35-V, single-channel gate drivers for IGBT and MOSFET renewable-energy applications

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Introduction

The electronics market segment labeled as renewable energy is a complex and diverse arena for electric power conversion. In point-of-load applications, the switching power converter typically is non-isolated; power levels are fairly low (<200 W); and the power is usually converted from one DC voltage to another, such as from 12 V to 3.3 V. Further, the power-stage switches are integrated or capable of being driven by low-current controllers or transistors. Integration between the controller and power stage is being realized today. Silicon (Si) MOSFETs dominate this arena, where higher switching frequencies are preferred and can reach speeds of greater than 1 MHz. These power switches generally are driven by a 5- or 12-V IC gate driver or similar solution.

Challenges to efficiently managing renewable-energy systems

In the electronic power train from a wind or photovoltaic power generator, there are some unique performance challenges. Typical power levels for renewable energy can range from 1 to 3 kW for micro-inverters, 3 to 10 kW for string inverters, and 10 kW to 1 MW for large central-inverter stations. In addition to DC-to-DC conversion, DC-to-AC and AC-to-DC conversion can also be used, and sometimes a combination of the two.

Older wind turbines were tied directly to the power grid but had to run at the power-line frequency. This made them inefficient across the many operating points they experienced. Newer wind turbines (Figure 1) often convert AC to DC and then DC back to AC so that the wind-driven generator can run at variable speeds for maximum efficiency.

Conversely, photovoltaic cells produce DC voltage/current. Generally, the voltage is boosted higher and then sent through a DC-to-AC inverter before being tied to the grid.

Renewable-energy trends

For most countries, generating renewable energy from sources such as wind and solar power makes up only a small percentage of their total power portfolio. In recent history, growth has been consistent year by year. There are places where renewable energy makes up a large share of the available power. Denmark, for example, generated nearly 34% of its total electricity from wind power alone in the first half of 2012, according to the Danish Energy Agency. According to its parent agency, the Danish Ministry of Climate, Energy and Building, Denmark has committed to having 50% of its total power supply come from wind by 2020. When wind energy makes up that large a portion of a country's total power, reliability of the conversion system becomes critical. This—together with the high-power connection to the grid, isolation safety requirements, and the cost of large renewable-energy conversion systems—means that system reliability is always the design priority, followed by efficiency. Therefore, protection features and reliability are preferred at all levels, from the controller all the way down to the FET/IGBT driver itself.

Typical power-management configuration

High power levels lead to higher system voltages, and therefore higher standoff voltages, for the components used within the converter. For lower power loss at greater than 400 V, most circuit designers prefer to use insulated-gate bipolar transistors (IGBTs) or the latest silicon carbide (SiC) FETs. These devices can have standoff voltages of up to 1200 V, with lower ON resistance than equivalent Si MOSFETs. These complex power systems often are managed by a digital signal processor, a microcontroller, or a dedicated digital power controller. Thus, they usually require both power and signal isolation from the noisy switching environment of the power stage. Even during steady-state switching cycles, the circuit can see massive changes in both voltage and current that can create significant ground bouncing.

