Four Key Design Considerations When Adding Energy Storage to Solar Power Grids

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Solar energy is abundantly available during daylight hours, but the demand for electrical energy at that time is low. This balancing act between supply and demand will lead to the rapid integration of energy storage systems with solar installation systems.

At a glance

This paper addresses these design challenges when adding energy storage to solar power grids:

1 Bidirectional power conversion

Advanced bidirectional power topologies can achieve safe, efficient transfer of power between the grid, the photovoltaic array and the battery-management system.

2 Higher-voltage batteries

Solar installations that previously used 48-V battery packs are adopting 400-V battery packs, necessitating higher-voltage batteries.

3 Sleek storage system design

To achieve a sleek design, engineers need to design thermally optimized systems with minimal natural convection cooling.

4 Current and voltage sensing

Systems switching at higher frequencies have several design considerations for sensing current and voltage accurately.

While photovoltaic (PV) solar installations continue to grow, the imbalance between the supply and demand sides of the solar grid has emerged as a major limitation. Solar energy is abundantly available around noon, when demand is not high, which means that consumers pay a higher cost per watt during peak usage in the morning and evening.

Energy storage systems (ESSs) for residential, commercial and utility solar installations enable inverters to store energy harvested during the day or pull power from the grid when demand is lowest, delivering this stored energy when demand is high. Adding ESS to a solar grid-tie system enables users to reduce costs by a practice known as "peak shaving."

In this white paper, I'll explore design considerations in a grid-connected storage-integrated solar installation system.

Bidirectional power conversion

Conventional solar installations comprise unidirectional DC/AC and DC/DC power stages, but a unidirectional approach presents a major barrier to ESS integration. It requires more components, modules and subsystems, all of which significantly raise the cost of adding ESS to an existing solar installation.

Adding storage to an existing solar installation entails combining two paths to charge and discharge the battery into a single path comprising both power factor correction (PFC) and inverter power stages. But how do you build bidirectional power converters to replace two unidirectional power converters?

The advanced bidirectional power topologies shown in **Figure 1** enable the safe, efficient transfer of power between the grid, PV array and battery-management system. Microcontrollers (MCUs) such as C2000™ real-time MCUs are popular for such power topologies. These controllers can each control one or multiple power stages to enable a digitally controlled bidirectional power conversion architecture for an ESS-enabled solar inverter. MCU-enabled control facilitates more sophisticated pulse-width modulation (PWM) schemes for the power switches handling the DC/AC and DC/DC conversions.

A hybrid inverter helps conversion stages achieve greater efficiency, which becomes far more important in an ESS-integrated microgrid because multiple power conversions are happening. Power converter systems handle DC/DC operations to charge and discharge batteries, as well as DC/AC and AC/DC operations that convert the DC power stored in the battery into AC to feed it into the grid and back.

Higher voltage batteries

In a storage-integrated microgrid system, a battery's primary function is to store PV energy and inject power into the grid when prompted. Lithium-ion battery packs offer much higher charge-storage capability per unit than lead-acid batteries.

With 400-V battery packs becoming popular in the electric vehicle (EV) segment, there is also a push toward increasing battery voltages in solar power grid installations beyond 48-V battery packs. But how do you manage power conversions for 400-V battery packs?

Along with MCUs that provide system control and communication to help ESSs integrate into larger systems, power switches with low losses and high efficiency also make energy storage systems safe and reliable. Compact power switches based on silicon carbide (SiC) and gallium nitride (GaN) materials, along with real-time control MCUs, help

