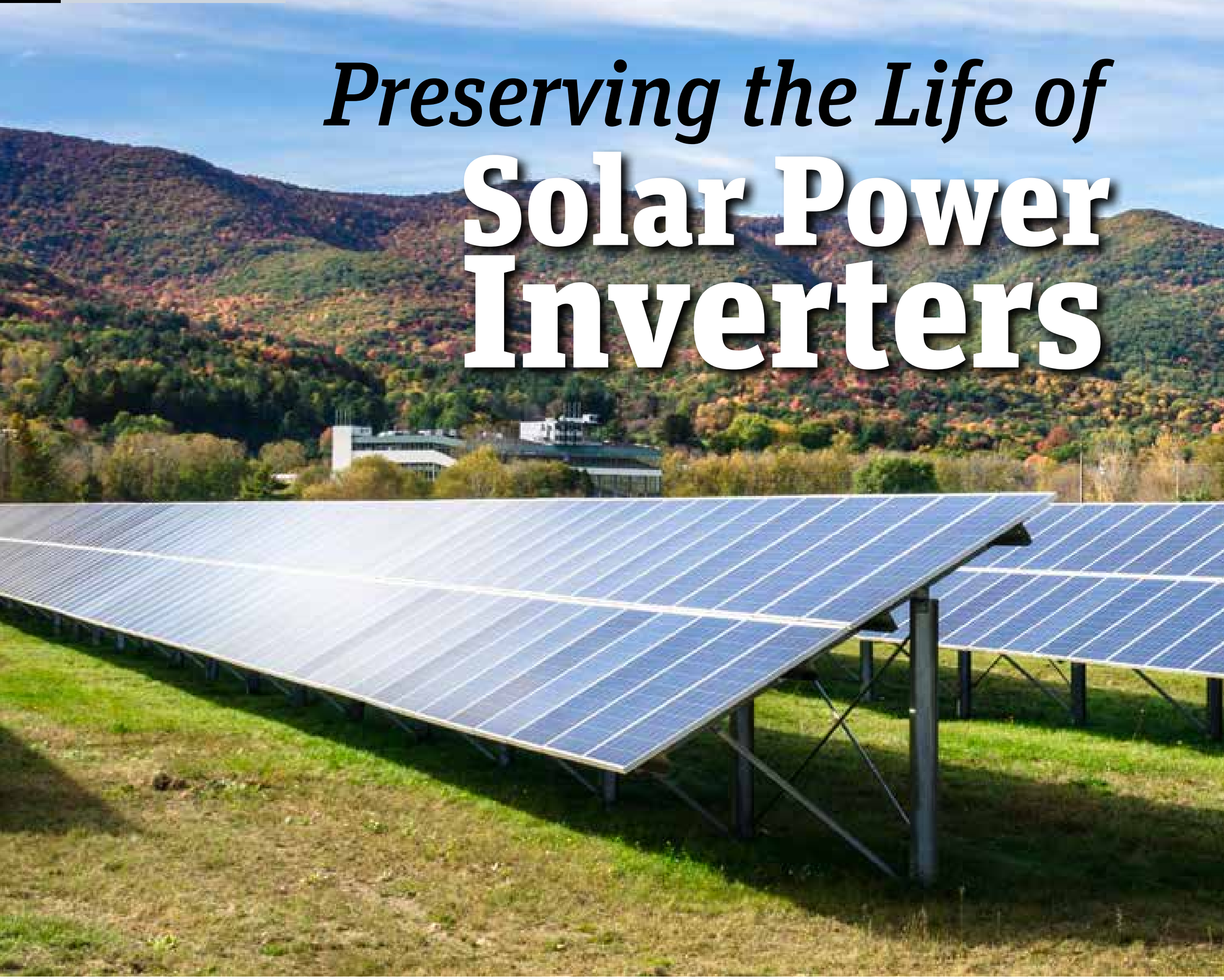
Preserving the Life of Solar Power Inverters



