Electronic Design

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Real-Time Control Enhances High-Voltage System Reliability and Accuracy

Sponsored by Texas Instruments: Power electronics systems have evolved from using analog controllers with minimal flexibility to real-time MCUs with AI capabilities to provide fault detection in high-voltage solar-energy or motor-control systems.

High-voltage systems serve applications ranging from renewable-energy generation to industrial motor control. Such systems require precise control to meet performance goals safely and reliably.

Analog controllers have traditionally served in such applications, but they're being supplanted by digital power controllers and real-time microcontroller units (MCUs) in modern high-voltage designs. In the latest innovation, MCUs apply artificial intelligence (AI) to real-time control applications to enhance functionality such as fault detection and mitigation.

From Analog to Real-Time MCUs

Reliability is crucial for high-voltage systems to enhance safety, reduce maintenance costs, and minimize downtime. While offering fast response times, analog controllers lack the flexibility to implement the functionality required for modern high-voltage designs.

In contrast, digital power controllers such as Texas Instruments' UCD3138A boost flexibility by allowing for parameters such as voltage and current thresholds to be adjusted under software control. In addition to performing power-control functions, the UCD3138A can handle housekeeping functions and communicate with other devices over communications links such as the Inter-Integrated Circuit (I2C) interface.

To help you get started with digital power controllers, TI offers the PMP40586 reference design, which employs a UCD3138A to control a 400- to 12-V, 1-kW power stage. TI produced a fully assembled board to test and validate the design, verifying such specifications as less than 500-mV peak-to-peak deviation in response to a 0% to 100% load change.

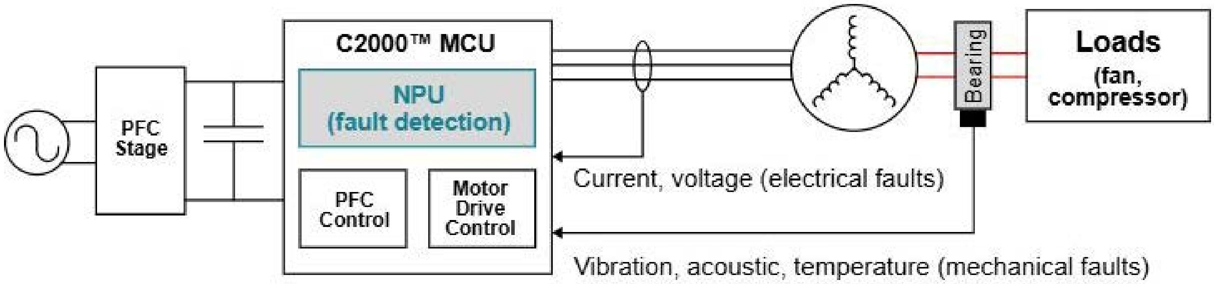
Digital power controllers remain good choices when you don't need full power-supply control-loop customization. They generally enable parameter optimization through an easy-to-use graphical user interface (GUI) rather than requiring an extensive firmware development effort.

However, if the application is a grid-tied inverter or motor drive that requires adaptive control and real-time response to system conditions, you might want to choose a real-time MCU such as a member of TI's C2000 family. To help illustrate the specific capabilities of C2000 MCUs, TI offers the TIDA-010933 reference design, in which a TMS320F280039C 32-bit C2000 MCU implements the control algorithm for a 1.6-kW bidirectional microinverter.

In this design, the MCU provides a one-chip solution for control of the microinverter DC-DC-converter and DC-AC-inverter power stages. It also implements the maximum power-point tracking (MPPT) algorithm necessary to extract maximum power from a solar-panel array.

Running Convolutional Neural Networks

Representing the latest advance in real-time high-voltage designs is the integration of neural-network processing units (NPUs) into MCUs, thereby bringing AI capabilities to real-time control applications. Such MCUs can run convolutional-neural-network (CNN) models to reduce latency



1. A TI C2000 MCU with an NPU can detect bearing faults based on current, voltage, vibration, acoustic, and temperature data.

to assist in optimizing applications ranging from arc detection in solar-power installations to bearing-fault detection in industrial motors.

