Integrate Protection with Isolation In Home Renewable Energy Systems

AVAGO TECHNOLOGIES

Whitepaper

Home energy systems based on renewable sources such as solar and wind power are becoming more popular among consumers and gaining increasing support from governmental bodies. Such systems, however, need fault protection in order to achieve the product lifetime that consumers demand as well as isolation to ensure consumer safety. Integrating the two capabilities can help simplify system design as well as lower cost.

The typical renewable energy system has multiple parts (see Figure 1) operating in different voltage domains. At one end of the system are the power sources, such as solar panels, wind turbine generators, and batteries. The primary power sources – solar panels and wind generators – typically include some form of power conditioning. In the case of solar panels, this conditioning includes a DC-DC converter to smooth out the illumination-dependent raw DC voltage from the panels as well as maximum power point tracking circuitry to match the load on the panels to their output level. For wind turbines a rectifier and DC-DC converter combination turns the generator's variable AC into a stable DC voltage.

Because the battery pack is a secondary power source, capable of storing and delivering energy, its connection to the DC Link is more complex than that of the primary sources. The battery charge controller must control the voltage and current it delivers when charging the battery as well as condition the power the system draws from the battery. Current sensing of both the AC power the inverter is delivering as well as the DC power the primary sources are delivering determines which way and how much energy flows through the battery charge controller.

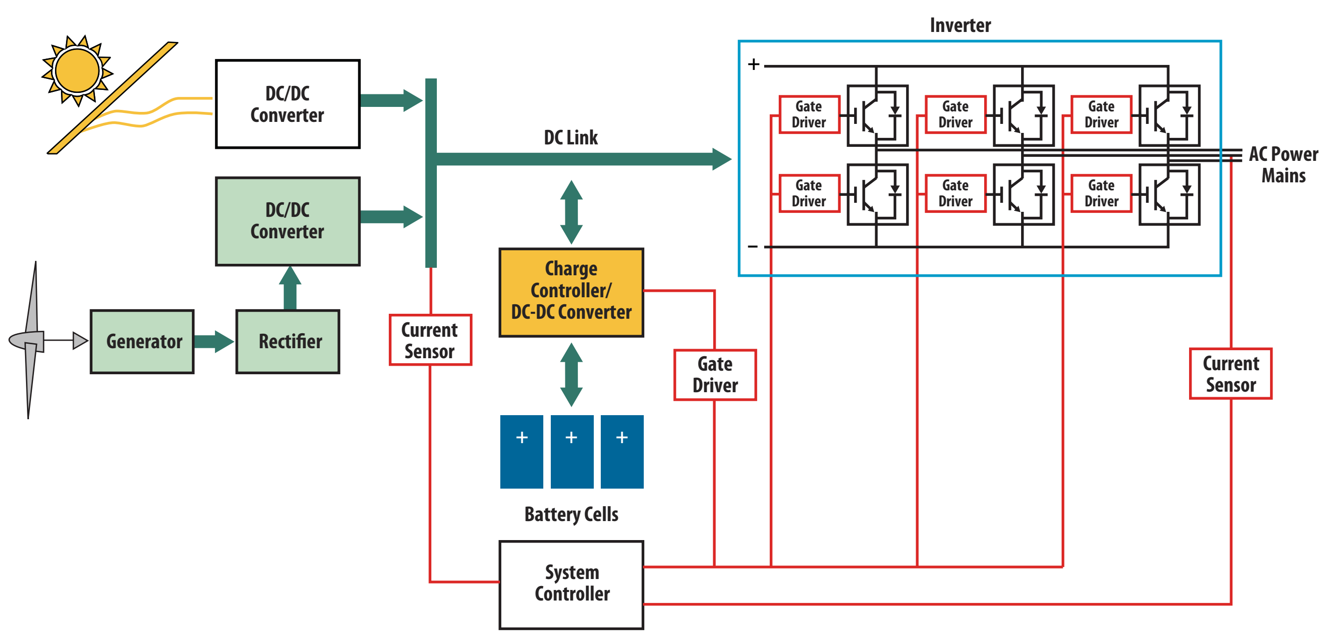

Figure 1. Home alternative energy systems need isolated connections (red) between the high voltage power circuits and the controller managing power flow.

The conditioning allows the power sources share a common connection called the DC Link to drive the inverter that supplies standard AC power to the household. The inverter may also feed energy back into the power grid when system's energy generation exceeds the local demand. To maximize efficiency in generating grid-compatible AC voltages, home alternative energy systems typically utilize a DC Link voltage of 600 V to 1200 V.

