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PROGRAMMABLE POWER

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Comprehensive Test Solutions for Domestic Grid-Tied Solar Inverters

An integrated approach that surrounds the inverter promises to accelerate the transition to solar energy

Improvements in solar array technology and competitive cost pressures in solar energy products are enabling rapid industry growth. As a result, solar systems are becoming increasingly cost-effective for residential and commercial use, especially when global government incentives for implementing green technologies are taken into account.

According to Pike Research, a market research and consulting firm that focuses on global clean technology markets, global solar demand will increase to 10.1 gigawatts (GW) in 2010 providing a year-over-year increase of almost 43%. This growth is due to lower costs and enhanced availability of subsidies. By 2013, the solar market demand will exceed 19 GW, a 25% compound annual growth rate (CAGR) from 2010.

Yole Development, a market research and business development consulting company, has been watching the photovoltaic (PV) market for many years. Yole forecasts the CAGR for the PV inverters used for solar panels to exceed 30 to 45% over the next 5 years. The market for residential PV applications was approximately $3.8B in 2009. About 5% of these sales are test and measurement related, representing a T&M total available market (TAM) of $190M for residential applications. This includes T&M equipment across the value chain from that required to test the IGBTs or other power semiconductors used in the inverters to those items required for system-level specification and regulatory compliance testing.

As a leading designer and manufacturer of complete test solutions including power sources and test equipment, AMETEK has extensive knowledge of the requirements and solutions for solar power systems. Today, the large majority of world solar product sales are in applications tied to the electricity grid. This white paper will focus on the testing requirements of these grid-tied solar products.

Supporting the Market's Requirements

The demand on solar inverter manufacturers to support the market's rapidly accelerating requirements can create difficulties. The challenges include being able to assess the competitive impact on their inverter designs of:

- *Changing PV panel electrical parameters and technologies (monocrystalline, polysilicon, CdTe thin film, CIGS thin film, concentrated PV...)*
- *Evolving regulatory environments (e.g., IEC 61000-3-15)*
- *Changing utility requirements and pricing, and government tariffs and incentives*

Fundamental to all of these areas are myriad testing requirements. Historically, the inverter industry has directly involved the sun and solar arrays in the testing process. Because of variations in these areas, repeatability and consistent metrology are some of the biggest challenges for PV testing today.

Taking solar technologies from the laboratory to residential and commercial installations requires testing at several points including product design validation, production acceptance testing and at installation. As new technologies such as micro

PV inverters are introduced, the requirements for testing change. For example, micro inverters use many smaller inverters instead of one large inverter. This results in improved PV system efficiency, potentially enhanced system reliability and fewer safety concerns, but requires test stimulus equipment operating at lower DC voltages with higher output bandwidth to faithfully react to the inverter's Maximum Power Point Tracking (MPPT) algorithms.

The Challenge

Inadequate testing can seriously impact any product's success. Difficult-to-implement test equipment, testers with inadequate accuracy and repeatability, and equipment that does not easily interface with other parts of the PV system can cause significant delays in a new product's introduction. Three areas of PV/solar technologies that need to be explored further include solar array simulation, house load simulation and utility simulation (see Figure 1). In addition, continually evolving and newly emerging standards add to the complexity of the solar power situation.

Solar Array Simulation

Solar arrays operate in an uncontrolled environment. The output is highly dependent on a range of conditions including the intensity of the sunlight (full sun vs. cloudy conditions), ambient temperature, external shading effects (from tree branches or chimneys), dust, bird droppings and other factors. All of these elements affect the capacity of the solar array to produce power.

The inverter must be designed to allow for maximum power transfer from the solar array to the inverter. This maximum power point (MPP) is most commonly determined on a continuous basis. Most PV inverters are designed to harvest the maximum amount of energy available from the PV array at any point in time. To do this, they typically use a MPP tracking control algorithm to continuously present the optimum load to the PV array for maximum power transfer.

