IXAN0014

Comparative Performance of BIMOSFETs in Fly-Back Converter Circuits

*One of the typical applications for a flyback converter is the auxiliary power supply for the IGBT gate driver in an inverter. The essential requirement for a switch of a flyback converter in a drives inverter is a high breakdown voltage combined with fast switching speed. To minimize the predominant switching losses, the switch-on and -off energies have to be low. The main advantage of the BIMOSFET lies first in its lower turn- on losses and secondarily in its lower conduction losses. A comparison of the total energy losses between a MOSFET and a BIMOSFET results in **35 % less total losses** for the BIMOSFET.*

Flyback Operation

The Flyback Converter is one of the most simple converter types. The minimum configuration consists of only a switch, a transformer, a diode and two capacitors as shown in fig. 1. The energy in this converter type is stored in the air gap of the ferrite core. Primary current ramps up during the on state of the switch storing magnetic energy, which is then transferred to the output by the diodes when the switch turns off. The power range for this converter type is limited to approximately 300 W.

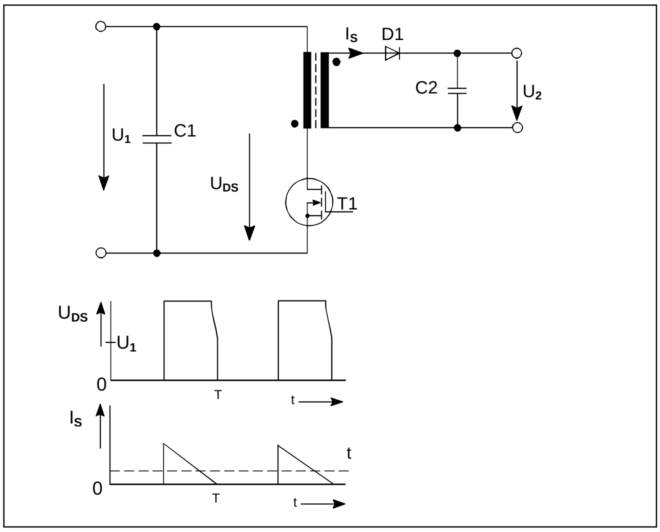

Figure 1: flyback

The advantages of this circuit are the very wide input-output voltage ratio and the feasibility of adding more secondary windings to create multiple output voltages. Furthermore, it is advantageous to have galvanic insulation between primary and secondary side. The disadvantages are the high breakdown voltage required for the switch and the RFI emission generated by the air gap in the transformer. The flyback converter can not work without load or closed regulation loop as otherwise the output voltage will exceed allowable limits.

Flyback Application

One of the typical applications for a flyback converter is the auxiliary power supply for the IGBT gate driver in an inverter. This application has all the requirements, which can be fulfilled ideally by a flyback converter.

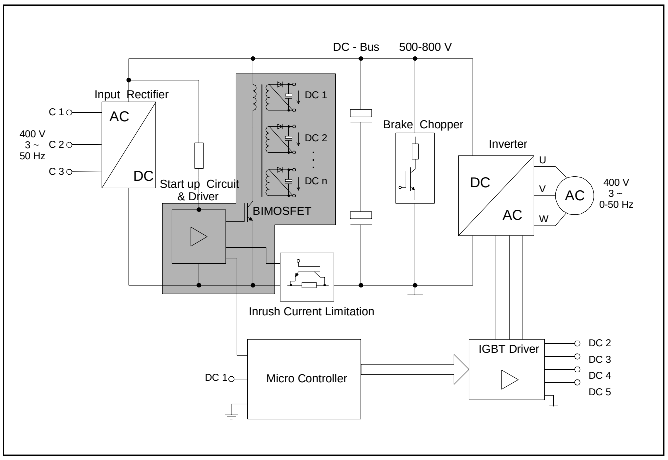

Figure 2: inverter

The shaded area in fig. 2 shows a converter with the start-up circuit as part of the drives inverter. The auxiliary power supply can be built very cost effectively with relatively few elements.

Since the input voltage for the converter is the DC-power bus, there is a wide voltage variation. During the precharge of the bus capacitors, the power supply has to work properly with very low DC-bus voltages, as well as under braking operation of the motor, when the bus voltage reaches high values up to 750 V. The output voltage can easily be regulated by varying the transistor duty cycle.

