Optimizing the Switching Stage in Wind Power Applications

Efficient power conversion is an important part of maximizing the cost-effectiveness of the switching stage in a wind-powered generator. Much effort has been expended in maximizing switching efficiency with excellent results. In this article, we will look at optimizing the utilization of the switches to increase the amount of power that can be processed by a given system. This, in addition to the benefits obtained by optimized switch driving, can show an increase in power throughput for a given system by >20 %.

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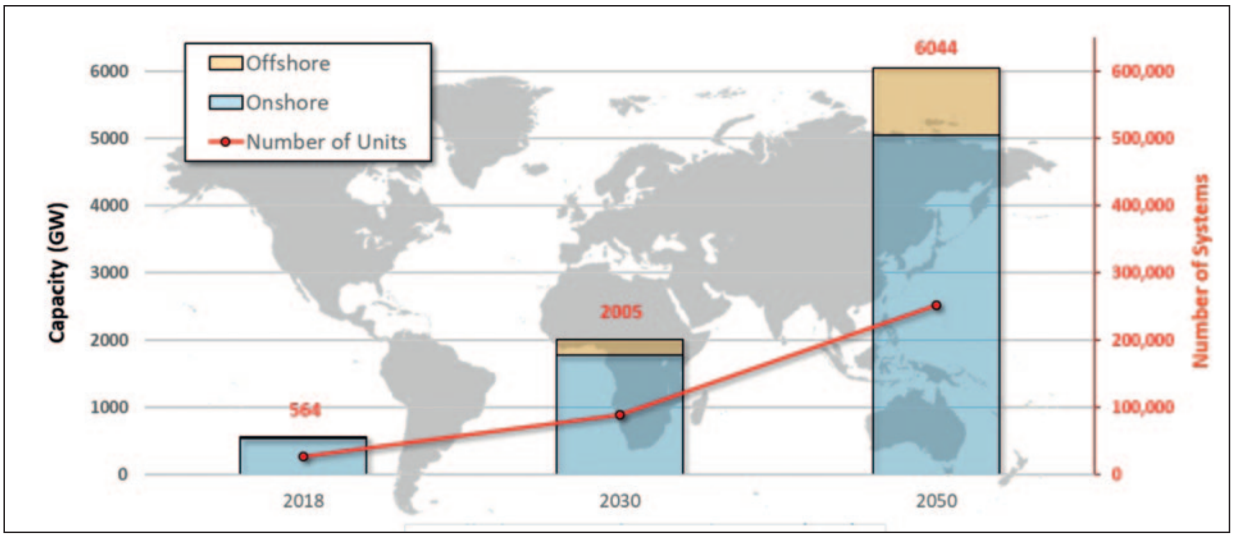
A rapid expansion in wind-powered energy generation has already begun (Figure 1). A typical 10 MW windmill will require up to 40 dual IGBT drivers in the two inverter stages alone.

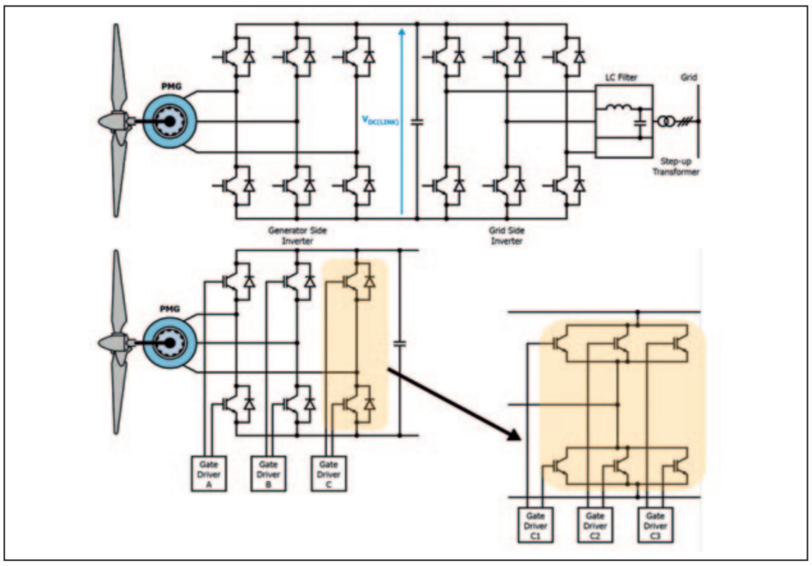
Maximizing DC rail voltage (DC-link) in an inverter