Solar arc fault monitoring can help ensure the safety and reliability of solar-power systems. Solar arc faults often result from insulation breakdowns or loose connections and may generate intense heat, potentially causing fires. Motor-bearing fault detection can help prevent unexpected failures, minimizing downtime and maintenance costs. For both the solar and motor-bearing examples, AI is able to improve accuracy while avoiding false alarms, which could otherwise lead to unnecessary downtime and fruitless inspections.

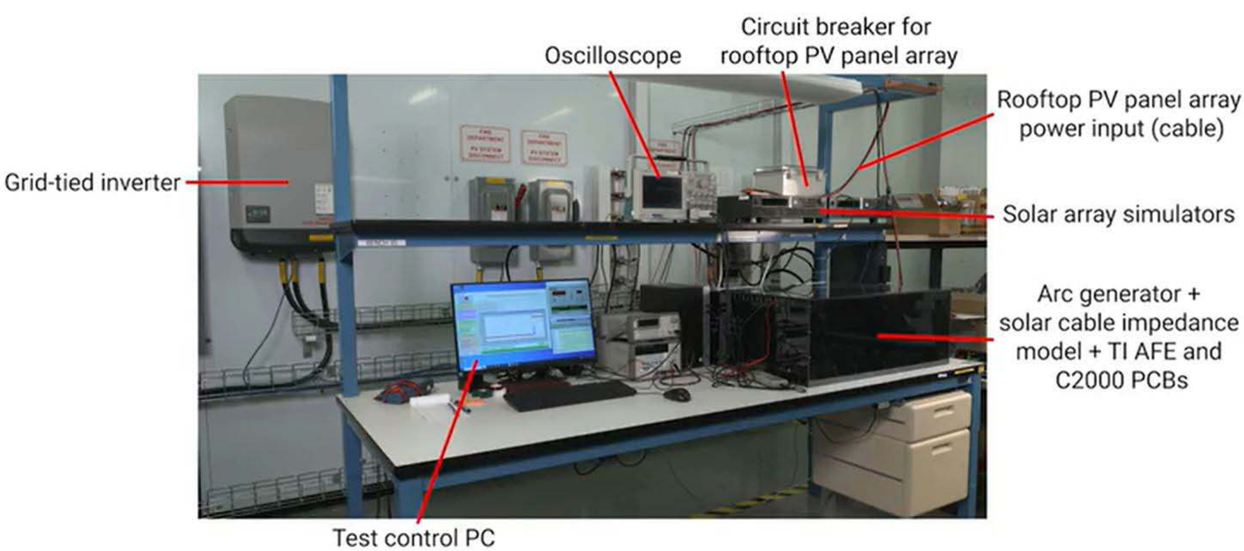
Traditional fault-detection methods acquire data and apply rules-based decision-making to determine when a fault occurs. However, rules-based approaches generally require considerable expertise to develop and offer limited flexibility.

In contrast, edge AI, achieved by running CNN models locally on a real-time MCU, enables fault-detection systems to learn and adapt, improving fault detection accuracy while avoiding false alarms. CNN models can extract meaningful information from a variety of sensor outputs. In *Figure 1*, for example, a TI C2000 MCU with an NPU is able to detect bearing faults based on current, voltage, vibration, acoustic, and temperature data.