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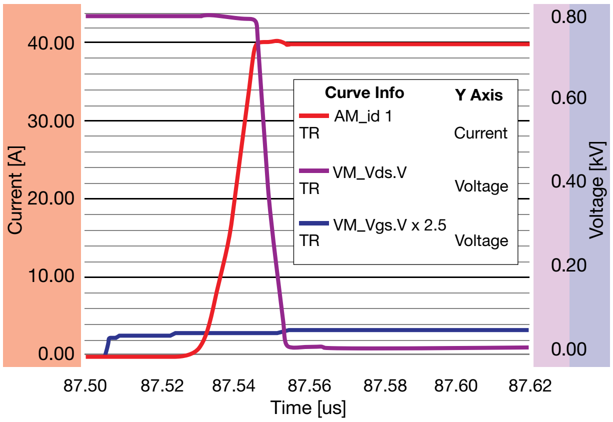
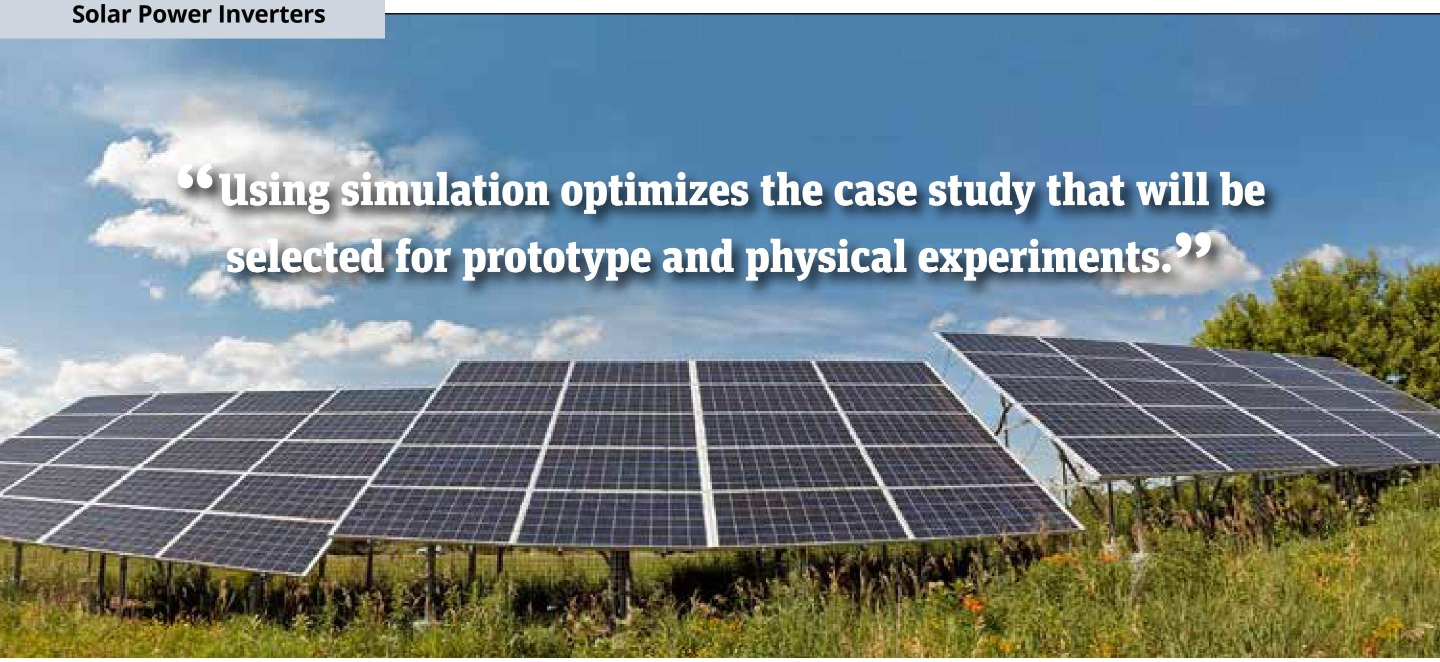
Utilities increasingly require that the inverters that connect solar power and other distributed generation systems to the grid be capable of injecting reactive power to help maintain the stability of the grid. However, producing reactive power increases the thermal stress on inverters, which has the potential to reduce their lifespans. University of Pittsburgh researchers use ANSYS simulation software to electronically and thermally characterize inverters before the prototype stage so that designers can make better decisions in the early phases of the product development process.