All the insulated DC- outputs can be generated by adding more separated secondary windings. For example the 5 V supply for the micro controller, ± 15 V for current sensors, a common +15V supply for the driver of the three lower IGBTs and three separate +15V supplies for the upper IGBT drivers.

Requirements for the Switch

The essential requirement for a switch of a flyback converter in a drives inverter is a high breakdown voltage. In a flyback converter the maximum voltage applied to the switch is approximately two x the input voltage. Therefore, the minimum breakdown voltage must be higher than 2 x Vin. For standard inverters for motor control used off mains of 400 V, the DC-bus voltage can reach up to 750 V in the motor braking mode of operation. Here a breakdown voltage of at least 1600 V is needed.

Flyback converters normally run with switching frequencies between 50 to 100 kHz. To minimize the predominant switching losses the switch-on and -off energies have to be low. To achieve this, a high switching speed by the switch is obvious. A common trick to avoid switch-on losses in a fly back topology is not to turn on the transistor until the current in the output diode has reached zero (discontinuous mode). There must be a deadtime until the next cycle starts. The advantage here is less transistor and diode commutation losses, which allows higher switching frequency in order to reduce the size of the transformer.

BIMOSFET™ Chip Technology

Standard high voltage IGBTs are too slow for flyback applications. The new family of high voltage BIMOSFET transistors is fulfilling these needs.

The conventional construction for both MOSFETs and IGBTs is commonly referred to as DMOS (double-diffused-metal-oxide-silicon), which consists of a layer of epitaxial silicon grown on top of a thick, low resistivity silicon substrate, as shown in Fig. 3a.

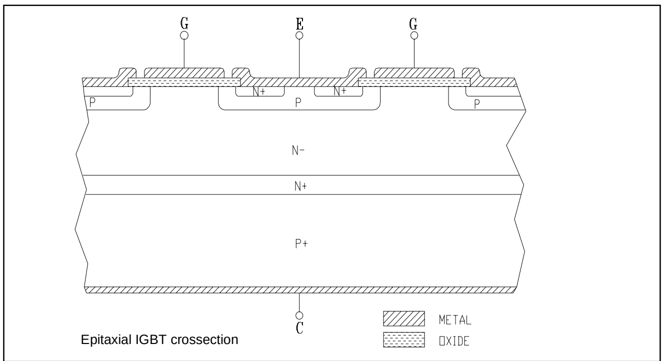

Figure 3a: Cross section

However, at voltages in excess of 1200 V, the thickness of the N-silicon layer required to suppport these blocking voltages makes it more attractive and less costly to use a non-epitaxial construction as illustrated in Fig. 3b. This type of construction is also known as "homogeneous base" or "**N**on **P**unch **T**hrough" (NPT).

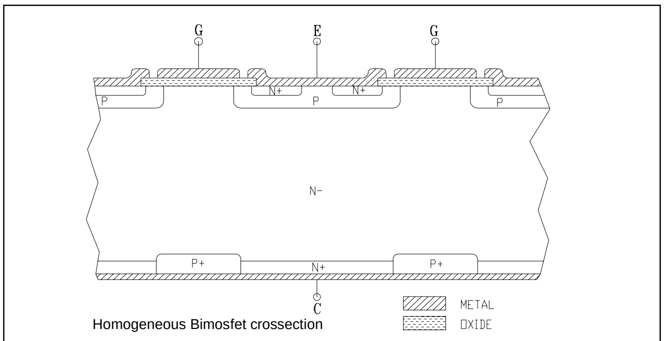

Figure 3b: Cross section

Referring to Fig. 3b, the typical pnpn structure for the IGBT has been maintained, but note that an N+ collector- short pattern has been introduced in order to reduce the current gain of the PNP transistor and consequently its turn-off switching behavior. However, now there is a "free" intrinsic diode from emitter to collector, not unlike that found in a MOSFET, which led us to coin the acronym BIMOSFET transistor. The turn-off behavior of the BIMOSFET transistor is controlled by the amount of collector shorting. In order for the diode to optimize reverse conduction and not cause commutating dV/dt problems, the lifetime of the minority carriers must be reduced by irradiation.

There are two types of BIMOSFETs: The standard type has been designed for IGBT like control with V_{GE}=15V/0V, while the "G" type can be operated with the same gate voltages as a MOSFET, as is explained in the following section. Besides, static and dynamic behaviour of both types are the same.