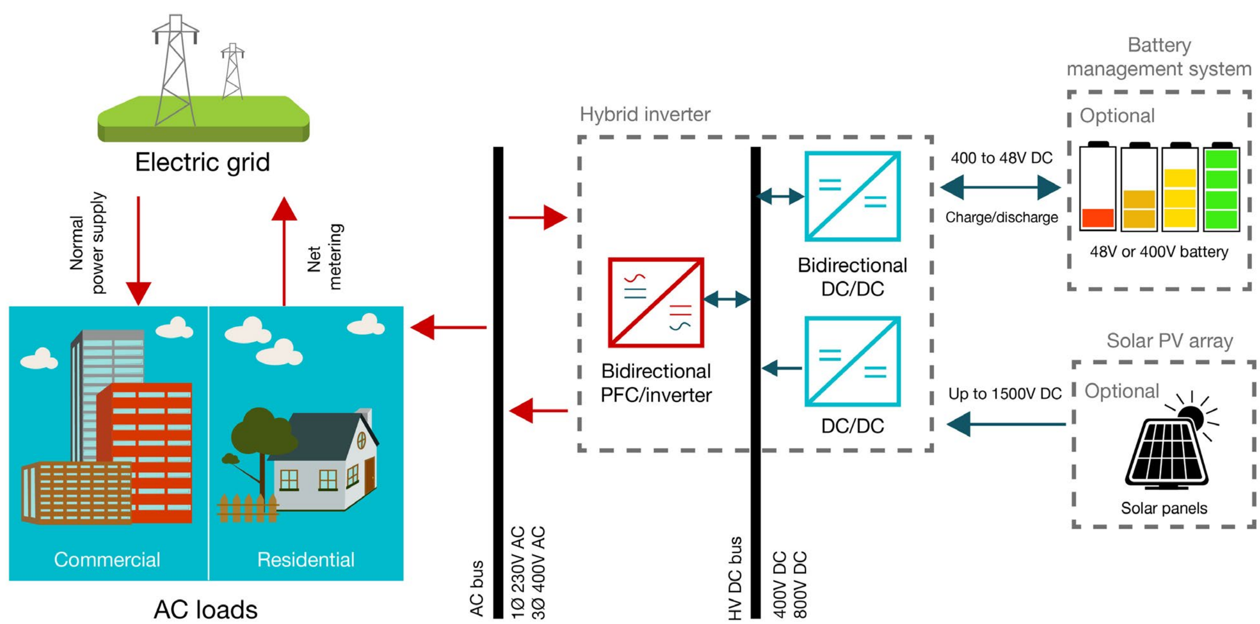

***Figure 1**. Block diagram of a bidirectional PFC and inverter stage.*

ensure the adaptation of a bidirectional converter so that it can operate with various DC storage energy units. See **Figure 2**.

Wide-bandgap semiconductors such as SiC and GaN will play an important role in addressing power conversion systems that can handle increased battery-voltage ranges given the converter's higher power density and lower switching losses. Power conversion systems also help battery packs manage power fluctuations in distributed generation systems better, and make grid operations smart and resilient at higher and wider voltage ranges.

Eventually, solar installations might mimic the battery packs used in EVs. There is a growing belief that the battery packs currently used in EVs will be recycled for a second life as a grid-connected ESS.

Wide-bandgap materials for efficiency and natural convection

In order to create a sleek wall-mounted storage system, you must ensure that the inverter design is thermally optimized with minimal natural convection cooling. A distributed power architecture can spread the concentration of heat throughout the system. Such architectures also enable the energy storage inverter needed to support high current levels at different voltages, and to provide a reliable transient response to rapidly changing loads.