Figure 1. Simplified power flow from wind turbine to grid

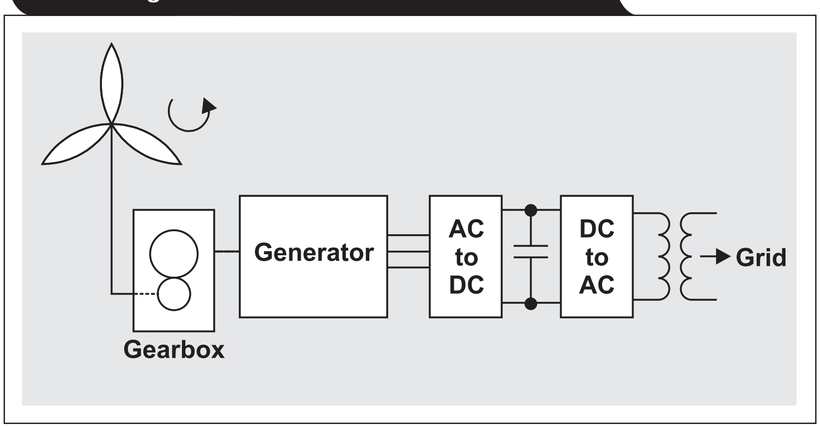


Figure 2. Basic structure of single-phase inverter

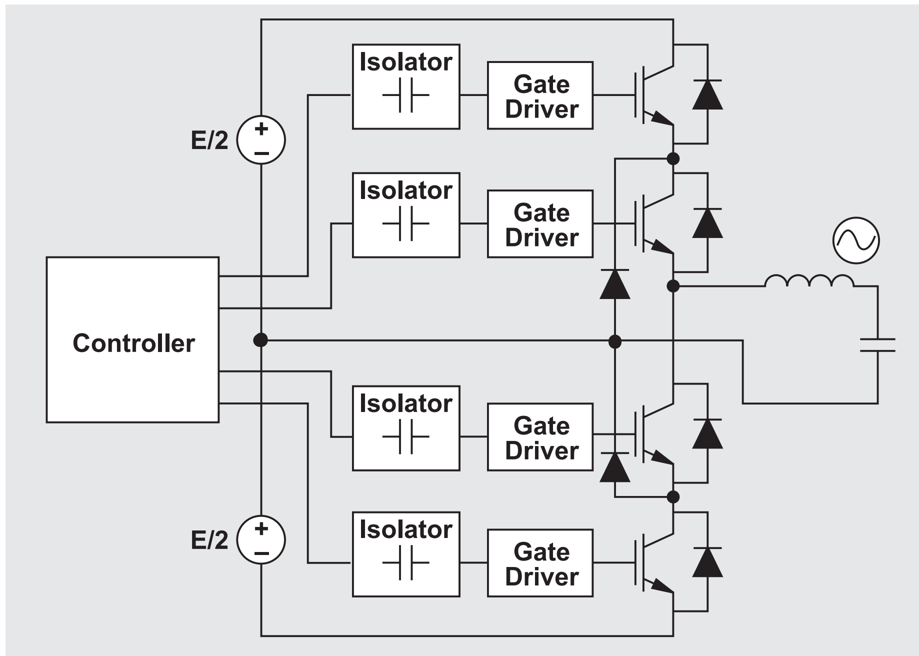
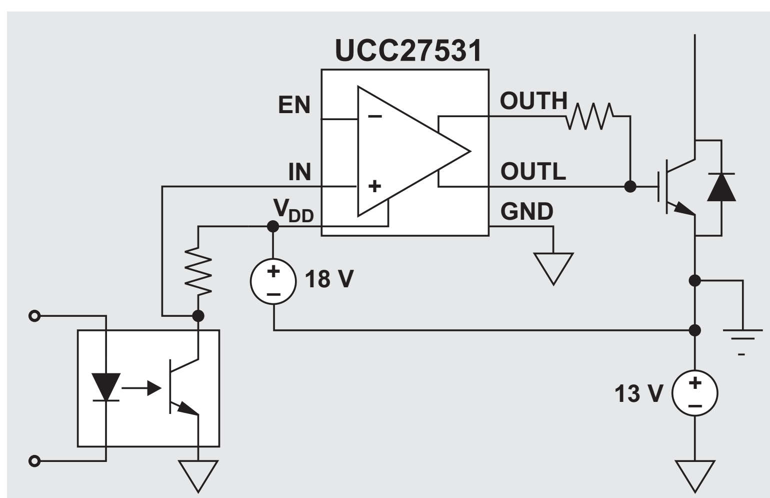


Figure 2 shows that even for a single-phase DC-to-AC inverter, there are many gate drivers needed to properly switch the IGBTs in the power stage. As a single-channel gate driver, the Texas Instruments UCC27531 can drive any of the switches in the switch bridge if it has the necessary signal and bias isolation. Signal isolation is achieved by using an optocoupler or digital isolator. For bias isolation, the designer can use a bootstrap circuit with a diode and a capacitor, or an isolated-bias supply. Another option is to connect the gate driver on the same side of the isolation as the controller, then drive the switch through a gate transformer after the gate driver itself. This option allows the driver to be biased with a non-isolated supply on the control side.