Typical wind-power inverter stages employ multiple groups of parallel-mounted IGBT modules (Figure 2), which offer more cost-effective and space-efficient implementation than single, large IGBT units. The factor that controls the maximum DC-link voltage (and therefore power) that can be processed by a given inverter stage is the maximum operating voltage that can be tolerated by each IGBT. The DC-link voltage must be set below the maximum rated IGBT blocking voltage to account for voltage overshoot during shutdown. By more accurately controlling the amount of voltage overshoot, it is possible to reduce the required voltage margin, raise the nominal DC-link voltage and process more power from each IGBT module.

Controlled turn-off of the gate driver –



ABOVE Figure 1: **Anticipated worldwide growth in wind power suggests a >10X expansion of wind power use by 2050 (IRENA 2019d)**



RIGHT Figure 2: **Simplified view of a four-quadrant wind inverter showing multiple parallel switches and their associated gate drivers. Each dual IGBT module processes the same DC-link voltage and (ideally) equally shares current with the other parallel modules**

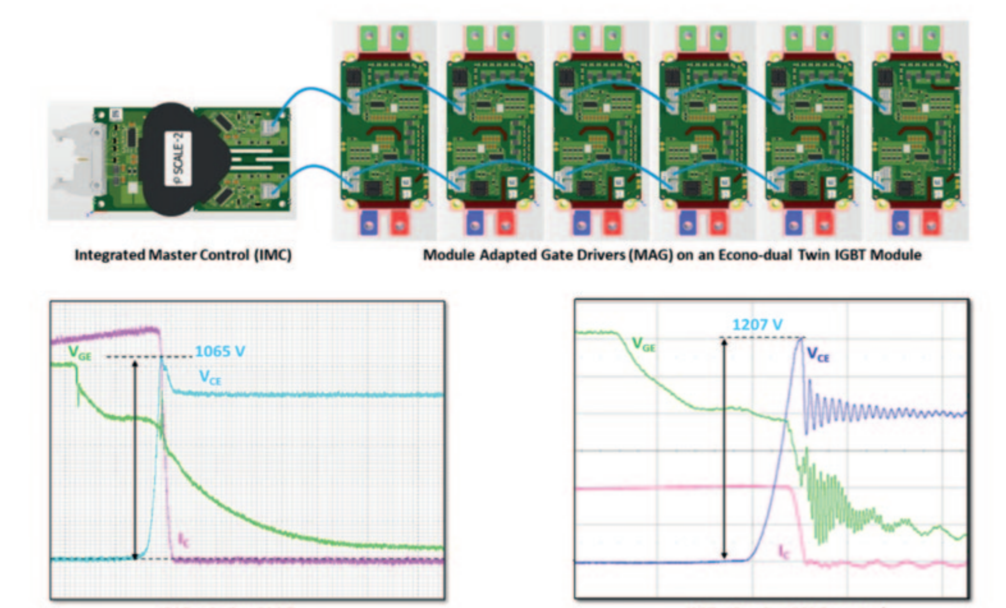


Figure 3: Controlled turn-off of the gate driver - IMC and MAG – SCALE-iFLex™ LT combines an MC module with active MAG drivers mounted on EconoDUAL 3 IGBT modules (a, top); and maximum voltage seen during short-circuit shutdown with a conventional passive gate drive circuit compared to a combination of IMC and MAG modules for low DC-link inductance (b, bottom)

Active Clamping (AC) and Advanced AC (AAC) – is most effective when active monitoring and shutdown circuitry is located near the switch as shown in Figure 3a. Figure 3b compares the clamping performance that can be obtained using a conventional passive detection architecture relying on a Master Control (MC) unit, and that which is obtained using an Integrated Master Control (IMC) that provides isolation and timing signals and Module Adaptive Gate drivers (MAG) with active drive circuitry mounted directly onto each gate driver to minimize the impact of parasitic circuit inductances and propagation delay.