The testing of inverters for this application (both in development as well as in production) requires a power source — a

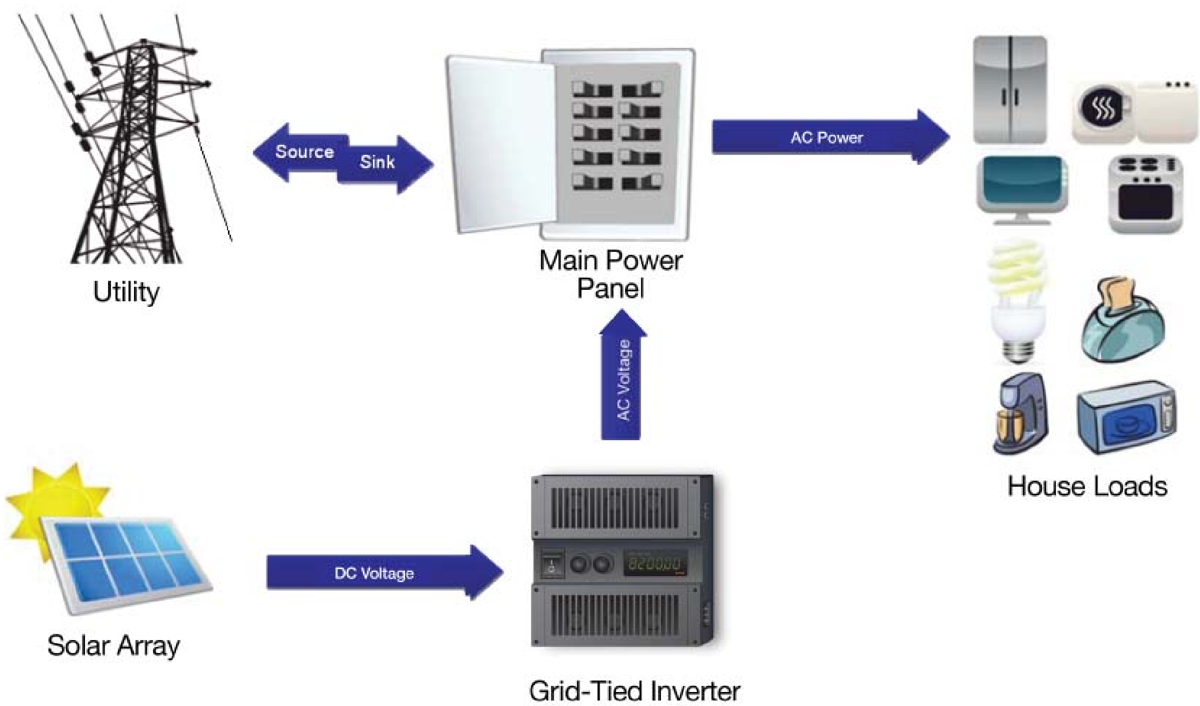

Figure 1. A typical grid-tied photovoltaic system has several different components and voltage levels - each requiring special testing.

Solar Array Simulator (SAS) — that can reliably simulate actual performance. With virtually hundreds of solar array panels available in the marketplace, this can be a daunting requirement.

Fortunately, the National Renewable Energy Laboratory (NREL) maintains a Solar Advisor Model (SAM) database that catalogs key parameters such as Voc, Isc, Vmpp at 24C and standard 1000 W/m^2 isolation for hundreds of commercially available PV products. The SAM provides powerful tools to help designers predict system performance for virtually any fill factor or solar material. A solar array simulator with the ability to access this data and incorporate it into a realistic, dynamic, interactive test of the inverter can pay big productivity dividends.

Many solar inverters generate AC ripple on their DC input that is connected to the photovoltaic array. For single phase inverters, the frequency of this ripple is twice the line frequency (120 Hz for US models). The simulator's power supplies must not suppress this ripple as a function of their regulation loop.

An increasing number of inverters (and virtually all micro-inverters) accurately measure amplitude and phase of the ripple voltage and current to quickly track the MPP of the array. This approach allows tracking the MPP at a much higher speed when compared to conventional dithering techniques (also called perturb and observe).

