Innovative IGBT Driver IC Resolves Dilemma of Gate Resistor Selection

The use of motor line inductors, dv/dt filters or sine wave filters helps to adapt the variable frequency inverter with its fast switching IGBT to the motor. This is normally much easier than an individual adaption to the application requirements of the inverter itself by individual selection of gate resistors. However, such a dv/dt filter increases the price, losses and size of a variable speed drive. This article describes a smart way to implement an easy-to-use adaption by means of an intelligent selection of an IGBT gate driver IC combining both, lower EMI and higher efficiency. **Dr. Wolfgang Frank, Infineon Technologies AG, Germany**

The operation of modern variable frequency inverters with pulse width modulation techniques results in a lot of negative side effects to motor drive applications. These side effects are e.g. degradation of the winding insulation in both non-potted windings and especially in potted ones, inverter operation with shielded cables [1], and motor bearing degradation. Especially voltage reflections at the motor clamps show a voltage doubling effect which, according to Figure 1, can already be measured after a few meters of cable length. Since this doubling effect occurs at every turn-on of the IGBT, the winding insulation degrades over time and reduces the lifetime of the motor as a consequence.

A simple countermeasure is to use dv/dt filters. However, the implementation of such filters leads to losses [2], which can be considerable especially in the lower motor power ranges. This has a negative impact on the efficiency of variable speed drives. Investigations already showed that the cost for filters or other countermeasures to limit the dv/dt are expensive [3] compared to the cost of the drive. The filters consist of inductors, capacitors and resistors. Therefore, the inductors have a reactive voltage drop, which reduces the motor voltage. The filters are also usually a limiting factor for the switching frequency of the inverter. A switching frequency up to 16 kHz is difficult for most dv/dt filters and also a derating of the filter must be considered in terms of motor current frequency and temperature.

Dilemma of gate resistor selection for turn-on

The proper selection of the turn-on gate resistor contributes significantly to the EMI characteristic of a frequency inverter. Because of the excellent switching behaviour of modern IGBTs, design engineers want to make use of their fast switching capabilities. On the other hand, power diodes show the tendency to tear off the current, when a relatively low diode forward current commutates to an IGBT. The results are strong, high-frequency oscillations as given in a) of Figure 2 as well as a high dv/dt. These oscillations may even damage the diode or IGBT. Therefore, some IGBTs have integrated gate resistors which prevent damage, but not oscillations.

The high-frequency portion of the collector current is certainly influencing the conducted EMI spectrum. This is visible in a range, where the line filter is not active any more. Therefore, the oscillations must be avoided in any case.

The second picture b) of Figure 2 depicts the commutation of the same forward current when using a turn-on gate resistor of 1.5 Ω instead of 0 Ω in the measurement of a) in Figure 2. This small difference in the gate resistance has a large influence on the switching behavior. All oscillations vanish and the turn-on is stable.

In order to prevent EMI hardware engineers typically select a higher gate resistance. However, as a disadvantage a higher gate resistor slows down the turn-on speed of the IGBT at higher collector currents. The turn-on behavior at collector

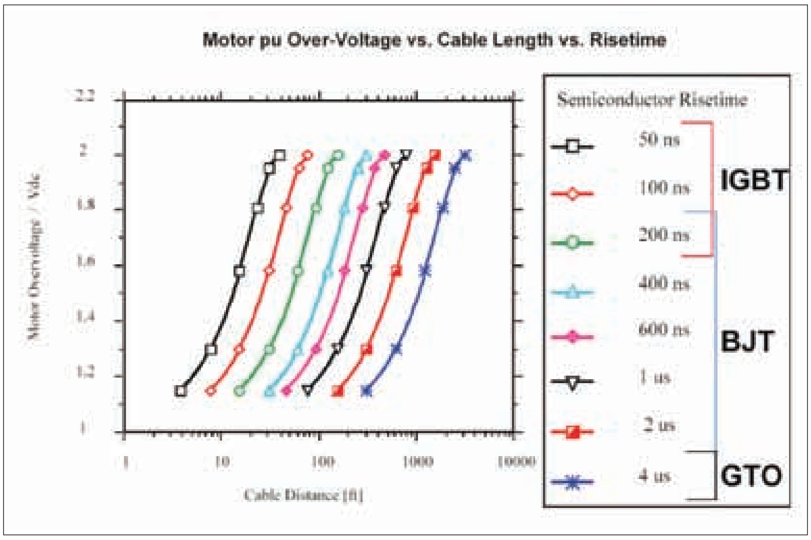

Figure 1: Motor per unit over-voltage as a function of the cable length and rise time of power transistors [2]