> “Tasking an *inverter* with producing reactive power significantly increases its *thermal loading*, which in turn reduces its expected life.”

Over 55 gigawatts of solar power are now installed in the U.S., enough to power more than 10 million homes. [1] But connecting all this solar power to the electrical grid presents special challenges. When a fast-moving cloud substantially reduces the power generated by a solar array, the power sent to the grid could drop, resulting in voltage instability and causing lights to flicker and sensitive equipment to stop operating. To address this problem, utilities might require that solar plants provide reactive power to maintain or compensate voltage during these disturbances. Reactive power is produced when the sinusoidal trajectories of current and voltage are out of phase with each other. Reactive power cannot be used to power electrical devices as with real power, but it can increase or reduce the grid voltage to assist in grid regulation. Tasking an inverter with producing reactive power significantly increases its thermal loading, which in turn reduces its expected life. University of Pittsburgh researchers have demonstrated a method to predict temperatures on the



Output from simulated test circuit used to validate electrical model of power electronics device



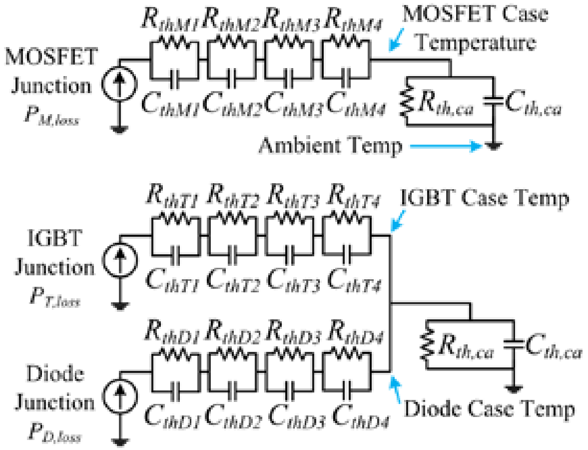
> “Using simulation optimizes the case study that will be selected for prototype and physical experiments.”

power electronic devices that make up an inverter, making it possible to optimize its design prior to building a prototype.

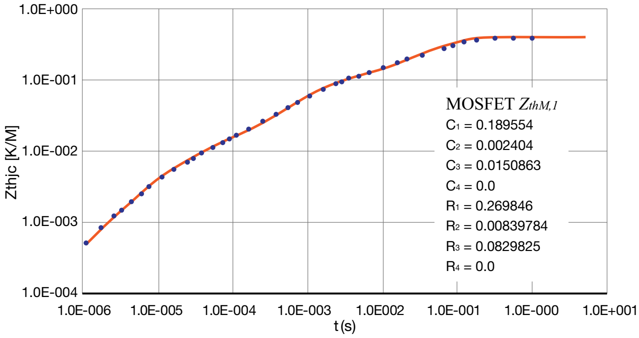
AVOIDING EARLY FAILURES IN SOLAR POWER INVERTERS

The latest generation of smart inverters is designed to support the grid, such as by remedying a grid disturbance through reactive power compensation. Performing reactive compensation can create additional device losses by raising the mean junction temperature and junction temperature fluctuations experienced by each power semiconductor in the inverter. Inverters switch the direction of current flow at a rate of 60 cycles per second to match the frequency of the alternating current. When the materials that make up the power electronics devices heat up and cool down on each cycle, thermal stresses are generated at the interfaces between materials with different coefficients of thermal expansion. If the quantity and magnitude of the thermal stress is high enough, thermal fatigue can occur at the interface, causing the device to fail. A helpful metaphor to conceptually grasp the physical cause of device failure is the repeated bending of a piece of metal wire. The wire will eventually snap from the cyclical bending. For an insulated-gate bipolar junction transistor (IGBT) module, the potential failure points include cracking of baseplate solder joints or chip solder joints and the lifting of wire bonds. The speed of degradation for a power electronic device is linked to the depth of the thermal cycle as well as to the average junction temperature.

Power semiconductors are traditionally modeled as thermal impedance networks consisting of resistor (R) and capacitor (C) elements connected in parallel to represent the thermal heat conduction through varying material layers. Each node in a thermal impedance network represents the interface between two different materials, such as the silicon wafer to the device package, the package to the heat sink, and the heat sink to ambient.