In AAC control, the VCE voltage is monitored as the IGBT is turned off. Active drive via a control ASIC is used to modulate the gate drive to limit current slew rate, which in turn prevents the DC-link voltage from rising to excessive levels. Reducing the value of RG(OFF) in the discrete solution would improve clamp control, but it would reduce switching efficiency. The clamping voltage that can be obtained using the fast response of the MAG-based control can be shown to provide 10 % safety margin for an 860 VDC link voltage. By using the appropriate active clamping approach and positioning the detection and protection circuitry on the switch module, a higher nominal DC-link voltage can be selected which delivers >9 % more power in a given system.

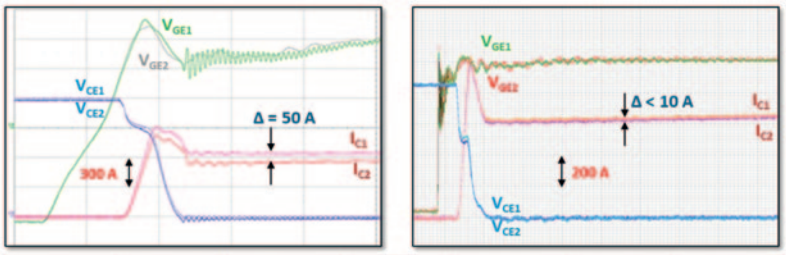
Current sharing

As shown in Figure 2, many wind turbine systems employ multiple IGBT dual modules in parallel. In a perfect system, the gate drives for each module would be identical and the IGBTs themselves would present similar impedance during conduction, resulting in equal current sharing. Total system current could be set at the maximum current per module multiplied by the number of systems in parallel.

Any imbalance in actual operation would lead to some modules working harder – creating increased heating in those modules. To prevent damaging overworked modules, the nominal current for each module would need to be reduced. So, using similar reasoning as was applied to the voltage calculation, by ensuring accurate current sharing, the power through each module may be higher, allowing more system power to be provided from a given IGBT arrangement.

Switch timing and gate-bias must be precisely matched between each switch module. Again, the provision of local drivers and control of gate voltage allows for close matching. Figure 4a shows the difference in performance between matched gate drives (timing match shown in Figure 4b) and a gate driver configuration that employs passive modular drives. Unbalanced impedance between the drive feeds to each module causes timing mismatches and reducing sharing accuracy.

If the current delivered to each module



Input	Command	$T_{D(A)}$ (μs)	$T_{D(B1)}$ (μs)	$T_{D(B2)}$ (μs)	$T_{D(B3)}$ (μs)	$T_{D(B4)}$ (μs)
INA	Turn-on	2.04	2.05	2.06	2.06	2.06
INB	Turn-on	2.06	2.08	2.08	2.08	2.09
INA	Turn-off	1.39	1.40	1.41	1.41	1.41
INB	Turn-off	1.41	1.43	1.43	1.44	1.44

Figure 4: Switch timing and gate-bias must be precisely matched between each switch module - comparison of current sharing between adjacent IGBT modules using passive MAGs (left) and actively driven MAGs with bias control (right). Nominal current is 600 A per module (a, top); and timing match for an actively driven MAG (SCALE-iFlex LT) showing timing mismatch across four modules of less than 20 ns. $T_{D(A)}$ shows the time delay for the switching signal induced by crossing the isolation barrier of the IMC (b, bottom)

