Bodo´s Power Systems®

IGBT Switch Drivers

Eliminating power stages brings major improvements in efficiency, size and cost

Semiconductor power switching technology has improved vastly in the last few decades. Power MOS FETs and IGBTs today are unrecognizable next to their counterparts from 25 years ago. Power switches used to be physically large, expensive and challenging to keep within their safe operating area (SOA). Now, they are small, affordable and rugged.

By Tom Lawson, CogniPower

The improvements in components were made incrementally, over the years, with gradual improvements in power converters, to match. This evolutionary trend toward higher speed, higher efficiency and improved reliability will surely continue. However, at some unremarked point along the incremental path, an opportunity opened for vastly more capable and tractable power converters.

Better power switches are essential, but not sufficient. Better switch drivers are needed, as well. Using switch drivers intended for previous generations of power semiconductors can make it impossible to take full advantage of the newer, more capable parts. With better switches and better switch drivers, entirely new topologies become practical, but also, there are evolutionary benefits for more conventional designs.

As Rds ON and Vsat ratings continue to fall, a larger percentage of total switching losses are resistive losses incurred during the actual act of switching. The push toward higher operating frequencies only emphasizes that trend. Faster transitions are required for efficiency, which means substantial peak currents are needed to drive the gate capacitance quickly through the active region. It is a non-trivial problem to increase the current drive capabilities of an existing gate driver. Paralleling drivers raises timing concerns, and increases system cost, so there has been a tendency to make do with transitions that are slower than optimal.

Better switch drivers are now available for faster switch transitions and tighter timing control. Now, precision can be maintained over a greater range of duty cycles at a given frequency. In addition, tighter timing shrinks the dead time required to prevent shoot-through in a totem pole switch or half-bridge. Reduced dead time reduces inductive overshoot. Snubber circuits used to absorb voltage spikes are bulky, expensive, inefficient and often need heat sinking.

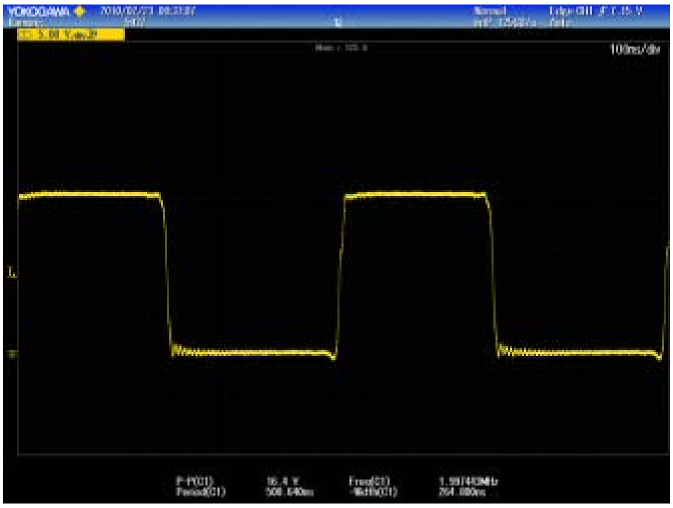

Figure 1: 1 kW FET totem pole running at 2 MHz, with 15 volt swing, no snubber

Figure 1 shows the performance of an ultra-low inductance totem pole constructed of MOSFETs in IR's Direct FET® package. The totem pole can deliver almost 1 KW of power, and is shown switching 15 volts at 2 MHz. Precise control of the high side switch is here obtained using a proprietary technique that allows dead times of a few nanoseconds, and in such circuits, every nanosecond matters. There is no snubber present, or needed. The stray inductance of this totem pole calculates to under 200 pH. A totem pole of this sort can operate efficiently at up to 10 MHz. CogniPower first showed this switch and driver combination at APEC 2010.

There are three essential elements for achieving this level of performance: better semiconductors, better switch drivers, and better control of stray inductance. Packaging improvements in FETs and IGBTs are enabling lower inductance structures, but system design also needs to focus on minimizing stay inductance. Simply placing faster switches in an existing system often leads to only marginal improvements because two of the three necessary elements are missing.

Smaller, faster parts should lead to physically smaller power converters running at higher frequencies, but that is not the general case. The „expedient“ approach to suppressing switching spikes points in the opposite direction. Expediency brings a series of compounding inefficiencies which all add to wasted energy and consequential heat buildup. Problems associated with heat removal can quickly dominate thinking regarding performance, size, reliability and cost. All too often the answer is to beef up the snubber, slow down the switching, and finally to enlarge the fan until the assembly stays under the temperature limit.

Concentrating on avoiding heat generation in the first place puts a design on the positive side of the list of compounding effects. Improved power switching semiconductor technology is only the starting point. Lowering inductance is key. Any length of wire has inductance. One inch of 18 gauge wire has about 20 nH of self inductance. For two parallel conductors, the inductance goes down with decreasing distance between, and down with increasing distance around the conductor cross sections. That explains why magnet wire, with its very thin layer of insulation, makes lower inductance twisted pair wiring than hook-up wire with its thick insulation. That also explains why stacked, thin conductive plates make lower inductance connections than round wire. In all cases, loops carrying significant currents should be kept as short as possible, and their loop area should be minimized.

