Journal of Applied Sciences

ISSN 1812-5654

science alert

ANSInet
an open access publisher
http://ansinet.com

Journal of Applied Sciences 13 (11): 2033-2038, 2013
ISSN 1812-5654 / DOI: 10.3923/jas.2013.2033.2038
© 2013 Asian Network for Scientific Information

A IGBT Drive Circuit with Adjustable Rise and Fall Time

Song Wang
School of Mechanical, Electrical and Information Engineering, Shandong University (Weihai)
Weihai, Shandong, China

Abstract: The Insulated Gate Bipolar Transistor (IGBT) is a composite device of MOSFET and bipolar transistors. It is widely used in the higher frequency, large and medium power equipments. Therefore, the protection circuit of driver board of IGBT is a very important part for IGBT application. In this paper, we propose an improved drive circuit based on the Fuji EXB841, which has the function of Vce protection, low voltage protection, soft-close mechanism and adjustable rise time Tr of break over and fall time Tf of shutdown. The improved circuit enhances the reliability of the drive board. The experiments exhibit the validity of the improved drive board.

Key words: IGBT driver circuit, rise time, fall time, protection circuit, EXB841

INTRODUCTION

The Insulated Gate Bipolar Transistor (IGBT) is a composite device of MOSFET and bipolar transistors. It has the advantages of higher input impedance, fast response and easy to drive but also has the advantages of lower saturation voltage, bigger current capacity and higher withstand voltage of bipolar Darlington power transistor (GTO). It can work in tens of Khz frequency properly. IGBT is mainly used for power equipment. It occupies a dominant position in the higher frequency of large and medium power equipment (such as inverter, UPS power, high frequency welding machine (Li *et al*., 2011; Li *et al*., 2012), etc. The requirements of rise time Tr of breakover and fall time Tf of shutdown are different due to the different specifications of IGBT as well as types of applications (Herzer *et al*., 2002). Therefore, a good driver protection circuit should have the function of regulation Tr and Tf respectively. Moreover, the driver protection circuit should have undervoltage and overcurrent protection functions. Therefore, the driver protection circuit is a difficult and critical part of application. An excellent driver protection circuit is a necessary part to ensure efficient and reliable operation of the IGBT (Zhang, 2013; Han, 2013). It should first be able to provide certain amplitude of positive and negative gate voltage and has sufficient drive capability and appropriate gate resistor connected in series. For the isolation circuit, the signal lag must be very small.

Currently, there are various drive circuits for IGBT and their respective functions are different. From the aspects of isolation circuit, IGBT driver can be divided into two categories, optocoupler using and the other using a pulse transformer, both of which can realize signal transmission and isolation. At present, using optocoupler is majority.

The Fuji EXB841 drive has a simple structure, with over-current, over-voltage and slowly shutting off protection and has higher driving ability and switching frequency (Zhang *et al*., 2000). Therefore, it has been widely applied in practice, such as PMSM drive (Wang, 2013). Although EXB841 has a strong driver function and various advantages but the IGBT rise time Tr of conduction and fall time Tf of the shutdown are not adjustable, so the reliability of the protection circuit is limited. This leads to the limitation of the applications. Through a comprehensive analysis of a variety of driver protection circuits, we propose a new full functional and reliable IGBT deiver protection circuit with the functions of undervoltage protection, adjustable rise time Tr of conduction and fall time Tf of the shutdown to solve this problem.

