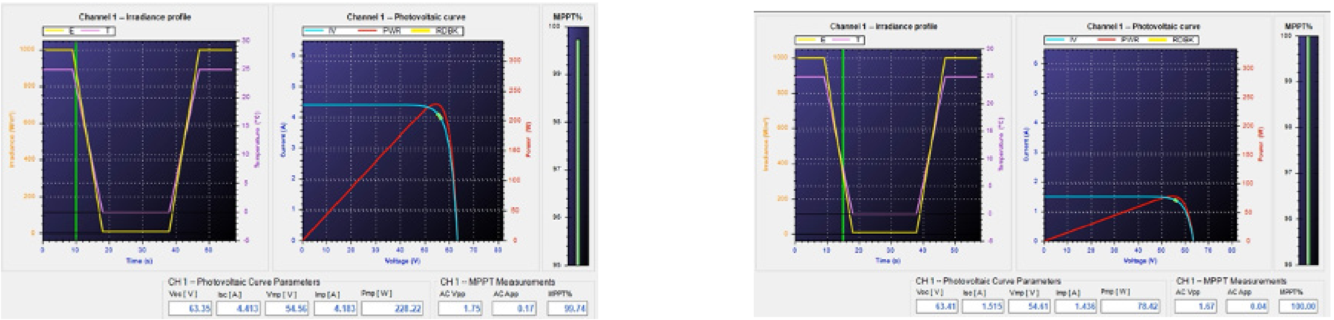

Figure 1. Successive stills from a video showing how a photovoltaic IV curve changes in response to decreasing irradiance.

the PV cells. Additionally, it is not enough to simply provide a software capability to create a soft I-V curve. The simulator must be able to maintain the I-V curve parameters dynamically during cloud cover while the inverter's MPPT tracker algorithm is searching for the maximum power point. This takes a specialized, high performance power topology.

An effective PV panel simulator will need to accurately model any PV panel the inverter under test may connect to over its lifetime. To that end, the National Renewable Energy Laboratory (NREL) maintains a System Advisor Model (SAM) database that catalogs the key parameters—such as the material, the number of cells in series, the number of parallel strings, the open-circuit voltage, the short-circuit current, the maximum-power current and voltage, and the angle-of-incidence coefficients—for tens of thousands of commercially available PV products.

In any PV-inverter system, the goal of the inverter is to extract the maximum power possible from the PV panel at any given time and under any conditions of illumination. To that end, an inverter must continually locate a panel's maximum power point (MPP). Inverters implement a maximum-power-point tracking (MPPT) function, optimizing power transfer to the grid or other AC load by identifying the MPP "knee" on the PV panel's IV curve. Figure 1 shows successive frames from a video showing changes in the photovoltaic IV curve in response to declining irradiance. The green spot on the blue curve on the right indicates the inverter's MPPT function.

Several techniques exist for implementing MPPT. For example, the inverter may dither or impose a ripple voltage on the PV panel's output as it searches for the MPP. It is critical that a power supply not suppress this ripple as part of its regulating function, which requires minimizing the power supply's output capacitance and modifying its control loops. In addition, a supply with suboptimal response time will not accurately track the PV panel's IV curve, resulting in an inadequate test. Further complicating the test process, a solar panel uniformly illuminated by sunlight will have a single MPP. Still, a partially shaded panel may have multiple apparent MPPs, and the inverter must determine which is the true MPP. Furthermore, an inverter that exhibits adequate static tracking efficiency may not offer acceptable dynamic tracking efficiency—it may lack the necessary responsiveness to perform well with rapidly changing irradiance conditions, a situation that an effective test system will identify.

Figure 2 illustrates the dynamic MPPT accuracy of an AMETEK Programmable Power Elgar PV simulator (left) and a competitive model (right) at three MPPT tracking frequencies. For each graph, the blue line represents the ideal curve. The red lines on the charts on the left show that the Elgar unit matches almost precisely the ideal programmed IV curve profile. The red lines on the graphs on the right illustrate the performance of a competitive unit, showing that as the frequency increases, the tracking error increases and at the highest frequencies begins to exhibit a ballooning characteristic.

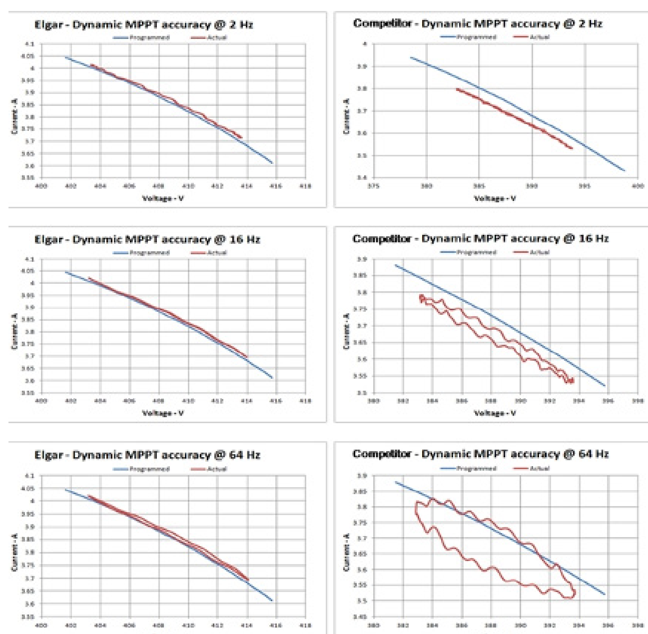

Figure 2. An AMETEK Elgar solar-array simulator offers performance that closely matches a programmed ideal curve, while a competitive unit exhibits increased tracking error at high frequencies.