RC network used to characterize power semiconductor thermal impedance

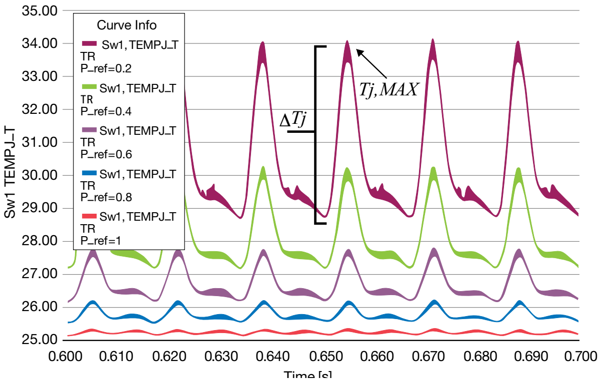


Transient thermal impedance model based on imported data sheet measurements

The challenge with this approach is that determining the RC constants for each material layer requires building a prototype test circuit and performing a lengthy and expensive series of physical experiments to determine the RC constants for each material layer in a power semiconductor module. During a design process, many different prototypes must be built and tested to evaluate different design alternatives. This entire process can take substantial effort for a typical power semiconductor.

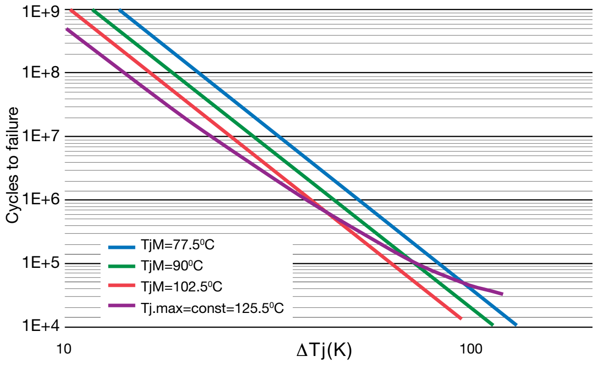
CHARACTERIZING THE DEVICE BASED ON DATA SHEET MEASUREMENTS

University of Pittsburgh researchers used multidomain system simulation (now contained in ANSYS Twin Builder) to develop electrothermal device models for the CREE C2M0040120D power metal oxide semiconductor field effect transistor (MOSFET) and the Infineon IKW40T120 Si-based IGBT. Using device characterization simulation eliminates the need for a prototype and physical experiments in order to observe temperature dynamics. This elimination is possible due to RC network parameter calculations based on data sheet test circuit measurements provided by the device manufacturer. ANSYS provides a system-level library for IGBTs, MOSFETs and diodes for quick evaluation of circuit behavior and control algorithms. When the researchers constructed a simulated test circuit using the two device models, the electrical performance of the device models matched the expected turn-on and turn-off times provided by the data sheet. They used the device characterization tools' device sheet scan utility included in the system simulator to import thermal impedance curves from the device's data sheets. Then the system simulator automatically calculated thermal impedance network model parameters for each level of the device.



Calculated junction temperature of SiC MOSFET for varying load requirements

The researchers then evaluated different design configurations to optimize the critical trade-off between reactive power performance and device lifetime. These device models were used successfully to support research efforts at the University of Pittsburgh in assessing the impact of smart grid features on the reliability of grid converters. Researchers demonstrated the ability to accurately predict the electrical and thermal performance of these devices. They were able to quantify the increase in the rate of device degradation for a device that provides a given level of reactive compensation. This made it possible to observe the trade-off between reactive performance and device lifetime in a fraction of the time required compared with conventional approaches.



Device lifetime as a function of junction temperature cycles.
Chart courtesy SEMIKRON International GmbH.

1) Cree Inc., "Silicon Carbide Power MOSFET C2M Technology," C2M0040120D Datasheet, 2015. [Online]. Available at www.cree.com

Reference

[1] U.S. Solar Market Insight, seia.org/us-solar-market-insight (07/03/2018)

ANSYS Twin Builder
ansys.com/twin-builder