Inverters in a home alternative energy system typically handle from 1 kW to 30 kW and create 1 or 3-phase AC power. They operate by switching the DC Link voltage at a frequency around 50 kHz under pulse-width modulation (PWM) control. To handle this switching frequency as well as the high currents and voltages involved in AC power, inverters typically use insulated gate bipolar transistor (IGBT) switches.

Control Processors Gain Enhanced Isolation

Both the inverter's PWM switching and the battery charge controller's operation depend on the instantaneous AC power the system must supply at any given moment. To handle this dynamic requirement, home alternative energy systems typically incorporate a processor-based system controller that monitors both the AC load and the DC Link currents and drives the switching transistors that manipulate the battery controller and inverter operation. The system controller also monitors system status and controls system response to fault conditions such as short circuits, overloads, and insufficient source power.

The system controller, however, operates in a different voltage domain than the elements it controls. The power sources operate in the tens of volts, the DC Link at hundreds of volts, but the system controller's logic circuits typically operate around 3 V – 5 V. To minimize the possibility of damage to the controller in the event of a fault condition, then, there must be some type of isolation between the power and logic voltage domains. Such isolation not only serves to protect the controller logic from the high DC Link voltages it helps protect the user, who typically interacts with the system through the controller's interface.

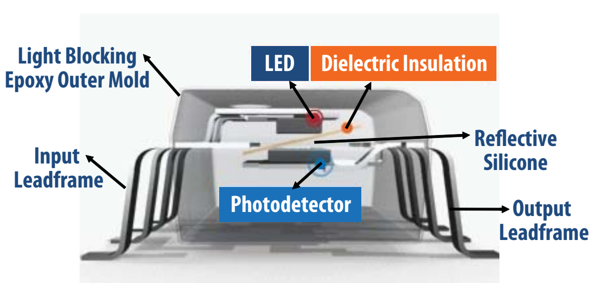

Figure 2. A transparent, conductive barrier inside the optocoupler provides reinforced isolation between low-voltage inputs and high-voltage outputs.

The best way to provide isolation for the high-voltage control connections is with gate-drive optocoupler. Simply using high-voltage driver ICs or magnetic coupling can only provide basic insulation separation between voltage domains, and they depend on the integrity of the insulating materials in the packages and windings. Failure of this insulation would result in a direct high-voltage connection to the logic, with immediate destructive results.

Optical couplers from Avago Technologies, on the other hand, offer reinforced galvanic isolation (Figure 2) that increases safety and system reliability. Like other high voltage ICs, these gate-drive optocouplers accept logic-level control signals and drive the gates of IGBTs to switch high-voltage power. But the reinforced insulation provides two levels of protection using a single layer of insulation barriers: one basic and one supplementary. If one fails, the other is still present, and so the system is regarded as fail-safe.

Avago's gate-drive optocouplers have several additional attributes valuable in switched-power designs. One is high common-mode noise rejection, which helps prevent PWM switching noise from feeding back into the system controller. Another valuable attribute is precision in switching.

