Increasing Power Density in Welding Machines Using TRENCHSTOP 5 IGBT

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Introduction

The demand for portable low cost welding machines, especially in developing countries, is increasing. Discrete IGBTs and MOSFETs are broadly used in the Manual Metal Arc (MMA) and Tungsten Inert Gas (TIG) types with power range from 1.5kW up to 6kW. Mostly, these machines use current mode PWM controls and simple topologies, like Two Transistors Forward (TTF), Half Bridge (HB) and Full Bridge (FB), typically with Zero Current Switching (ZCS) turn-on and hard-switching turn-off. For these configurations, high frequency is one of the most important design trends to improve performance and to reduce cost at system level. Infineon’s TRENCHSTOP™ 5 IGBT technology, thanks to the dramatic turn-off losses reduction, is the most promising candidate, which is fully capable to accomplish the strong technical requirements of the welding machines.

TRENCHSTOP 5 IGBTs improve the performances compared to the previous generation IGBTs, while operating at higher switching frequency. They are also suitable to directly replace, in proper layouts, conventional High Voltage MOSFETs reaching switching frequencies up to 100 kHz. The operation at higher switching frequency leads to the reduction of the magnetic components’ size and of the capacitors’ number. However, a simple “plug-and-play” replacement of former IGBTs is not always possible due to potential issues induced by higher di/dt and dv/dt, such as high voltage overshoot at turn-off, oscillation at turn-on or degradation of EMI figures.
IMPROVEMENTS IN HALF BRIDGE TOPOLOGY

The drastic reduction of the turn-off losses may result in substantial mechanical changes of the primary side of the converter, thus to a simplification of the mechanical solution. This leads to even further improvements of the PCB layout and the gate driver design. Consequently, the machine’s dimension and weight can be significantly reduced. Figure 1 shows a welding machine demonstrator designed for this purpose. It is a single phase 4.5kW half bridge MMA/TIG welding machine. In this case it is possible to replace two 40A/600V IGBTs per switch with a single IKW50N65H5 TRENCHSTOP™ 5 IGBT thanks to adequate layout improvements both in power loop and signal loop.

Furthermore, due to the reduction of the switching and conduction losses, the temperature of the devices is strongly reduced, even allowing the use of isolation foils. Figure 2 depicts the case temperature profiles for different technologies of Infineon IGBTs. A noteworthy difference in case temperature, between diverse technologies, can be observed. In particular, TRENCHSTOP™ 5 outperforms former TRENCHSTOP™ silicon by 40K. The test is performed dimensioning the gate resistance $R_{G(off)}$ to keep the voltage overshoot at turn-off within 80% of the breakdown voltage, thus limiting the collector-emitter voltage at a maximum value of $V_{CE}=520V$. The lower the stray inductance of the board, the lower is the $R_{G(off)}$ that can be chosen in order to meet the limits imposed. Also, the maximum Gate-Emitter voltage oscillations are considered in the test. Indeed, the acceptable value in this test is $-25V < \Delta V_{GE(max)} < 25V$ per less than 200ns. Alternatively, it is possible to use TRENCHSTOP™ 5 in non-optimized layouts by adjusting the passive gate network. In such a case, by introducing a larger gate resistance for the turn-off and a $C_{GS}/R_{G}$ gate clamping structure, it is once again possible to keep $V_{CE}$ and $V_{GE}$ overshooting within acceptable values. However, it results in a strong reduction of the benefits deriving from the use of TRENCHSTOP™ 5 IGBTs. This highlights the importance of an appropriate layout.

An opportunity to reduce the stray inductance in the power boards even further is to use TRENCHSTOP™ 5 IGBT technology in surface mount assembly on isolated substrates. This results in a more compact solution with a single heat sink for both high- and low-side IGBT. As a consequence, a special IGBT isolation like IMS or Al$_2$O$_3$ ceramic with an additional reinforced isolation is required. The introduction of these technical changes leads to a significant reduction of the dimensions and weight of the entire machine. An example is given in Figure 3. Here, the second half bridge MMA/TIG welding machine demonstrator, thanks to its new design, causes a reduction of 35% in dimensions and 15% in weight compared to the former demonstrator.

This concept allows achieving an overall stray inductance of 40nH, which can be further reduced by 20nH if a different package assembly combination and a full bridge topology design is introduced. The stray inductance reduction enables systems to run at switching frequency exceeding 100kHz, which implies the possibility to use a single heat sink to increase the power density and reduce the transformer size along with the number of DC-Link capacitors needed.

Fig. 2 Thermal results using different Infineon IGBT families on the 4.5 kW welding machine demonstrator

IMPROVEMENTS IN FULL BRIDGE TOPOLOGY

Another design example, a 3.5 kW Full-Bridge high frequency welding machine, is illustrated in Figure 4. Here, the purpose of the design is to showcase TRENCHSTOP™ 5 in full bridge topology replacing conventional MOSFETs for lower cost, better manufacturability as well as higher reliability. Once again the low turn-off losses of the TRENCHSTOP™ 5 IGBT technology are the key enabler of the system architecture improvements achieved thanks to the new design. This feature,
along with the higher current carrying capability of IGBTs compared to MOSFETs, allows replacing three conventional HV-MOSFETs with one single IGBT device. Due to a lower number of devices required, the power- and driving-stage can be easily integrated on a smaller board instead of having a driver board on top of a power board. Compared to this common approach, the total board area needed for the new approach is one third smaller than the former version. Moreover, the significant reduction of parasitic inductance in the power loop allows turning off the TRENCHSTOP™ 5 at higher di/dt, still maintaining the voltage overshoot within the recommended specification.

The demonstrator was developed to simplify the architecture, as well as to increase power density. With this hardware, it is possible to show how to reduce the effort for the assembly process which greatly improves the manufacturability for mass production and reduces the system cost. The components saving and the layout optimization imply a material cost reduction of about 30%, in a dimensions decrease of 30% and in a 35% lighter machine than a commercial solution.

A straightforward benchmarking test was performed running this Full-Bridge welding platform at 100kHz to check its performance at high frequency operation. The test scope is to measure the maximum output current capability while maintaining the same IGBT temperature swing between case and ambient. At the same time, system efficiency and maximum Collector-Emitter and Gate-Emitter Voltage overshoots are monitored. For a correct comparison, the driving setup is the same until reaching system instability or a fault is triggered. The results of the test are summarized in Table 1.

At 100kHz operating frequency, TRENCHSTOP™ 5 shows a performance not to be reached by any other comparable device. H5 IGBT provides 30% higher output current than the best alternative and delivers 70% more output DC current compared to second best option, meanwhile avoiding additional effort to smooth driving waveforms. H5 IGBT reveals 1% to 3% higher efficiency than any other candidate at maximum output current level of the welding machine. This allows the welding machine to grant a higher energy efficiency grade.