Notice that there are a number of factors here that conspire to send a designer down a slippery slope. High voltage spikes caused by stray inductance force the selection of higher voltage parts, which will be physically larger, which in turn will increase the loop area. Higher voltage parts are more capacitive, which slows them down, requiring increased dead time. Slowing of switching speed will limit voltage stress but will increase thermal stress. A larger heat sink will likely mean longer connections and more loop area, again leading to increased inductance. Adding suppression components will help mitigate voltage spikes, but will not provide escape from the slippery slope because snubbers and clamps work by dissipating stray energy as heat. The easy solutions, in the end, usually involve increasing air velocity, which may go a long way toward explaining the debilitating fan noise inside many data centers. And, just because the air conditioning costs appear in a different budget doesn’t mean they are not real.

All of the above argue for designing efficiency in at the beginning of the design cycle, instead of adding it on at the end. Striving for clean switching waveforms all the way from start to finish brings efficiency, as well as other benefits. Those benefits include reduced EMI, increased reliability and more speed. Stray inductance causes energy storage where it is not wanted or needed. Inductors are well known for their whack-a-mole ability to resist suppression. Resonances are set up between stray inductance and capacitance: inductive energy vanishes into capacitive energy and then reappears as inductive energy, depending on when you are looking. Quick fixes either waste stray energy as heat, or produce unexpected consequences.

Even with an optimized power switching geometry, there will still be a maximum switching speed beyond which voltage overshoot becomes a limiting problem. In systems with controlled stray inductance, a very capable switch driver is required to approach those limits. In the case of Econo-Dual IGBTs, gate capacitance can be substantial. Switching a gate with 100nf capacitance from -15 to +15 volts in 200ns requires a peak gate current of almost 30 Amps. It is difficult to speed up a switch driver already running at its limits. CogniPower switch drivers were designed to handle more demanding applications from conception.

Figure 2 shows a fully isolated half-bridge switch driver capable of delivering peak gate currents of 30 Amps. It produces near-ideal gate drive waveforms, so a system can be optimized based on the switches themselves, instead of on the complex interaction of the limits of the switches and their drivers.

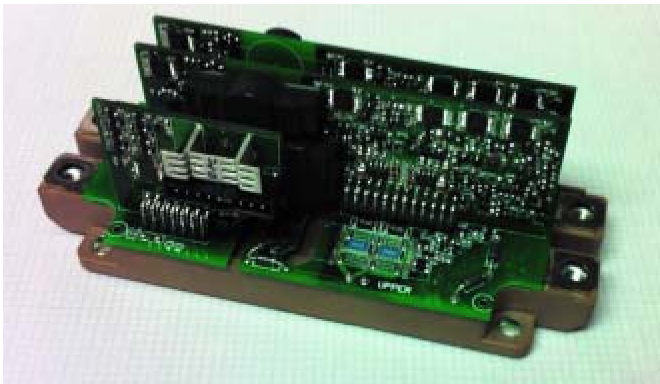

Figure 2: CogniPower fully isolated half-bridge gate driver on Econo-Dual IGBT power module

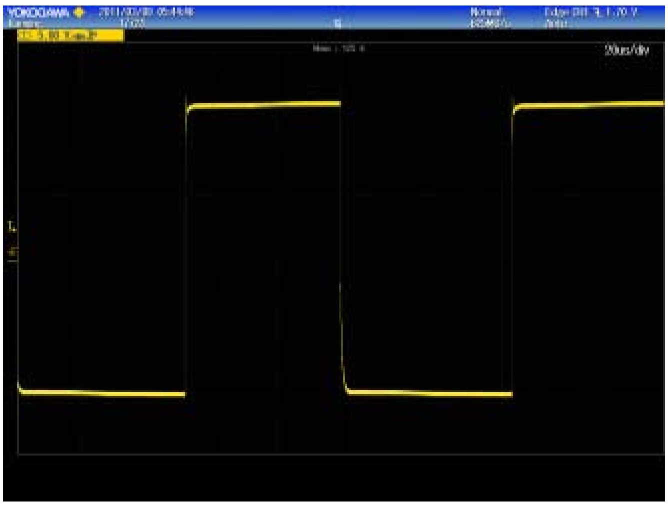

Figure 3: Gate drive waveform of CogniPower Switch driver running Econo-Dual IGBT module

Figure 3 shows the lower gate drive waveform of the pictured system running at 20 kHz. The nominal gate drive voltage is +/- 15 volts. Note the fast transitions through the active region.

20kHz is fast for these types of modules, but with near-ideal gate drive signals, the limits of the modules, themselves, can be extended.