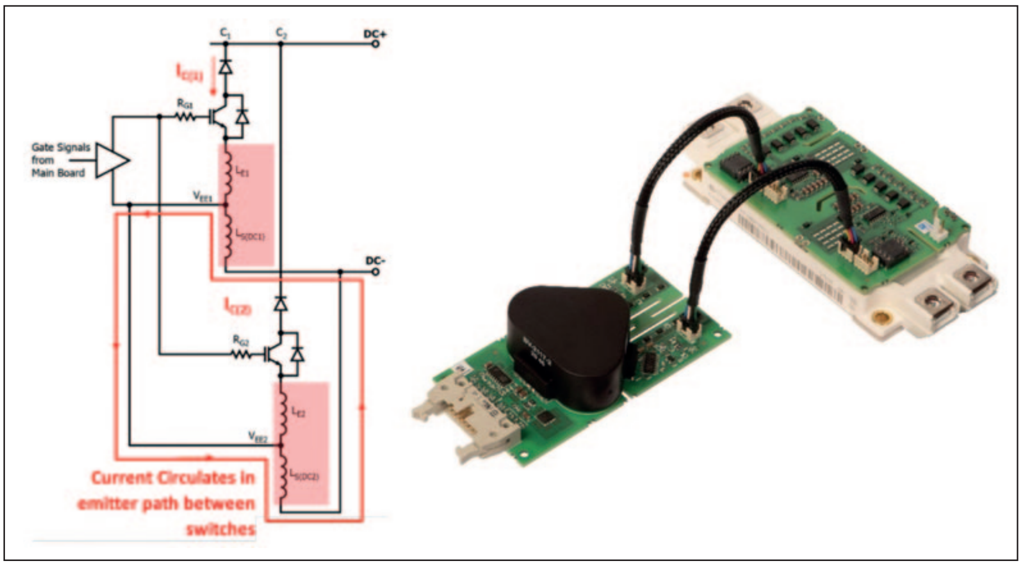


Figure 5: Large loop areas between the IMC and passively-driven gate drive modules create large parasitic inductance that can cause circulating common mode currents which limit switching frequency and can cause significant timing mismatch – often sufficient to cause jitter between modules

is close (within approximately 5-10 %), the module will naturally compensate and balance the collector currents due to the heating effect on RCE(ON), which has a positive temperature coefficient. Under these circumstances, current sharing will be very good once thermal equilibrium is reached in the system.

To reduce common mode currents flowing between modules (Figure 5), it is important to reduce the loop area (and therefore parasitic inductance) as much as possible. The propagation delay associated with large emitter loops can be in the order of 800 ns with mismatch of as much as 80 ns between modules. Active gate drivers located on the IGBT module (MAGs), which reduce the loop area and common mode chokes, are effective in reducing common mode currents. As well as reducing current sharing, gate drive can be challenging, being susceptible to EMI which can cause false triggering – a phenomenon only partially addressed by passive filtering.

Current imbalance between adjacent modules of an inverter phase means that an active MAG approach can increase output power by as much as 15 % compared to that achieved with a passive module drive stage with less accurate current sharing.

Optimizing gate drive for highest switching efficiency

The role of gate resistance in controlling the switching loss (especially turn-on loss) in an IGBT is well known. An actively driven gate signal located on the local MAG is able to support a low impedance gate drive for turn-on and turn-off. Turn-off losses are relatively constant compared to gate resistance, but the low gate impedance is important in preventing voltage overshoot during shutdown. The turn-on resistance of the gate-driver stage strongly influences switching loss, and there are important efficiency benefits associated with having a driver stage that can support a low on-resistance (0.7 Ω is shown in Figure 6) from a relatively high current drive stage. SCALE-iFlex LT can deliver up to 20 A of gate drive current per MAG channel due to the active drive-stage booster in the ASIC for each channel. Typical values for a discrete driver with remote driver stage will be in the order of 2-3 Ω.

With discrete local gate driver stages, it is often necessary to increase gate driver resistance on individual modules to achieve better load balancing between switch modules and, in discrete circuits to increase the effectiveness of the Active Clamp circuit. Optimizing drive to enable low gate resistance and better switching performance can increase overall switch efficiency by up to 3 %.

Conclusion

Combining the system utilization benefits of higher DC-link voltage and better current sharing with the efficiency that can be gained from localized gate drive, we can substantially increase system utilization efficiency. There is some crossover in parameter effect, so a straight addition of the benefits is difficult, but improvements in driver utilization of more than 20% are certainly possible. This suggests that with careful design and the utilization of active MAGs supporting the IMC, it is possible to remove one in five of the IGBT modules employed in a typical wind turbine inverter application – a very significant saving in space and material.