Figure 2a

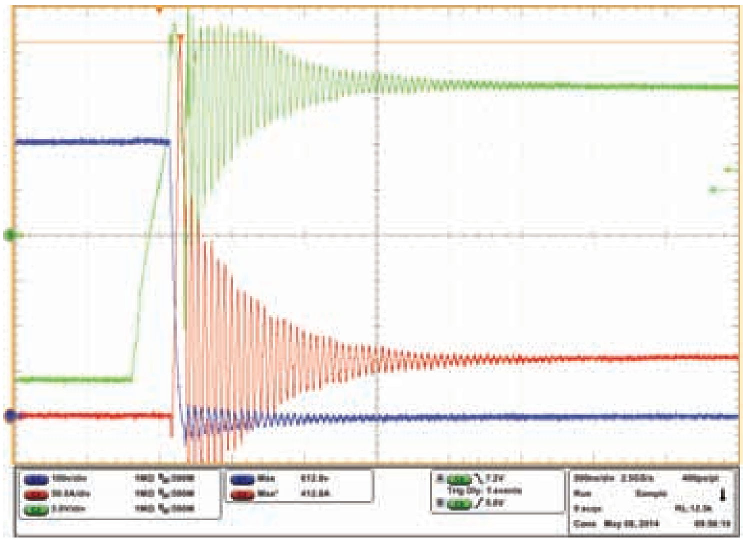

Figure 2b

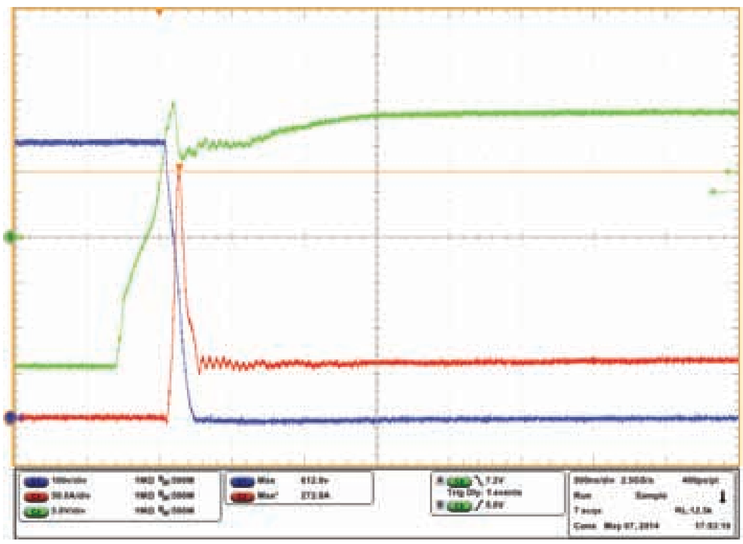

Figure 2: Commutation of low currents at 10 % of nominal current level (a: R_{Gon} = 0Ω, b: RGon = 1.5Ω; V_{DC} = 600V; I_C = 60A; -15V < V_{GE} < 15V) with collector-emitter voltage (blue), collector current (red) and gate-emitter voltage (green) with a standard gate driver

current levels above e.g. 15 % to 20 % of the nominal current is not tending to oscillate any more. Fewer losses will be achieved, if a lower gate resistor is used in the operating area above.

The dilemma described can be resolved with the new gate driver IC EiceDRIVER™ 1EDS20I12SV. It can softly turn-on the IGBT when it is operating at low collector current levels and it can also quickly turn-on at high collector current levels. This is made possible by a user controlled current source providing 11 different levels. These levels can be selected by the system control pulse-by-pulse in real-time.