Figure 4 is a detail of the gate depletion with a depletion resistor of 1.1 ohms. The gate swings through the active area in under 50ns. The switching loss, then, will depend almost entirely on the characteristics of the switch itself, and not on extra time spent in the linear region. These faster transitions extend the maximum attainable frequency of operation.

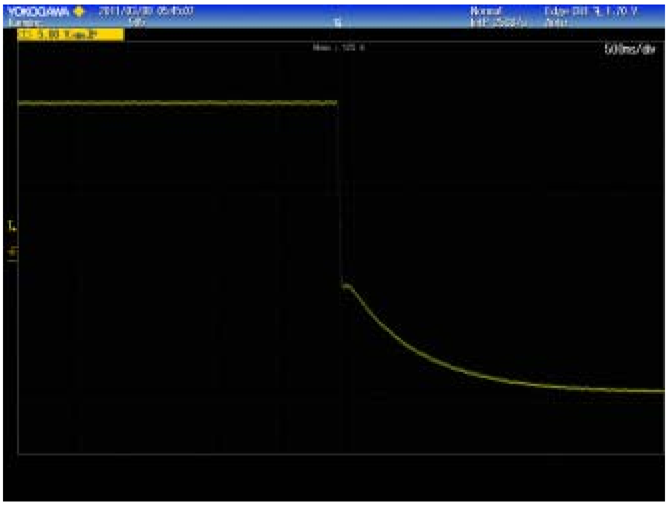

Figure 4: Detail of gate depletion

The advantages of higher operating frequencies are well understood. Benefits include better transient response and physically smaller magnetics and filter capacitors. Emerging switch technologies like SiC and GaN promise to break through to much higher frequencies of operation. CogniPower drivers are ready with the timing precision and power handling needed to take full advantage of the capabilities of these new switch types. CogniPower IGBT drivers can operate up to 1 MHz, far beyond the limits of present Econo-Dual IGBTs, but completely appropriate for other power switching technologies.

Faster switching places a premium on the dv/dt immunity of the isolation barrier. Optical isolation is often used for convenience, but optical isolators are near their limits even without the higher dv/dts now encountered. CogniPower switch drivers use only transformer isolation, and the coupling capacitance across the transformer isolation is kept very low for superior immunity. There are other good reasons for avoiding optical isolation when pushing switch drivers to the next level. Optocouplers are relatively slow and capacitive, and they limit the attainable voltage isolation as well as the dv/dt immunity. Optocouplers vary unit to unit more than other semiconductors and they show larger aging effects, all of which limits timing accuracy. They also tend to be the first point of failure, limiting reliability.

There is one case where conventional transformer isolation is more limiting than optical isolation: error reporting. In the event of desaturation, it can be essential to quickly transmit error information and act upon it. This situation is particularly critical in the case of multi-level systems where all the control activities originate on the unisolated side. A conventional transformer isolator is able to send information in only one direction at a time. That causes blackout periods when switch data cannot be sent to the isolated side, or when error information cannot be sent back. Relying on the ability of the power switches to survive at the fringes of their SOA while waiting for a switch driver communications blackout period to end is suboptimal. Some data isolators use two transformers, one for each direction of data flow, but that approach adds size and cost and stray capacitance. That extra capacitance degrades dv/dt immunity. The best answer is to allow full, simultaneous, bidirectional communications through a single transformer isolation barrier. CogniPower switch drivers employ patent-pending technology for single-transformer, full-duplex communications. That unique ability allows both performance improvements and cost reductions.

Other features of CogniPower switch drivers include overvoltage and overcurrent protection for the drivers, and an undervoltage lockout circuit for the isolated side of each driver. For improved efficiency, synchronous rectification is used in the isolated power supplies. A minimum ON or OFF cycle time protects the power switches. The input logic voltage is selectable to 3.3, 5 or 15 volts. For maximum reliability, no electrolytic capacitors are used. The drivers operate in half-bridge or direct mode, and can accommodate multi-level systems. The CP-ECD-5W series driver shown provides 5 Watts of power per gate. An option is available for these drivers to supply 9 Watts per gate of average drive power. That is enough to drive an ordinary Econo-Dual module at about 100kHz, faster than practical. The extra power could be used to drive, say, four paralleled modules at 25kHz. If even more power is required, the precise timing allows multiple switch drivers to be used in parallel.

CogniPower switch drivers open a path to more capable power converters. Switched energy can be managed more aggressively given more responsive power switches. New topologies are becoming practical. The ability to handle wider voltage ranges and more extreme duty cycles opens opportunities for skipping entire stages of power conversion. Eliminating power stages brings major improvements in efficiency, size and cost. For more conventional designs, cleaner switching benefits can be enjoyed in the form of higher operating frequencies, higher efficiencies, reduced snubbing requirements, smaller physical size, smaller fans, cooler operating temperatures or a combination of those benefits.

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