Faster tracking of the MPP results in a much higher overall efficiency in cloudy conditions, where the irradiance is constantly changing. It is likely that all solar inverters will use this approach in the near future, since end users are very sensitive to the overall efficiency of their solar energy installations. To satisfy this requirement, the PV simulator must be capable of reproducing the voltage / current behavior of a solar array even in the presence of this ripple.

Another requirement of this process is the ability to simulate the MPP for multiple strings of solar panels since most installations use a large number of panels.

House Load Simulation

Simulating residential loads is an area that requires special test considerations. For example, how does the inverter respond to high crest factor (HCF) loads? (Note: HCF is the ratio of the peak value to the root-mean-square (rms) value of a waveform.) This can occur with the switching power supplies in TVs, computers, microwaves and even when a refrigerator turns off and on. Products with switching power supplies can also be a source of harmonic distortion. How do all these different types of loads affect the PV grid-tie inverter? A load simulator provides the answer for testing.

Utility Simulation

Utility simulation is among the newest testing requirements. There are very few established standards but areas of concern to utility companies include:

- *Anti-islanding*
- *DC injection*
- *Utility anomalies, including phase loss, voltage dips and interruptions, and frequency disturbances*
- *Harmonically enriched waveforms test inverter tracking capability*

One of the problems that can occur if the connection to the utility grid is not established correctly is a situation called islanding. As defined in IEEE 1547, islanding is "a condition in which a portion of an Area Electric Power System (EPS) is energized solely by one or more Local EPSs through the associated point of common coupling (PCC) while that portion of the Area EPS is electrically separated from the rest of the Area EPS." Since unintentional islanding of a distributed power source may cause power quality issues, interference with grid protection devices and other problems, an ***anti-islanding*** function in equipment ensures the detection of electrical islands and proper disconnection from the electric power system.

The standards state that when the grid supply is lost, the inverter must turn off within a specified amount of time and the voltage rise must be limited. Tests to verify these capabilities are just being developed. Custom software as well as hardware is required to perform specific anti-islanding tests.

Utility companies commonly have a small (mV) DC component on their AC power, so testing for ***DC injection*** is one of the required tests. This testing determines how an inverter reacts to the DC component. Simulating the utility mains requires adding the DC components which can be a problem in some power source designs. A sustained DC voltage could lead to saturation of the inverter's magnetics resulting in a 50% drop in output power.

The IEC committee realizes that these situations can occur and is working feverishly to develop test standards to validate inverter performance with various anomalous conditions.

To produce the voltage levels, distortions, dips, interrupts and other ***anomalies*** that end products normally experience while operating off the utility line power, the power source used in product testing requires either manual or computer programming capability. While these immunity tests evaluate a product's ability to withstand common public supply disturbances, additional tests are required to measure emissions or the disturbance contribution that the product itself may produce. Accomplishing both requires clean AC power sources that supply and receive energy from the product being tested. The latter requirement defines a regenerative system.

The importance of odd and even harmonics and their impact on the power grid is well known, however, interharmonic susceptibility/distortion is a rather recent development. Values in between the integer harmonics, such as the 2.6 or 3.5 harmonic, can cause problems in some common products such as microwaves, washing machines and more. For example, the safety switches in these products can be affected by certain interharmonic values and not function properly.

All of these aspects must be addressed in a solar inverter. Testing the inverter to verify its capability and establish its performance levels requires programmable power.

Standards Compliance

Perhaps today's biggest challenge for PV systems is the testing required to comply with the standards. To establish conformance, suppliers must test their product(s) to demonstrate that they meet the requirements of local, national and international standards. Table 1 shows some of the more critical standards, including the latest standard expected to be released in late 2010, IEC 61000-3-15.

In many cases, products are being developed concurrently with the standards. As a result, it is necessary to bridge the gap between standards and the testing that must be performed to meet them. This can be accomplished by working with a supplier that is closely tied into the standards development agencies and their subcontractors.