Gate current control IC during turn-on process

The most innovative feature of the new EiceDRIVER is its gate current control function. It divides the turn-on process into three sections according to a) in Figure 3: The first section (t0 to t1) is the charging from a negative voltage to a defined value in the range of V_{GE} = 0. This section is called the pre-boost section and lasts for a fixed duration of t_{PRB} = 135 ns. The preboost current level I_{PRB} during this phase is adjustable for each individual IGBT type. The second section (t_1 to t_3) is the turn-on control section. The instantaneous constant gate drive current I_{gg} can be adjusted within 11 different values. The IGBT gate voltage passes the Miller voltage level during this time. The practical application of the device proposes usually a smaller turn-on gate current I_{gg} compared to the preboost current I_{PRB}. Nevertheless, it is also possible to achieve even larger turn-on currents Igg than the preboost current I_{PRB}. This is shown in b) of Figure 3. Finally, the gate capacitance of the IGBT is fully charged correlating to the desired gate voltage level in section 3 ($t > t_3$).

The used gate driver IC is able to control the dvCE/dt transient of the IGBT by selecting a suitable current level during section 2. The turn-on delay time $t_{d(on)}$ is constant and predictable. This has an effect on the design of the IGBT dead time and the motor current control loop, offering additional potential for improvement.

The IC controls the gate current by means of a closed loop with the controlled current source circuit, which consists of a p-channel MOSFET and a current sense resistor. The current source is extremely precise with a tolerance of ± 10 % during

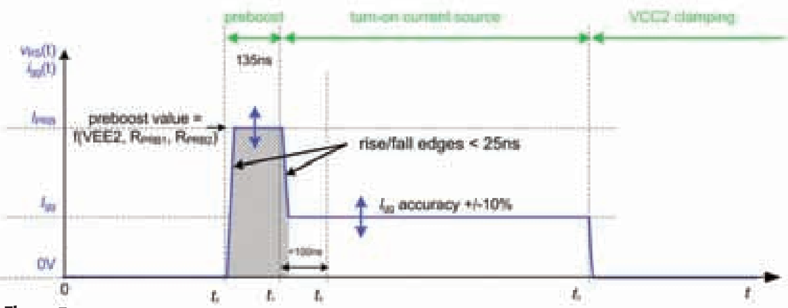

Figure 3a

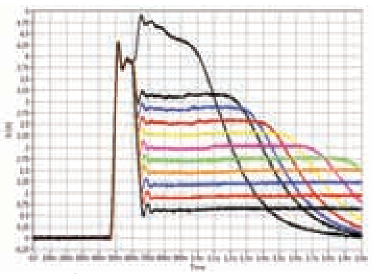

Figure 3b

Figure 3: The three phases of a turn-on process with (a) theoretical waveforms for gate current (blue) and voltage (green) and (b) example of measured waveforms of gate current for speed levels 1-11

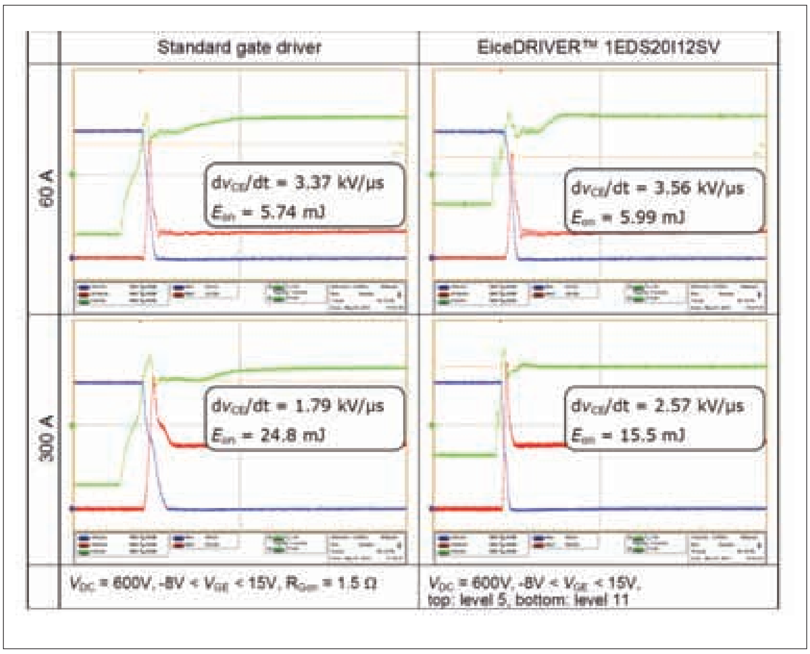

Figure 4: Large advantage of more than 40% with 1EDS0I12SV regarding turn-on energy compared to standard gate driver in a gate driver design example showing the collector-emitter voltage (blue), the collector current (red), and the gate-emitter voltage (green)