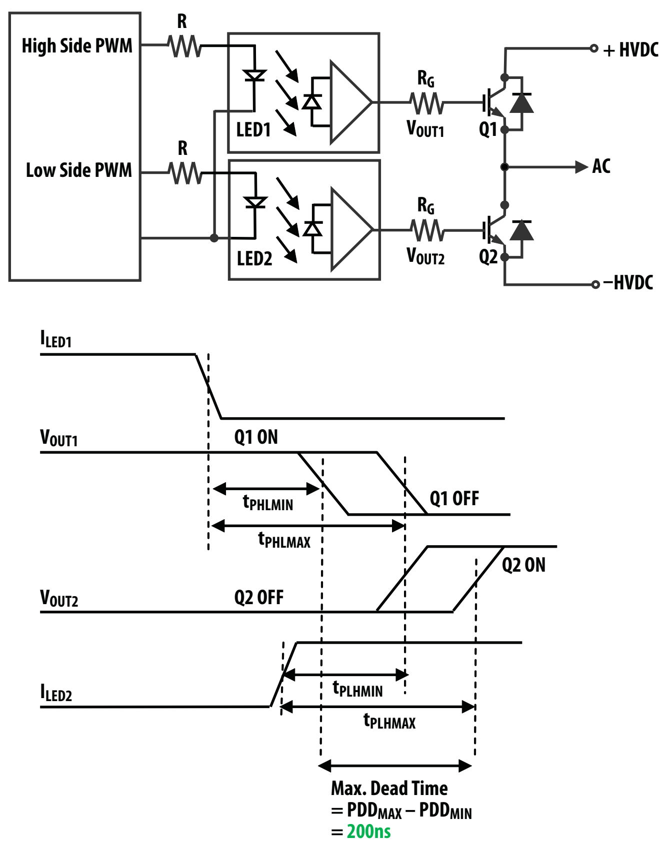

Figure 3. Inverter designs alternately drive IGBTs in pairs, creating a risk of short-circuit if drive timing does not accommodate variations in driver propagation delays.

Precision Switching Increases Inverter Efficiency

Precision switching in power applications is essential for maximizing power conversion efficiency without compromising system safety. In order to produce an AC power signal, inverters operate IGBT switches in pairs (Figure 3). Should both switches be conducting simultaneously, however, they would short-circuit the DC rails and damage the system. To prevent this condition from ever occurring, the PWM signaling must include some "dead time" between turning off one IGBT and turning on the other.

Unfortunately, this dead time has a detrimental effect on the inverter's power conversion efficiency. During the dead time no current flows from the source to the load. As a result, not all of the source energy available is being converted and delivered to the load, reducing system efficiency.

The amount of dead time a design needs depends largely on the device-to-device variability in propagation delay between the control signal input and the gate drive output. A safe value would be at least equal to the difference between the fastest turn-on and slowest turn-off that devices exhibit. The more precise the device's switching (less variability), then, the less dead time the design needs. Avago's gate-drive optocouplers exhibit variability less than 200 nsec, or less than 1% of the switching period in typical inverter designs, allowing inverters to achieve power conversion efficiency in the high 90's.

While high conversion efficiency is important in inverter designs, it is not the only attribute needed in home alternative power systems. Such systems must provide a service lifetime of 15-20 years in order to be acceptable to consumers, and the inverter's reliability is an important factor in achieving this goal. Repairing or replacing an inverter would cost \$2000 – \$4000 or about 10% of the initial system cost, so to be cost effective inverter designs should include protection against common failure modes.

Protections Ensure Extended Inverter Lifetime

The most critical component in the inverter needing protection is the IGBT. These devices can fail under a number of conditions that have a high probability of occurring during a 20-year system lifetime. Short-circuits on the AC output, low voltage on the control gate inputs, noise from switching transients, and failures in the system controller all have the potential of damaging the IGBT when protection is not in place.

How damage occurs can be seen by examining IGBT behavior during various conditions. In normal operation the gate drive (V_{GE}) to the IGBT – typically around 15 V – is sufficient to put the transistor into saturation when turned on. In saturation the device is able to handle currents of several hundred amperes while exhibiting a low collector-emitter voltage (V_{CE}) drop (Figure 4), minimizing the power loss and resulting heat generation in the IGBT. Achieving saturation, though, requires a gate drive greater than 12 V.

In a home alternative energy system the system logic supply voltage that provides the gate drive can sometimes fall below 12 V. This may happen because of low primary energy input due to insufficient light or low wind or due to other naturally-occurring conditions. It can also happen during system power-up before the logic supply stabilizes. If the logic supply is low, then gate drive from the optocouplers will also be low.

A low gate drive (~10 V) allows the IGBT to slip into its linear operating region, with potentially disastrous consequences. In the IGBT's linear operating region, V_{CE} can rise quickly when the current draw through the device exceeds a critical value that is typically much lower than the inverter's intended capability. This rising voltage together with the current draw increases heat generation in the IGBT that can quickly lead to device damage or failure.

Even with gate drive at its design level the IGBT can slip out of its saturation region if the current draw through the IGBT becomes excessive (Figure 5). Such excessive current draw can be the result of an overload on the AC lines, a short-circuit of the inverter's supply rails, or a failure in the controller that regulates output voltage through PWM switching. As with the low gate drive condition, the result of desaturation due to excessive current draw is an increase in V_{CE} with consequent heating and device failure.