AMETEK Programmable Power offers a variety of measurement capabilities for solar-inverter test applications. Figure 3, for example, illustrates the measurement setup for the MPPT recovery time test following a test protocol from Sandia National Laboratories for evaluating grid-connected inverters. The test involves taking measurements on both the leading edge and trailing edge of a fast ramp profile, as shown in Figure 4. With the inverter turned on and tracking the maximum power point, the test indicates how well the inverter responds to conditions such as intermittent cloud cover. The test requires two sets of parameters for each edge: "Trigger time," with defaults indicating the end of the leading-edge ramp (33 s) and the end of the trailing-edge ramp (66 s); "Max recovery time," the maximum expected recovery time for the inverter under test; "MPPT Recovery," the minimum MPPT accuracy that the inverter must meet after recovery; and "Tolerance band," the MPPT accuracy tolerance band that the inverter must meet after recovery.

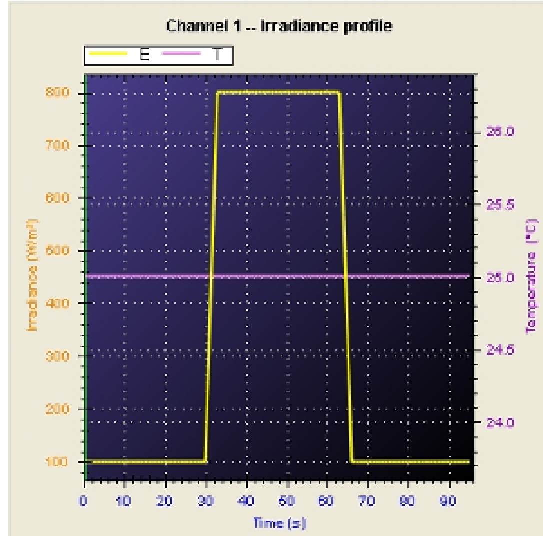

Figure 4. A test protocol from Sandia National Laboratories defines measurements on both the leading edge and trailing edge of a fast ramp profile.

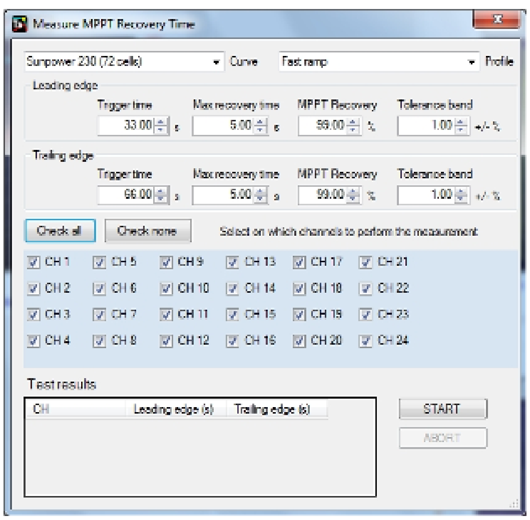

Figure 3. A test protocol from Sandia National Laboratories defines a grid-connected inverter MPPT recovery time test.

Inverter Output Test

While the inverter input test must guarantee the proper operation of functions like MPPT, the inverter's output also presents challenges. For a grid-connected PV inverter, a grid simulator must simulate utility anomalies, including phase loss, voltage dips and interruptions, and frequency disturbances, and it must be able to inject a DC component to see how well the inverter tolerates it.

Standards compliance is a key focus of grid-connected inverter tests. One issue is islanding, a condition that can occur if a grid connection is not properly established. Because islanding can lead to power quality and other issues, grid-connected equipment includes an anti-islanding function. Test of this function following IEC 62116, "Utility-interconnected photovoltaic inverters—Test procedure of islanding prevention measures," must ensure that if islanding does occur, the inverter shuts off within a specified period.

Grid-connected inverters must comply with other standards as well, including IEC TR 61000-3-15, "Limits—Assessment of low-frequency electromagnetic immunity and emission requirements for dispersed generation systems in LV network" and IEEE 1547-2018, "Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces." In addition, IEC 61727 applies to utility-interconnected PV power systems operating in parallel with the utility.

Some standards are country- or region-specific. For example, the TUV Rheinland G.S. S1 certificate demonstrates full compliance with the GPSG (the German equipment safety law) for Germany and the EU LVD (Low Voltage Directive) requirement. Yet another relevant standard is UL 1741, which covers inverters, converters, charge controllers, and interconnection system equipment used in standalone (not grid-connected) or interactive (grid-connected) power systems.