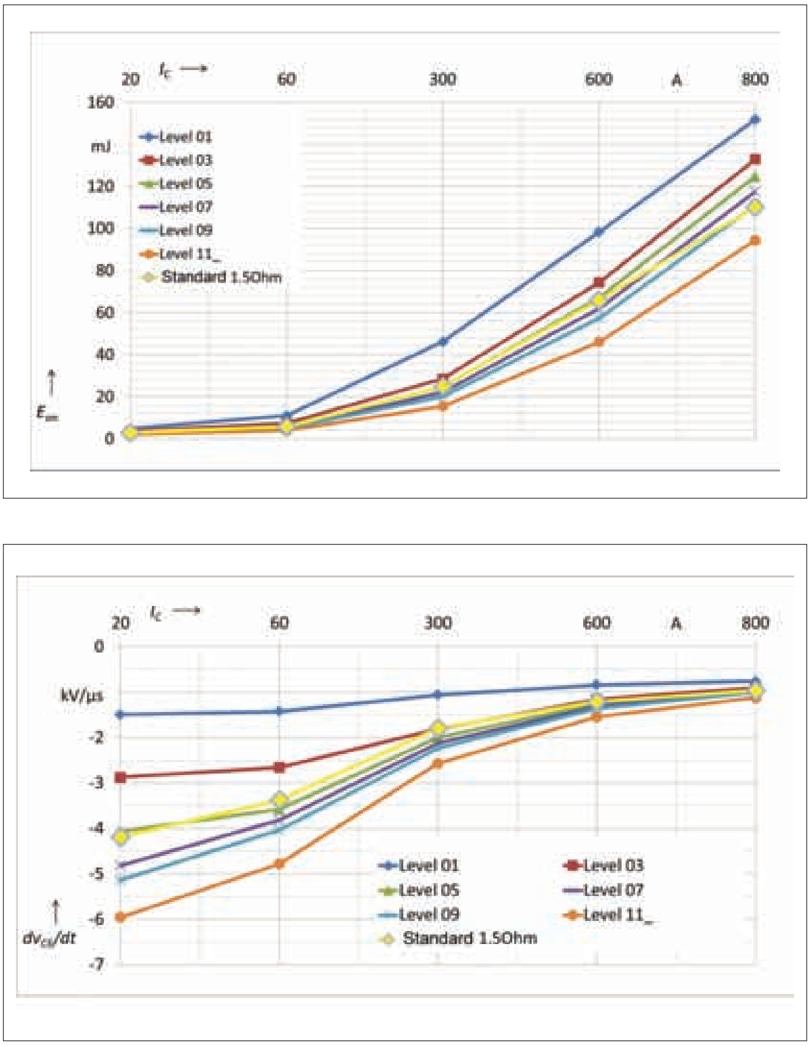

Figure 5: Example of dv_{CE}/dt range (bottom) and turn-on energy E_{on} of 1EDS-SRC gate current control IC for speed level 1, 3, 5, 7, 9 and 11 compare to standard driver at IGBT junction temperature of 25°C

the turn-on phase. This solution is more cost efficient than a similar setup using bipolar transistors. Additionally, the p-channel MOSFET provides a rail-to-rail capability, which is not possible with bipolar transistors. The Driver IC can control in total up to three p-channel MOSFETs (BSD314SPE) in parallel, which covers a range of current classes of up to 900 A of 1200 V modules.

Effect of gate current control IC on transient collector-emitter voltage at turn-on

The adjustability of the controlled gate current of the EiceDRIVER 1EDS20I12SV allows the design engineer to change paradigms concerning the switching speed of the diode. An excellent EMI at low load condition of a frequency inverter can now be combined with a high efficiency at high load conditions, which is given in Figure 4. Another advantage is the turn-on propagation delay, which is more predictable compared to a pure resistive turn-on.

The standard gate driver uses the gate resistor value of the module datasheet. This is 1.5 Ω for FF600R12ME4 from Infineon Technologies. The selected 1.5 Ω leads to a turn-on energy of E_{on} = 24.5 mJ at 50% of nominal current. On the other side the 1EDS20I12SV shows similar switching behavior at low currents. The turn-on energy as well as the turn-on voltage transient dv_{CE}/dt are almost the same. The tremendous advantage is visible at high currents. A smaller turn-on energy of E_{on} = 15.5 mJ is achieved. This value is 40 % lower than the turn-on energy of the standard gate driver. Thus, the usage of the new gate driver IC results in a considerable improvement of the overall efficiency.