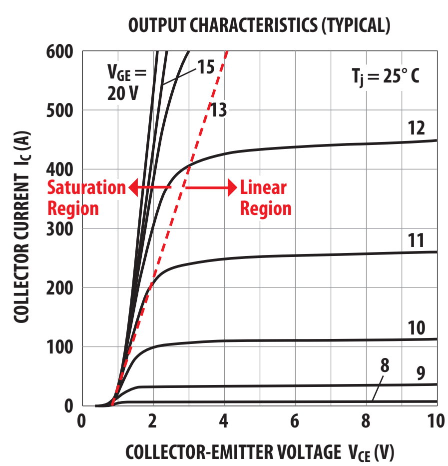

Figure 4. If gate drive voltage is too low, an IGBT may operate in its linear region instead of saturation, risking excessive power dissipation in the device.

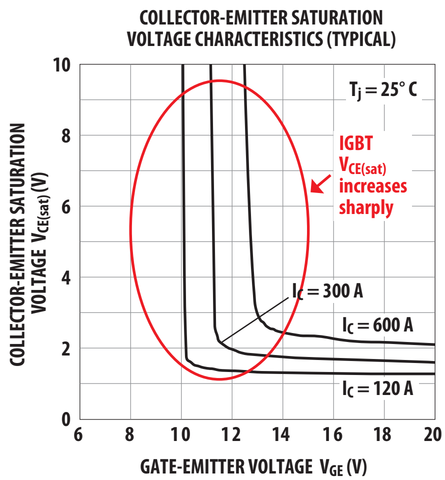

Figure 5. Excessive current draw through an IGBT, such as from a load short, can cause desaturation and increased power dissipation.

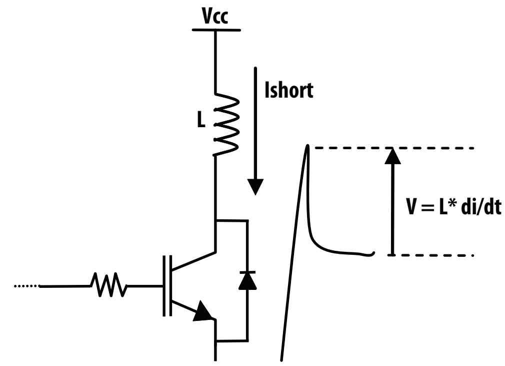

Figure 6. Turning off an IGBT too quickly can generate a damaging overshoot due to back EMF from parasitic inductance.

If the connection between the rail supply and the IGBT has too much inductance, rapidly switching off an IGBT – such as during a fault-triggered inverter shutdown – can trigger another failure mode. The back EMF from interrupting current through the inductance generates a voltage spike across the IGBT (Figure 6). This overshoot voltage, if high enough, can cause a breakdown in the semiconductor's internal structures, ruining the device. Overshoot voltages depend on the circuit's parasitic inductance and the IGBT switching time.

A fourth major failure mode for IGBT-based inverter designs arises due to parasitic Miller capacitor between the gate and collector. The Miller capacitor's discharge path runs through the gate driver to ground (Figure 7), creating a voltage drop across the gate resistance and driver output impedance. If the Miller capacitor holds enough charge, the voltage drop can be sufficient to keep the IGBT turned on after its driver turns off. This creates a rail-to-rail short in the inverter similar to what happens when there is insufficient dead time when switching.

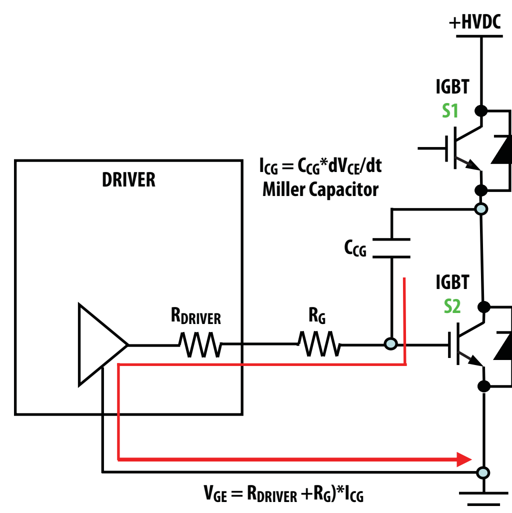

Figure 7. Parasitic Miller capacitance can discharge through the driver, holding the IGBT on and creating a short-circuit.

Integrated Protection Reduces Cost, Design Complexity

Protective circuits to prevent such failures can be designed into the inverter using discrete components. Avago's ACPL-332J/331J gate-drive optocouplers, however, offer an integrated alternative that eliminates the cost, board space, and design effort of a discrete design. The optocouplers provide protection against all four major IGBT failure modes.