Driver requirements

a) Standards BIMOSFET

Our tests have shown there is a significant influence on the losses by gate resistor and gate voltage. As a rule, we have found that a series gate resistor of less than 30 Ω has a tendency to oscillate while switching above 50 Ω increases mainly the turn-on losses. Therefore, the IXBH 9N160 BIMOSFET operates best at **15 V's gate drive** and by using a **gate resistor** between **30 and 50** Ω. To achieve full conduction, a gate drive of 15 V is necessary, because the threshold voltage of 6 V is relatively high compared to MOSFETs.

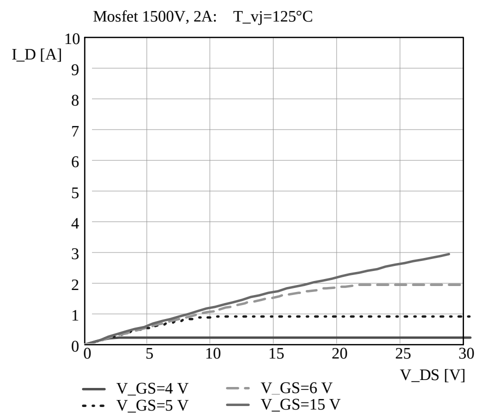

Figure 4a: output characteristics

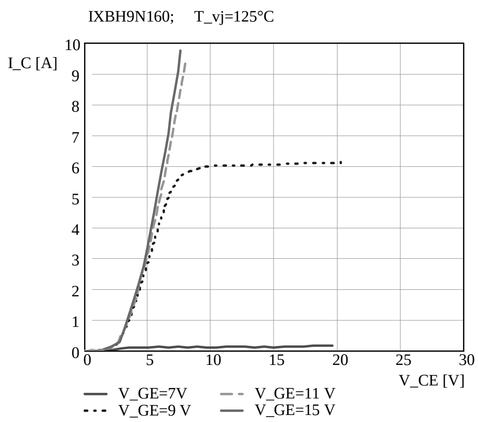

Figure 4b: output characteristics

b) BIMOSFET™ "G"- Type

The threshold voltage of "G" type BIMOSFETs™ is typically 4V and thus lower than of the standard type. Due to this fact it is possible to drive the part with an on state gate voltage of 10 V. This way a BIMOSFET™ may for example replace a 1000V MOSFET in a flyback converter. Because of the blocking voltage of 1400/1600V the snubber capacity may be reduced or even omitted. Nevertheless a drive voltage of 15 V is also applicable and will reduce switch on.
Type designations of "G"-Types end with "G". First parts are IXBF 9N140**G** and IXBF 9N160**G**.

Static behavior

When comparing the output curves we can see the linear characteristic for the MOSFET (fig.4a) and the bipolar behavior for the BIMOSFET (fig.4b).
As can be seen from figure 4a, the MOSFET can conduct 2 A with only 6 V gate drive. Comparing this to the BIMOSFET output characteristic in fig. 4b, one sees that there is no current flow with 7 V gate drive. Here lies the major difference for the BIMOSFET. We need at least 11 V to switch on properly at currents below 5 A.

