PV Array Simulator Development and Validation

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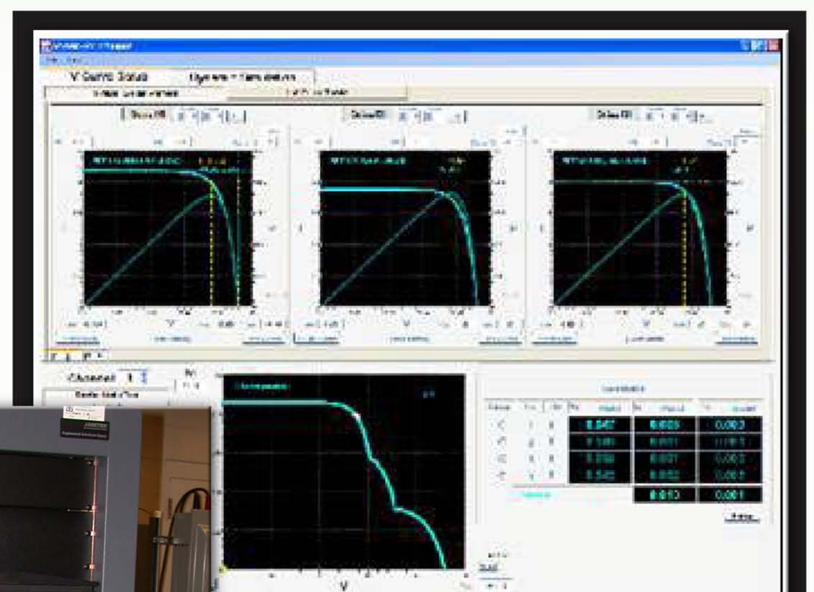
ABSTRACT

The ability to harvest all available energy from a photovoltaic (PV) array is essential if new system developments are to meet levelized cost of energy targets and achieve grid parity with conventional centralized utility power. Therefore, exercising maximum power point tracking (MPPT) algorithms under dynamic irradiance conditions and low irradiance conditions during startup and shutdown and evaluating inverter performance with various PV module fill-factor characteristics must be performed with a repeatable, reliable PV source. Ametek Programmable Power has developed a multi-port PV array simulator and is collaborating with Sandia National Laboratories to demonstrate and validate the performance of the simulator using actual PV arrays and previously recorded irradiance and temperature conditions.



PV Simulator

The PV simulator is a rack-mounted control computer with control software and PV simulation engines. The configuration evaluated for this paper has four programmable DC power supplies that are controlled by the PV simulation engines. Each of the power supplies is a high-speed switching supply that utilizes power MOSFET technology to minimize the output capacitor and inductor, which typically limits the performance of conventional power supplies for this application. The PV simulator is an integrated system that can simulate an IV curve with programmable parameters that are essential in developing a representative model of today's PV modules. These parameters are:

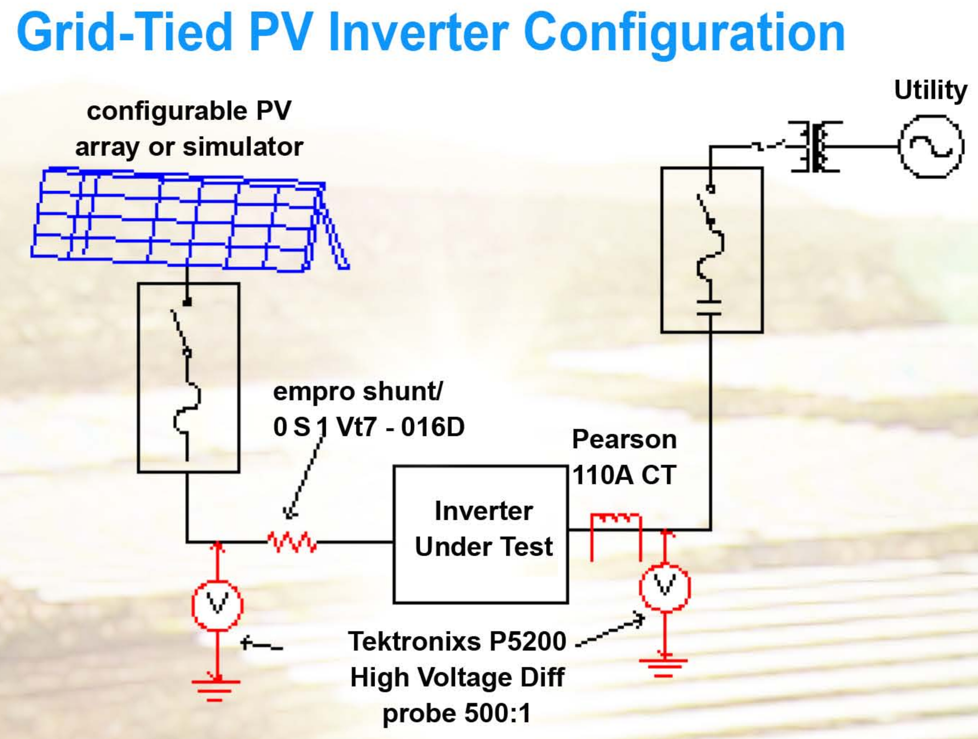
- **open circuit voltage (Voc),**
- **short circuit current (Isc),**
- **maximum power voltage (Vmp), and**
- **maximum power current (Imp).**