To eliminate problems caused by insufficient gate voltage, Avago's ACPL-332J/331J optocouplers incorporate an under-voltage lockout (UVLO) feature. The UVLO circuit keeps the optocoupler gate outputs clamped at zero volts until the logic supply reaches the positive-going UVLO threshold, which releases the clamp. To prevent oscillation if the supply voltage remains near the threshold value, the circuit includes hysteresis. The clamp will not re-engage until the supply drops approximately two volts below the positive-going threshold.

A desaturation detector in the optocoupler prevents load shorts and other triggering conditions from causing damage to the inverter. The detector monitors the V_{CE} of the IGBT the optocoupler is driving and triggers a local fault shutdown sequence if the voltage exceeds a predetermined threshold of 7 V. The shutdown sequence includes generating a FAULT signal so that the controller can implement a controlled system shutdown, reset, or recovery as appropriate.

The shutdown sequence includes a "soft" turn-off of the IGBT to prevent overshoot its potential damage when responding to a fault. The soft turn-off uses a two-stage operation to discharge the IGBT's gate capacitance (Figure 8). The first stage activates a weak pull-down device that drains the gate relatively slowly – preventing a rapid change in IGBT current – until V_{GE} drops below 2 V. At this point the second stage activates a pull-down device 50x more conductive than the first stage to complete the turn-off with a hard clamp.

The optocoupler prevents the parasitic turn-on due to the Miller effect by providing a low-impedance discharge path for the current (Figure 9). The active Miller clamp monitors the gate voltage and, if V_{GE} goes below 2 V, turns on a transistor that connects directly to the IGBT gate. The transistor bypasses both drive and the external gate resistor, preventing the Miller current from keeping the gate active.

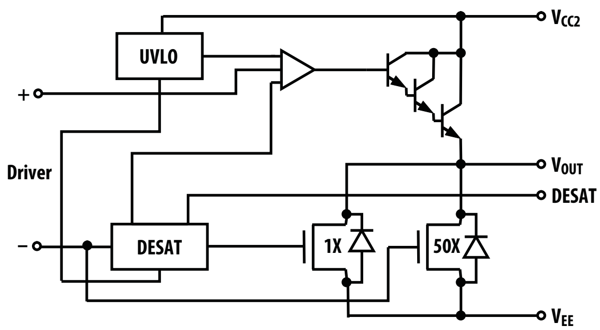

Figure 8. To prevent overshoot Avago's optocouplers use a two-stage "soft" shutdown of the IGBT.

The integration of these protective circuits in Avago gate-drive optocouplers can greatly enhance the safety and reliability of alternative energy systems. Such systems need both isolation between their logic and power voltage domains and protection against common fault conditions. Avago optocouplers offer enhanced galvanic shielding to provide a fail-safe barrier between users and the system's high voltages and built-in protective circuits to simplify inverter system design and reduce cost. Both attributes help increase system reliability, ensuring that alternative energy systems have the installed lifetime and cost-effectiveness that home users require.

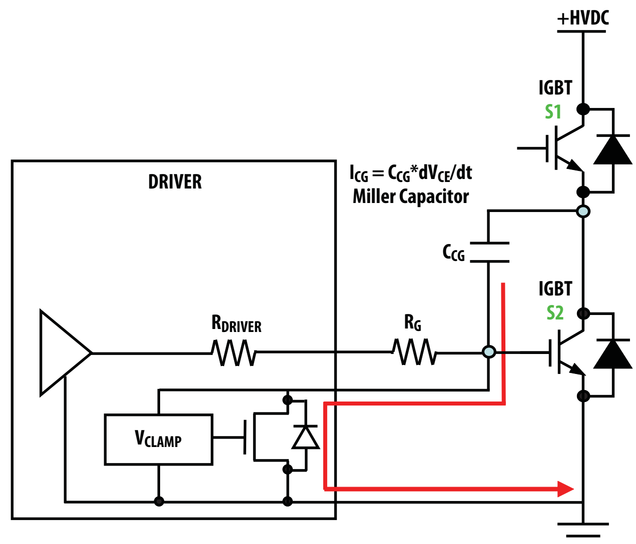

Figure 9. An active Miller clamp prevents parasitic capacitance from keeping an IGBT on when its driver is turned off.

For product information and a complete list of distributors, please go to our web site: **www.avagotech.com**

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