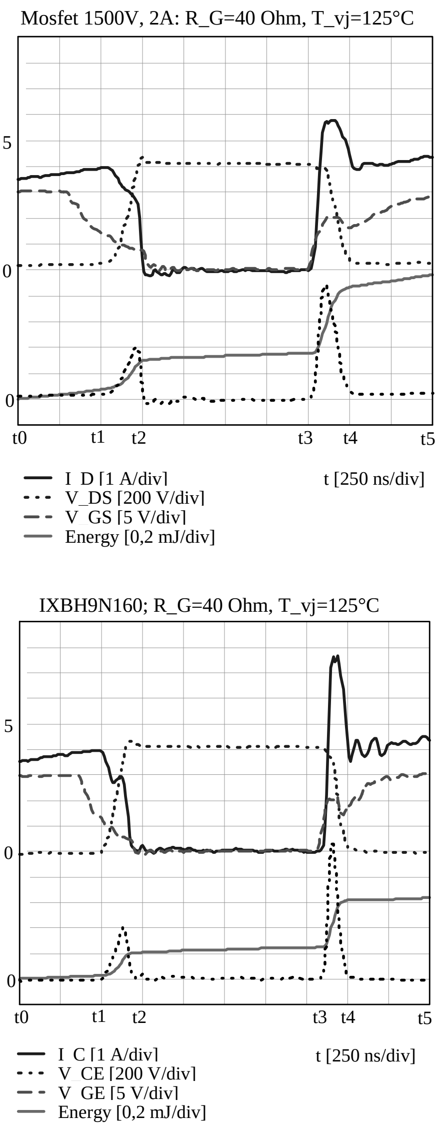

Figure 5: switching curves

For higher peak currents, we need 15 V gate voltage for proper conduction. There is a significant difference in the on-state losses. At 2 A and 15 V gate drive, the MOSFET has a voltage drop of 18 V and the BIMOSFET has only 4 volt drop. This leads to 4.5 times less conduction losses. We also can see the much higher current capability of the BIMOSFET, which can easily conduct more than 10 A compared to the MOSFET, which is limited to 3 A.

Switching behavior

We have done several comparative measurements to quantify the performance of a standard high voltage MOSFET and the BIMOSFET. The figures 5a and 5b show a full switching cycle and allow the calculation of the total losses. The parameters drain current, drain voltage and gate voltage have been measured. The power dissipation and the total energy have been calculated from these data.
The test equipment was a double pulse tester, in which the freewheeling diode is still conducting when the MOSFET is switched on. Consequently, the turn-on waveform is impacted by the diode's recovery behavior. However, the performance is comparable because the diode's influence on the MOSFET or BIMOSFET is the same.

The conditions are as follows:
Turn-off current amplitude = 4 A
Voltage = 800 V
Gate drive = 15 V, 40 Ω
Junction temperature = 125°C

The time from t0 to t1 is the end of the conduction phase. At the end of this phase we can see a rise in the energy curve (solid line below), which is caused by the higher on state losses of the MOSFET.

The next step (t1 to t2) is the turn-off. The dotted line (Ptot) below shows no significant difference in turn-off losses although they might be slightly less for the BIMOSFET.
After turn- off (t2 to t3), there is no visible tail current for the BIMOSFET. The slight increase in energy that we can see during the off-state might be a measurement error, since we have the same for the MOSFET, which definitely has no tail current.

The next phase is turn-on from t3 to t4. We easily can see that the major losses occur during turn-on. The upper solid line shows a high peak current, which is mainly caused by commutation of the diode. In comparison, the turn-on time for the MOSFET is longer than for the BIMOSFET. The peak power for the MOSFET is approximately 4 kW for 250 ns. The peak power for the BIMOSFET is 5 kW but only for a duration of 130 ns. Therefore, the total switch on energy for the MOSFET is 0.5 mJ and only 0.4 mJ for the BIMOSFET. This is 20% less for the BIMOSFET.

The last 500 ns, from t4 to t5, are the beginning of the conduction phase. The energy curve for the MOSFET shows a rise caused by the high on resistance. The BIMOSFET curve is almost flat, which is a sign for a low saturation voltage (compare fig.4b).

Product range

Type	BV_{CES} min. V	V_{CEsat} @ 25°C max V	I_{C25} A	t_r ns	t_f ns	Gate drive V	Housing
IXBH 9N140 **IXBH 9N160**	1400 1600	7.0	9	60	40	15	TO247
IXBH 9N140G **IXBH 9N160G**	1400 1600	7.0	9	200	70	10	TO247
IXBF 9N140G **IXBF 9N160G**	1400 1600	7.0	7	200	70	10	i4-Pac™
IXBH 15N140 **IXBH 15N160**	1400 1600	7.0	15	60	40	15	TO247
IXBH 20N140 **IXBH 20N160**	1400 1600	6.5	20	60	40	15	TO247
IXBH 40N140 **IXBH 40N160**	1400 1600	7.1	28	60	40	15	TO247
IXBF 40N140 **IXBF 40N160**	1400 1600	7.1	28	60	40	15	i4-Pac™

In summary

The main advantage of the BIMOSFET lies first in its lower turn- on losses and secondarily in its lower conduction losses. The total energy loss per pulse is shown at time t5 where we see that the MOSFET value is 0.95 mJ and for the BIMOSFET, only 0.62 mJ. This results in **35 % less total losses** for the BIMOSFET.

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