An array temperature coefficient can be implemented to best replicate module and array characteristics and replicate the performance of the simulated array configuration. The IV curves are produced utilizing the following formula:

- **Io=Isc*(1-C1(exp*(V/(C2 x Voc))-1*Eeff**
- **C1=(1-(Imp/Isc))*(exp(-Vmp/(C2 x Voc)))**
- **C2=((Vmp/Voc)-1)/(ln(1-Imp/Isc)) Where: Eeff=Ginc/Gstc, Gstc=1000 w/m^2 (standard test conditions) Ginc=Incident irradiance (Actual Irradiance)**

Laboratory evaluations of utility-interconnected PV inverters at Sandia National Laboratories Distributed Energy Technologies Laboratory are typically conducted using c-Si module technologies and the utility. A 50kWSTC Solar World SW175 module array can be configured to meet the voltage and power required to evaluate the device under evaluation. Utility-interconnected PV inverter evaluations are categorized in two distinct performance characteristics: 1) utility compatibility evaluations, and 2) inverter power quality and PV utilization/optimization evaluations. To demonstrate the effectiveness of the simulator in delivering PV power comparable to the actual PV array, a series of tests have been performed that characterize an inverter's performance when connected to PV vs. the performance of the same inverter when connected to the PV simulator. These tests involve an inverter with a deficient Maximum Power Point Tracking (MPPT) algorithym.