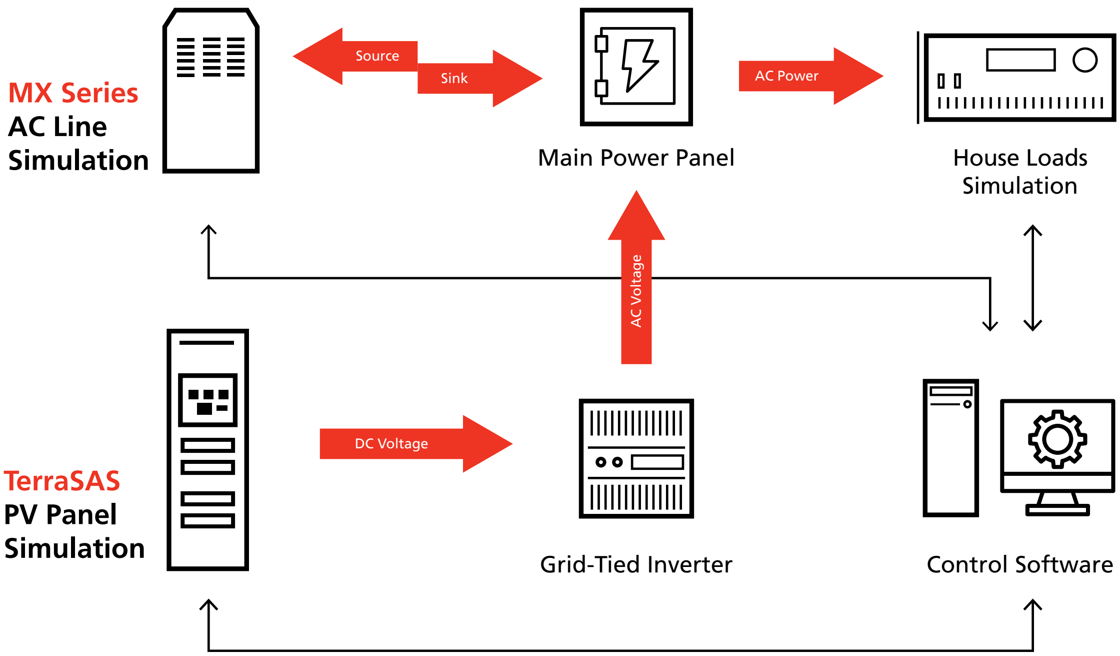

Figure 5. Programmable instruments that simulate the solar panels, household or other loads, and the grid interface surround an inverter under test.

Surround the Inverter

AMETEK Programmable Power's approach to comprehensive PV inverter test surrounds the inverter with programmable instruments that simulate the solar panels, household or other loads applied to the inverter output grid interface, as shown in Figure 5.

AMETEK builds on its 30 years of experience in solar array simulation and its comprehensive understanding of all PV topologies. The company's dedicated hardware and software solution for PV simulation is the Elgar ETS TerraSAS, which consists of programmable DC power supplies, a rack-mounted controller, keyboard, and LCD. Control software and a GUI interface provide complete simulation control and let users easily select from built-in NREL SAM databases of IV curves from commercially available solar panels. Users can also monitor functions such as dynamic irradiance profiles and real-time MPPT efficiency. The system includes output isolation and polarity-reversing relays. Versions are available for testing equipment ranging from microinverters to grid-tied inverters.

To simulate a variable home load, AMETEK offers the California Instruments 3091LD Series electronic load, designed to provide precisely controlled nonlinear loads for testing AC power-generation equipment. It can operate in constant-power, constant-resistance, constant-current, and constant-voltage modes and a short-circuit mode that can exercise the short-circuit-protection function of the equipment under test. In addition, the 3091LD can simulate high crest-factor (the ratio of peak-to-rms voltage) loads, which in the real world result from the prevalence of switching power supplies in home computers, T.V.s, entertainment consoles, and increasingly even appliances.

AMETEK's solutions for simulating the grid interface include the California Instruments RS/MX Series power sources, which provide high-power AC and DC outputs. This equipment can simulate utility power variability, including voltage and frequency deviations as well as harmonic distortion. The RS/MX Series can simulate utility disturbances to perform tests in accordance with UL 1741 and IEEE 1547. In addition, the RS/MX Series can dynamically test the inverter's ability to comply with the anti-islanding requirements. These units can also return a considerable amount of the energy used during the test to the grid, resulting in significant energy savings for the user.

Conclusion

Surrounding a PV inverter under test with programmable devices that can simulate PV panels, residential loads, and grid interfaces provides a comprehensive method of testing all aspects of inverter performance—from maximum power point tracking efficiency to tolerance for high crest-factor loads and grid anomalies. As technology and standards evolve, AMETEK will continue to refine its TerraSAS PV simulator, RS/MX sources, and 3091LD electronic load to simplify testing and help customers get products to market fast and with the utmost degree of confidence that their products will meet relevant specifications and standards.