Standard	Topic
IEC 62116-2008	Islanding prevention for utility-interconnected PV inverters
IEC61000-3-15	EMC Low frequency phenomena (in draft)
GS S1 – TUV	Full compliance to GPSG and LVD for CE compliance
IEC 61727	Utility connected PV systems operating in parallel
IEC TS 62578	Power electronics systems and equipment – operation and characteristics of active in-feed converter applications
IEC 62124	Photovoltaic (PV) stand alone systems - Design verification
UL1741	UL Standard for Safety Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources
IEEE 1547	Standard for Interconnecting Distributed Resources with Electric Power Systems
GB/T19064	Chinese National Standard
GB/T19535	Chinese National Standard
GB/T19604	Chinese National Standard
IEC 61000-3-15	Electromagnetic compatibility (EMC) - Part 3-15: Limits - Assessment of low frequency electromagnetic immunity and emission requirements for dispersed generation systems in LV network

Table 1. International and national standards that require accurate and repeatable power source to determine conformance.

AMETEK's Solution: Surround the Inverter

Surrounding the inverter with programmable devices to simulate the output of solar arrays, simulate the loads applied to the output of the inverter and simulate the interface with the grid provides a comprehensive and energy efficient means of testing these devices. Figure 2 is an example of a comprehensive testing system.

AMETEK has taken the expertise used to develop products for satellite solar applications and brought the technology down to earth. Using this expertise, AMETEK works with leading companies to advance the state-of-the-art for testing photovoltaic systems. Through this collaborative effort, AMETEK has addressed many of the issues these companies have identified in the testing of solar energy systems, including those that specifically apply to standards and conformance testing. AMETEK's specific areas of solar power expertise include:

- *Product Validation*
  - — Subsystem Research
  - — Product Development
  - — Compliance Testing
- *Production*
  - — Manufacturing ATE
- *Installation*
  - — Operational Verification
  - — Service and Support
  - — Mobile TerraSAS
- *Micro PV Inverters*
  - — Better optimization of PV strings
  - — Multi-channel systems
  - — Lower power levels per inverter (300W-500W)