Grid-Tied PV Inverter Configuration

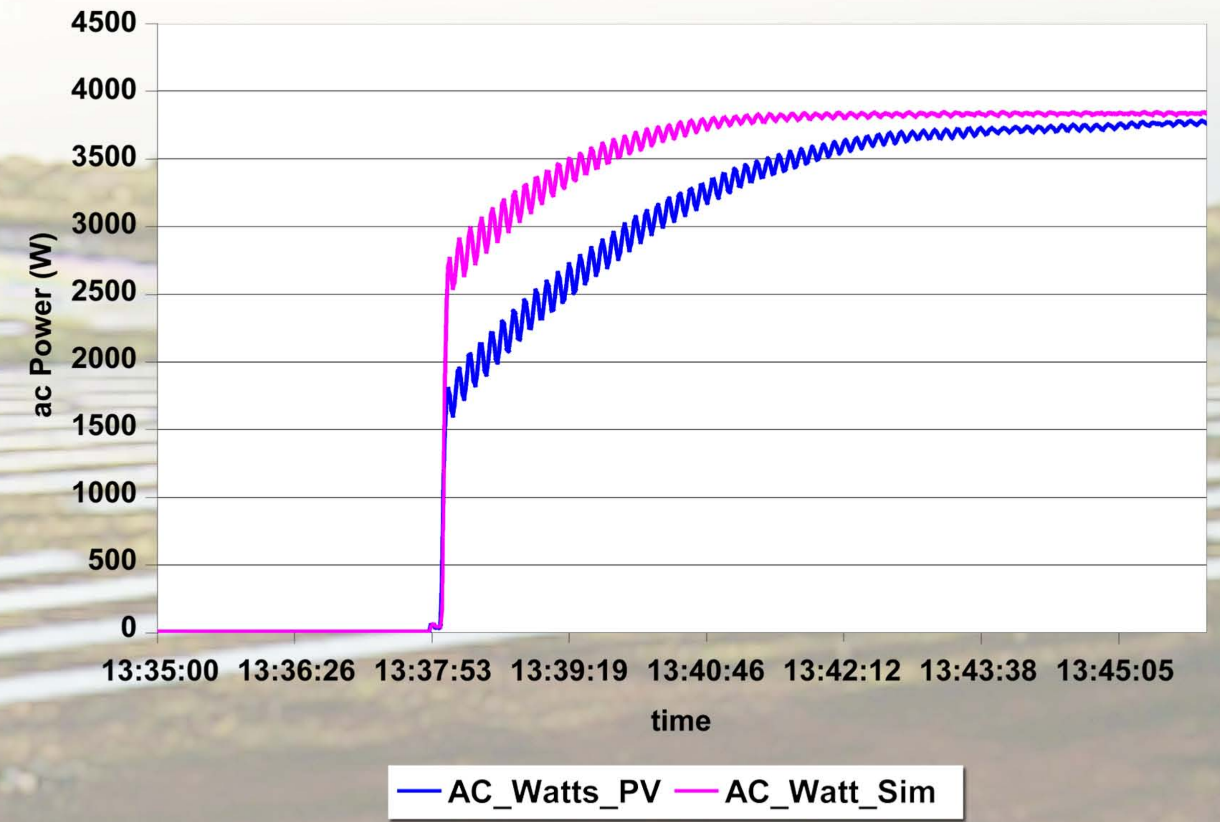


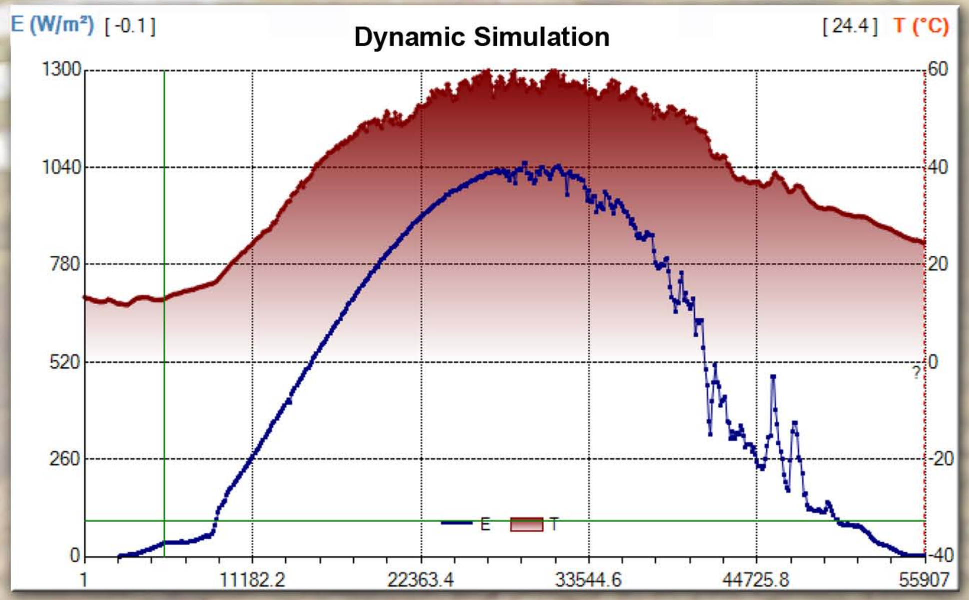
Test Results

Evaluations on the PV simulator were accomplished by monitoring the performance of a utility interconnected PV inverter when selling DC power to the utility. Providing a stimulus requiring a drastic change in MPPT operation shows the effects and influence that the DC source may have on the performance of the inverter.

The approach is to utilize the parameters of captured irradiance and module temperature to control the output of the simulator. Monitoring the inverter's performance during this operation shows only slight variations when comparing performance when connected to PV vs. when connected to the simulator.

Inverter response to PV and simulator





SUMMARY

The flexibility provided by a DC power source that has the characteristics and performance of a PV module and the configurability to operate at the necessary DC voltages and power levels enables new and innovative energy harvesting algorithms to be properly evaluated. It also enables manufacturers to optimize inverter operation over a range of module technologies and power levels without incurring the expense of installing PV or requiring access to a PV site. A device that provides a repeatable dynamic PV-like source enables designers and developers to optimize and validate new MPPT algorithms, enhance power quality controls, and perform interoperability among multiple devices.

While the performance of the PV simulator is promising, more tests need to be conducted to fully evaluate and understand its capabilities and limitations. Additional software functions, flexibility, and robustness are desired in new software and hardware revisions. Plans are to validate these enhancements as they become available.

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