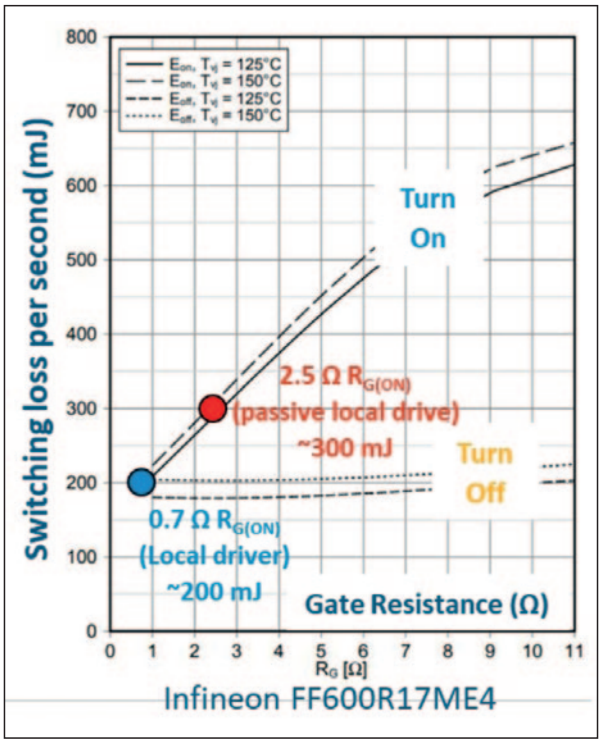


Figure 6: A localized active gate driver (MAG) is able to support a low gate drive resistance due to the buffered drive stage capable of delivering >1 A. This reduces turn-on losses by up to 50 % compared to the higher resistance typically needed to balance a passive gate driver stage

New Plug-and-Play Gate Driver Improves IGBT Module Performance by 20 %

Power Integrations announced its new plug-and-play SCALE-iFlex™ LT dual gate-drivers. The new drivers improve the performance of multiple parallel EconoDUAL modules by 20 %, allowing users to eliminate one of every six modules from power inverters and converter stacks. In addition to saving the cost of the driver and module, this reduces control complexity and costs related to modules, wiring, hardware, and heatsinking. SCALE-iFlex LT targets multiple applications in renewable energy generation and storage, and is particularly applicable to offshore wind turbines in the 3 to 5 MW range. Up to six EconoDUAL 3, or equivalent, power modules can be paralleled from the same Isolated Master Control (IMC) unit which has a more compact outline than conventional products. The Module Adapted Gate drivers (MAGs), which fit the footprint of the EconoDUAL module, each featuring two SCALE-2 ASICs – one per channel – to optimize symmetrical paralleling, efficiency and protection.

New gate driver eliminates one in six modules

"Dynamic and static current sharing is critical for robust operation of modules arranged in parallel. For the same power output, systems using SCALE-iFlex LT require just five parallel modules whereas competitive approaches need six. This substantial saving of cost and complexity is achieved by guaranteeing less than 20 ns of variance in turn-on and turn-off commands between modules and less than 20 A of variance between modules when conducting the rated 600 A. This allows the modules to operate reliably without current derating, which is obligatory with less advanced driver solutions," commented Thorsten Schmidt, product marketing manager at Power Integrations.

The new SCALE-iFlex LT gate-driver modules reduce switching losses by three to five percent, due to the fast turn-on and turn-off of the SCALE-2 ASIC which features an integrated booster stage. Advanced Active Clamping (AAC) protection enables higher DC link voltages to be achieved. A suite of other protection features, including short-circuit, are provided. Drivers feature reinforced isolation to 1700 V and may be ordered naked or conformally coated. As well as renewable energy, other applications include power quality, commercial air-conditioning units and medium-voltage drives. The new SCALE-iFlex LT gate drivers are available now.

Single gate drivers for "New Dual" modules

Single gate-drivers for the popular "New Dual" 100 mm x 140 mm IGBT modules are alo available. The compact new drivers support modules up to 3.3 kV and are suited for light-rail, renewable energy generation and other high-reliability applications that demand compact, rugged driver solutions. "SCALE-iFlex Single gate-drivers fit the outline of the latest standard IGBT power modules including the Mitsubishi LV100/HV100, Infineon xHP2 and xHP3, ABB LinPak, Hitachi nHPD² and other similar products, " Schmidt added.