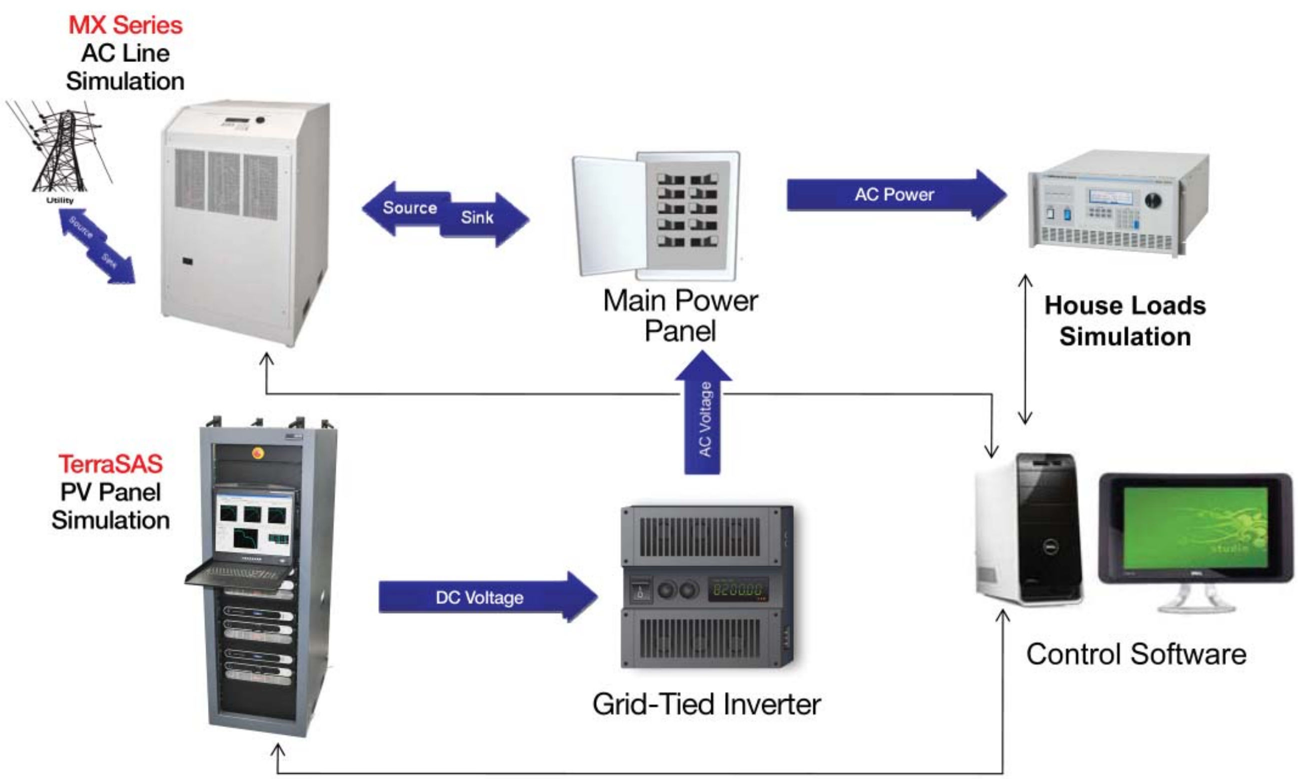

Figure 2. A complete test solution verifies the product's capabilities and ability to meet the numerous industry standards as well as the product's datasheet performance requirements at every point in the solar array system.

In addition, AMETEK has the ability to bring all these pieces together in a total system solution. Examples of individual solutions that have been specifically developed for the solar panel/inverter market include the TerraSAS photovoltaic simulator, the programmable AC load simulator, and the RS or MX Series programmable AC and DC power source.

AMETEK's TerraSAS, shown in the lower left hand corner of Figure 2, consists of programmable DC power supplies, a rack mounted controller, keyboard and LCD display with control software and GUI interface. The system includes output isolation and polarity reversing relays and a unique PV simulation engine that controls the power supply. This combination of hardware and software allows the TerraSAS to simulate most test protocols or combination of events that impact a solar installation.

For variable home loads, AMETEK has a programmable AC load simulator (upper right hand corner of Figure 2) to address:

- *A broad voltage range (3kVA-24kVA)*
- *Several operating modes*
    - Constant Current
    - Constant Voltage
    - Crest Factor
    - Power Factor
    - Short Circuit
- *A broad range of frequencies (45-440Hz)*

The RS/MX Series programmable, bidirectional power source / sink (upper left hand corner of Figure 2) is used to simulate the interconnection of the inverter with the grid. This equipment can simulate utility power variability (voltage, frequency, harmonic distortion) necessary to test the inverter's ability to source energy to the grid. With the RS/MX Series it is possible to simulate utility disturbances and perform UL1741 and IEEE1547 tests. In addition, the RS/MX Series can dynamically test the inverter's ability to comply with the anti-islanding tests required of grid-tied distributed resources. An added advantage of this approach is that a considerable amount of the energy used to test the inverter can be returned to the grid resulting in significant energy savings for the user.

With the RS/MX Series ability to change several variables including the effects of temperature, it is possible to simulate a full 24-hour day and take several readings on the inverters. This allows testing the efficiency of the inverter across its entire operating range – a capability that is unique in the industry.

As new standards are developed establishing new compliance requirements for various products and the overall system, AMETEK is intimately involved with the specification development and partnering with other organizations developing the standards and conformance procedures. In many cases, AMETEK actually provides test solutions while the standards are still in draft form. Since the systems are software based, if the standards change, updating the system simply requires a software revision.

Control software will increasingly play a key role in bringing the various hardware test elements together and reduce user's time to generate test results. With existing software for many test applications, custom software for a specific supplier requirement can be developed with relative ease. In fact, software allows the integration of solar test products. With all of the required test products, the TerraSAS, RS/MX and load simulator, AMETEK expects software to be an increasingly important part of its business.

With AMETEK provided test systems and software, the entire system can be controlled. This simplifies the testing and helps suppliers get products to market faster with a high degree of confidence that the data truly verifies that the products meet the standards and that the products do what their data sheets say they do.