The example of a gate driver design was developed to investigate more detailed the relation of the various speed levels of the EiceDRIVER as a function of the collector current. Since the gate current control loop allows for several degrees of freedom, there are even greater advantages for 1EDS20I12 possible.

The bottom part of Figure 5 shows the range of dv_{CE}/dt rate over various speed settings and collector amplitudes. It can be seen, that the control range of the gate current control IC is sufficient to cover the same range as with a common fixed gate resistor control, while enabling the advantage to change the dv_{CE}/dt rate pulse-by-pulse during operation. For this reason the commutation speed is not limited to a single curve. In fact, it can now cover even a full area of possible dv_{CE}/dt values. The dv_{CE}/dt area can be above or below the "nominal" dv_{CE}/dt line which is

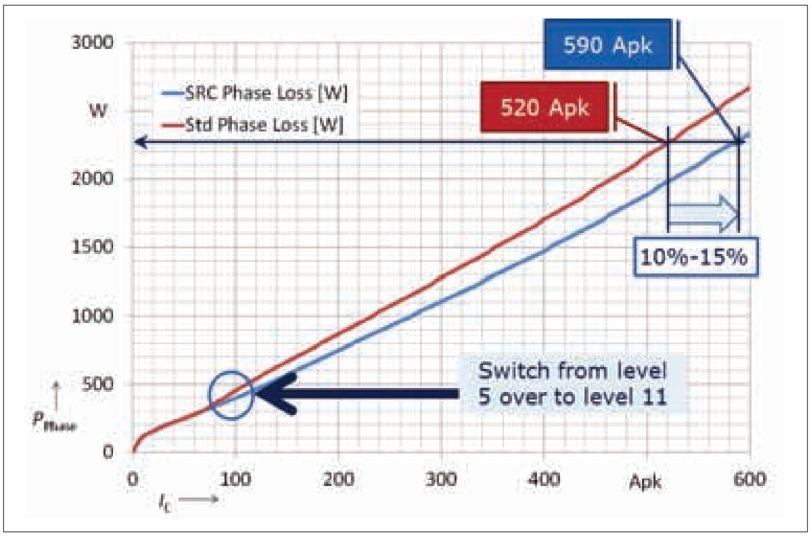

Figure 6: Calculated power losses per phase show a gain of 10 % - 15 % in respect to output current with slew rate control (blue) over a standard driver (red) (V_{DC} = 600 V, -8 V < V_{GE} < 15 V, f_P = 15 kHz)

achieved with the nominal gate resistor of 1.5 Ω. Figure 5 proves that it is now possible to stay below the critical values of dv_{CE}/dt in the application by setting the commutation speed according to the instantaneous electrical conditions of the application.

Figure 6 shows the improved calculated power loss of an EconoDUAL3 type FF600R07ME4 when using the EiceDRIVER 1EDS20I12SV only with level 5 for currents below 100 A peak and with level 11 for the instantaneous currents above 100 A peak according to Figure 5.

It can easily be seen that the slew rate control EiceDRIVER IC can gain approximately 10 % - 15 % more current using the same module compared with a standard driver circuit. The IC 1EDS20I12SV can therefore help to lower system cost by reducing e.g. the heatsink size. Aiming at higher power density, the new driver IC is obviously also supporting this goal.

Conclusion

This paper discusses the advantages of a novel and innovative EiceDRIVER™ 1EDS20I12SV gate current control IC, which uses a closed loop gate current control for turn-on. The advantages compared to dv/dt or sine wave filters are discussed. The turn-on properties can be adjusted pulse-by-pulse in real-time during operation of the application. It is shown by a switching test example, that the gate driver IC can control a wide range of collector-emitter transient voltage dv_{CE}/dt. In the discussed example, values from 1.5 kV/µs up to 6 kV/µs at small collector currents are achieved, which is superior over only 1 trade-off line when using a common gate resistor control. This helps to reduce the size of motor and EMI filters or even makes them superfluous. With this, system costs are significantly reduced, while at the same time system efficiency is increased.

The calculation of inverter losses shows an extension of output current by approximately 10 % - 15 % when using the EiceDRIVER™ 1EDS20I12SV. This advantage can be used to increase the output power of an inverter as well as improving the power density of the application.

Literature

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