Gate drivers in renewable energy

As a small, non-isolated gate driver, the single-channel UCC27531 is a good fit for the environment described. Its input signals to the IC are provided by an optocoupler or digital isolator. Its high supply/output-drive voltage range of 10 to 35 V makes it ideal for 12-V Si MOSFET applications as well as for IGBT/SiC FET applications. Here, a higher positive gate drive is typical, as well as a negative voltage pull-down on shutoff to prevent the power switch from false turn-on. Typically, SiC FETs are driven by a +20/–5-V gate driver relative to the source. Similarly, for IGBTs, system designers may use a +18/–13-V gate drive, for example (see Figure 3).

Figure 3. Driving a power switch with FET/IGBT single-gate drivers



Since the UCC27531 is a rail-to-rail driver, OUTH pulls up the power-switch gate to its V_{DD} of 18 V relative to the emitter. OUTL pulls down the gate to the driver's GND of –13 V relative to the emitter. The driver effectively sees +18 to –13 V, or 31 V from V_{DD} relative to its own GND. Further, the 35-V rating provides a margin to prevent overvoltage failure of the IC due to noise and ringing.

The split output with both OUTH and OUTL permits the user to control the turn-on (sourcing) current and turn-off (sinking) current separately. This helps to maximize efficiency and maintain control of the switching times to comply with requirements for noise and electromagnetic interference. Further, even with a split output, the single-gate driver maintains a minimum inductance on the output stage, preventing excessive ringing and overshoot. By having an asymmetrical drive (2.5-A turn-on and 5-A turn-off), the UCC27531 is optimized for average switch timing in high-power renewable-energy applications. Further, with the low pull-down impedance, this driver increases reliability by ensuring that the gate does not experience voltage spikes that could lead to false turn-on from the parasitic Miller-effect capacitance between the collector and gate for IGBTs and between the drain and gate for FETs. This internal capacitance can lead the gate to exceed the turn-on threshold voltage by pulling up on the gate when the collector/drain voltage rapidly increases during turn-off of the switch.

The input stage of the UCC27531 is also designed for high-reliability systems like renewable energy. It has a so-called TTL/CMOS input that is independent of the supply voltage, allowing for compatibility with standard TTL-level signals. It provides a higher hysteresis of about 1 V when compared to the usual 0.5-V hysteresis seen in classic TTL. If the input signal is lost and becomes floating for any reason, the output is pulled low. Also, with the large changes in voltage on the GND of the driver IC, it is possible for the input signals to appear negative if the GND bounces high during a switching edge. This driver addresses this concern by handling up to –5 V continuously on the input (IN) or enable (EN) during these events.

The UCC27531 comes in a 3 x 3-mm, industry-standard SOT-23 package, which is very competitive with a discrete two-transistor solution that has a discrete level shifter without negative-input capability or added protections. Beyond the obvious space savings, integrating the UCC27531's functions into a single IC package increases the system's overall reliability.

This single-channel driver is an attractive option because it can be located very close to the power-switch gate. Placement is more flexible than for a combination high-side/low-side gate driver in a single IC. This flexibility helps minimize the inductance between the driver and power switch and gives the designer better control of the switch's gate. Figure 2 shows how many high-power switches are in just a single phase of a DC-to-AC stage. Over a complete three-phase system with multiple conversions between DC and AC and back, and with boost stages of DC-to-DC conversion also needed in some applications, there becomes a need for many gate drivers. Each one must be strategically placed on the PCB to ensure a proper design.

Conclusion

In renewable-energy applications, conversion of power generated from solar arrays and wind turbines presents unique challenges to the system designer. These challenges include high voltages and power levels, meeting safety and reliability requirements, and the overall complexity of the completely interconnected system. Although gate drivers for power switches seem like a small part of the total system control and power flow, they are actually very important to the overall design performance.

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