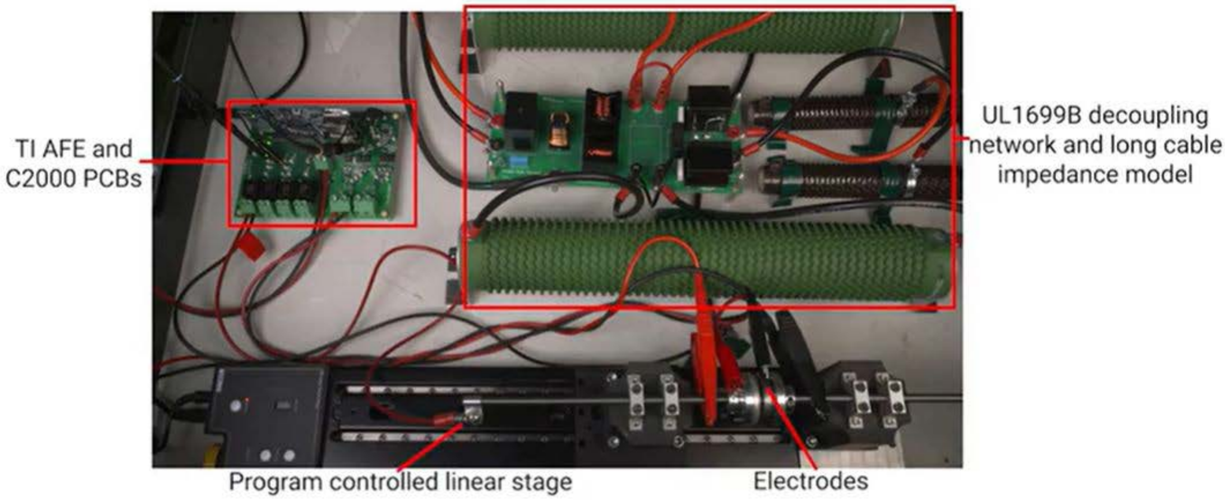
Arc Fault-Detection Details

Arc fault detection prevents potential damage in high-voltage solar-power systems by identifying when and where an arc occurs and deenergizing the positions of a system creating the arc. The traditional rule-based approach has limited adaptability and accuracy. In contrast, TI said its edge AI solution for arc fault detection achieves better than 98% detection accuracy, versus about 85% with traditional rule-based methods.

To demonstrate the solution's effectiveness, TI performed a live DC arc fault detection test under test conditions established in accordance with the UL 1699B standard. As shown in *Figure 1*, the test involved a grid-tied inverter, an oscilloscope, a rooftop solar-panel array cable, a circuit breaker for the rooftop array, a solar-array simulator, and an arc



2. An arc-detection test employed an inverter, an oscilloscope, a rooftop solar-panel array cable, a circuit breaker, a solar-array simulator, and an arc generator.



3. A linear stage, electrodes, a UL 1699B decoupling network, a TI analog front end (AFE), and a C2000 PCB rounded out the test setup in Figure 2.

generator.

And as shown in *Figure 2*, the test setup also included a program-controlled linear stage, electrodes, and a UL 1699B decoupling network with a long-cable impedance model. A TI analog front end (AFE) and PCB with a TMS320F28P-550SJ C2000 MCU monitored and analyzed the electrode gap voltage looking for arc signatures *(Fig. 3)*. TI reported that the demonstration achieved better than 99% detection accuracy.

The TI arc-detection solution supports customers at several levels. Customers new to arc fault detection can begin with TI's arc-detection reference design and then use TI's Arc Insight GUI, Edge AI Studio, and ML Model-Maker for arc signature data collection, model training, and code deployment.

Customers who collect their own arc signature data but don't have models have two options. First, they can evaluate TI AI models online and use Edge AI Studio for model training and code deployment. Alternatively, they can evaluate TI AI models using their data offline, employing TI's Tiny ML Model-Maker for model training and code deployment. Finally, customers who have their own AI models and data can use TI's Neural Network Compiler to handle code deployment.

Turning to Digital Power Control

Digital power-control implementations offer significant advantages over analog versions, adding flexibility through programmability. TI offers a lineup of digital power products, including real-time MCUs that can apply AI to applications such as fault detection. The company also has a variety of development tools and reference designs to help customers at all levels get off to a successful start with their projects.