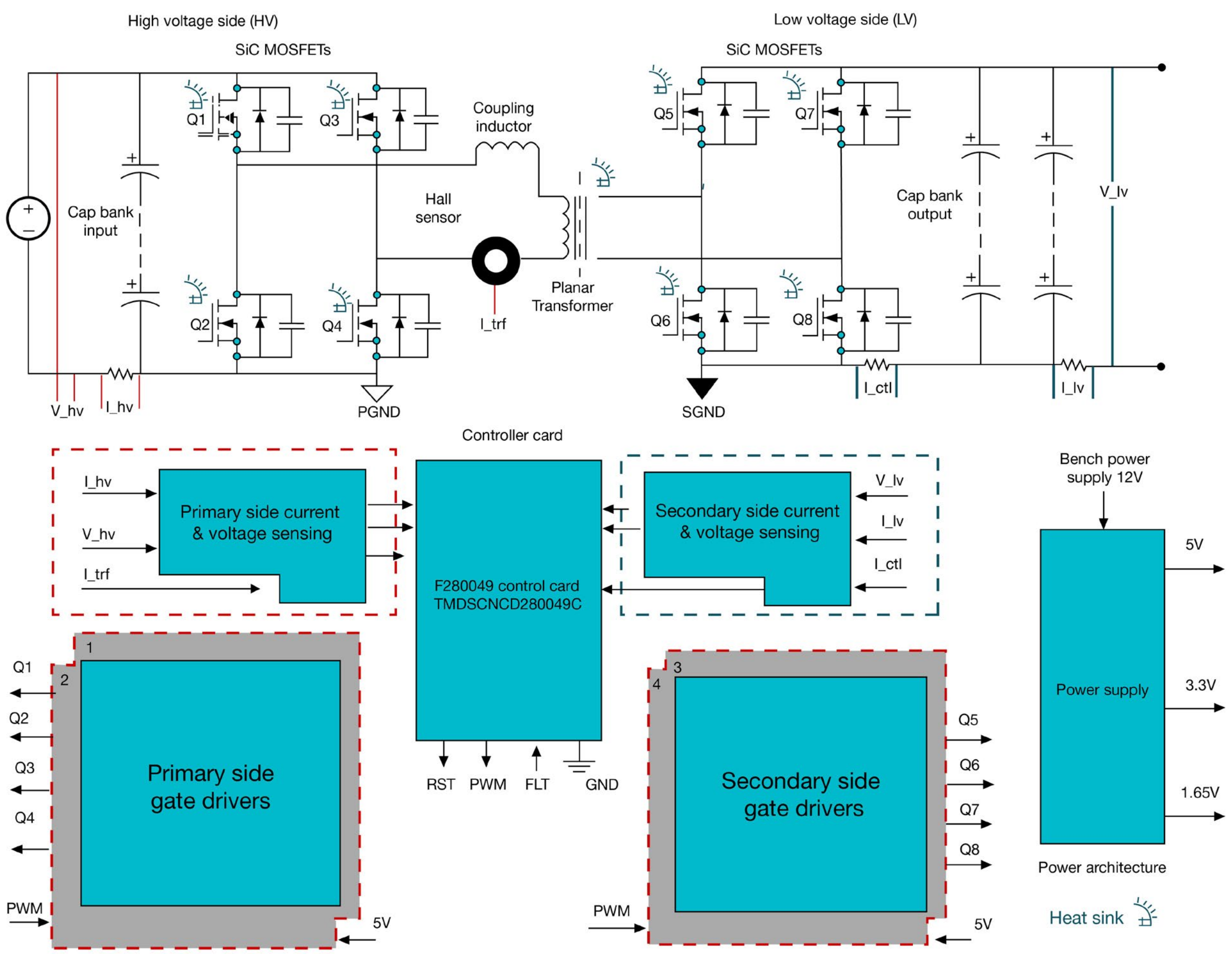

__Figure 2__. A dual active-bridge DC/DC converter design facilitates bidirectional operation to support battery charging and discharging applications.

Such a system will require gate drivers that can support fast switching and provide protection at switching frequencies from 100 kHz to 400 kHz. If switching is not fast enough, power-conversion stages can suffer huge efficiency losses.

That's where wide-bandgap materials such as SiC and GaN come into play, offering faster switching and higher power density. These semiconductor devices facilitate design systems where there is no need for fan-based cooling. The [LMG3425R030](), a GaN device with integrated driver and protection features, provides a compact form factor, higher power density and faster switching capabilities.

The gate driver translates the digital PWM signal from the controller to the current required by the SiC or GaN field-effect transistor. The PWM-based controllers ensure that voltages and currents are accurately sampled at multiple power conversation stages.

The **Bidirectional High-Density GaN CCM Totem Pole PFC Using C2000 MCU** reference design includes a bidirectional totem-pole bridgeless PFC power stage that employs a C2000 real-time MCU and the **LMG3410R070** GaN FET with integrated driver and protection (**Figure 3**). The 3-kW bidirectional design supports phase shedding and adaptive dead time for efficiency improvements, and a nonlinear voltage loop to reduce voltage spikes during transients in PFC mode.

Current and voltage sensing

Power design switching at high frequencies includes the challenge of accurate current and voltage sensing. Shunt-based current measurements are not only more accurate; they also offer faster response times to react quickly to any change in the grid, shutting off the system in case of a short circuit or grid connection loss. Current measurements are an inherent part of inverter-centric designs

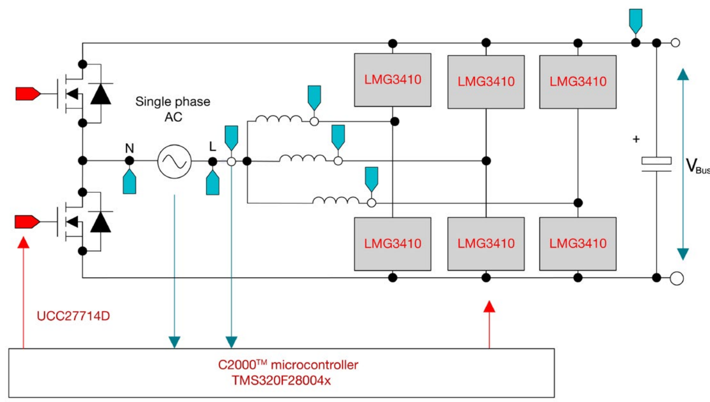

***Figure 3**. The GaN CCM totem pole reference design employs digital control using a C2000 real-time MCU and a fast switching GaN device with integrated gate-driver and protection features.*

because control algorithms require current sensing for control purposes. Design solutions are available for isolated current measurements using external shunts and isolated amplifiers or modulators and power supplies. For example, the **Three-Level, Three-Phase SiC AC-to-DC Converter Reference Design** employs the AMC1306 isolated modulator for load current monitoring. The **AMC3306** is a next-generation isolated modulator with integrated DC/DC converter that enables single-supply operation.

For any digital signals that need to transfer data across various voltage domains in inverter-driven applications using higher voltages, isolation devices could be used to overcome voltage limitations. Digital isolators such as the **ISO7741** enable high-frequency signals to cross power boundaries, while protecting low-voltage digital circuits from the high-voltage domain.

Power converters have to measure the grid current in order to ensure that the current is in phase with the voltage. Current and voltage measurements also control the battery-charging current as well as inverter operation and overload protection.

Conclusion

Hybrid inverters, which provide bidirectional AC/DC and DC/DC power conversions, will likely replace traditional solar inverters in a few years. Hybrid inverters are allowing solar inverter designers to implement power conversions with a wide range of output power and voltages.

For storage-capable solar inverters, higher and wider battery voltage ranges matter. Along with the need for high efficiency and natural convection, basic building blocks such as MCU-based control and wide-bandgap semiconductors with integrated gate-driver and protection features can accommodate these higher and wider battery-voltage ranges.

C2000 real-time MCUs and LMG3425R030 GaN devices are able to handle bidirectional energy transport in a storage-capable solar grid. Likewise, shunt-based current and voltage sensing can ensure that higher voltage batteries and fast switching power converters work safely and reliably.