IMPROVED DRIVER CIRCUIT

The schematic diagram of EXB841 is shown in Fig. 1. In Fig. 1, +20 V drive power is divided into two parts of +15 V and +5 V through R2 and Z2. When the control pulse from the control circuit inputs the optocoupler P0, the amplifier Q2 will be turned on and the IGBT gate will obtain a +15 V drive signal and breakover. When the control pulse disappears, Q2 will be breakover, the gate-source of IGBT will obtain a-5V leading to the cut-off of IGBT. If IGBT has a fault of overcurrent during conduction period, it will depart from saturation and uDS will rise. The protection circuit will detect it by diode

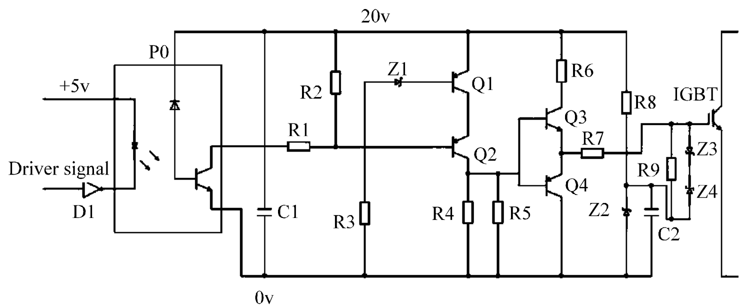

Fig. 1: Schematic diagram of EXB841

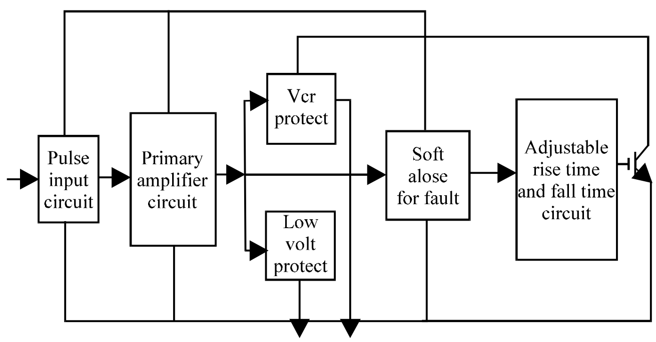

Fig. 2: Improved schematic diagram of IGBT drive circuit

D1,the driver will reduce the gate voltage to make the IGBT into the soft turn-off state in 10 us and send the overcurrent signal to control circuit by pin 5 at the same time. The above content is the working principle of EX841 protection circuit.

Based on the EXB841, Figure 2 is the diagram of the improved protection circuit. From Fig. 2 we can see the improved driver board compose of several parts, include pulse input part, primary amplifier part, Vce (Hemmer, 2009) and low voltage protection part, soft-close part and the adjustable rise time and fall time part.

Figure 3 is the protection circuit and Fig. 4 is the circuit of adjustable rise time Tr of conduction and fall time Tf of the shutdown.

From Fig 3 we can see, the circuit includes a power source 20V to provide an operating voltage VCCA, a voltage reference unit VCCB and an opticalcoupled P1 for providing a control pulse input. The the primary power amplification of the gate pulse, which is used to turn-on and turn-off the IGBT, includes a transistor Q2. The Vce is used to monitor the protection circuits and the monitor part mainly composes of R5, D1, Z1, D4, D5 for over-current protection of the IGBT. The soft shutdown circuit composes of R8, R7, D2, C4 to prevent to shut down the IGBT excessively fast and generate large noise in overcurrent and undervoltage status. There is an undervoltage protection unit in the circuit, which used to block the output of proectetion circuit. It composes of R18, R19, R20, R21, Z5, Q7.

Vce protection: The working process of the circuit is as follows. The pulse signal PWMS from control system is amplified by the primary amplifier circuit, adjusted the rising time Tr and fall time Tf by the regulation circuit. In this process, if the drive power supply is under-voltage (VCCA drops below 18V), the undervoltage protection circuit will be triggered and it will turn off IGBT slowly and then block the output of drive protection circuit until the driverpower is restored to normal state. If the IGBT is overcurrent due to short circuit, the Vce monitoring and protection circuit will be triggered, it will first turn off IGBT softly too and then block the control pulse of drive protection circuit until the overcurrent condition is released. In addition, depending on the application we can adjust the negative voltage of IGBT gate, where you can adjust the voltage value of regulator Z2, so this extends the range of applications of the driver protection circuit.

Rising time Tr and fall time Tf regulation: Combined with Fig. 4, we discuss the working process and principle

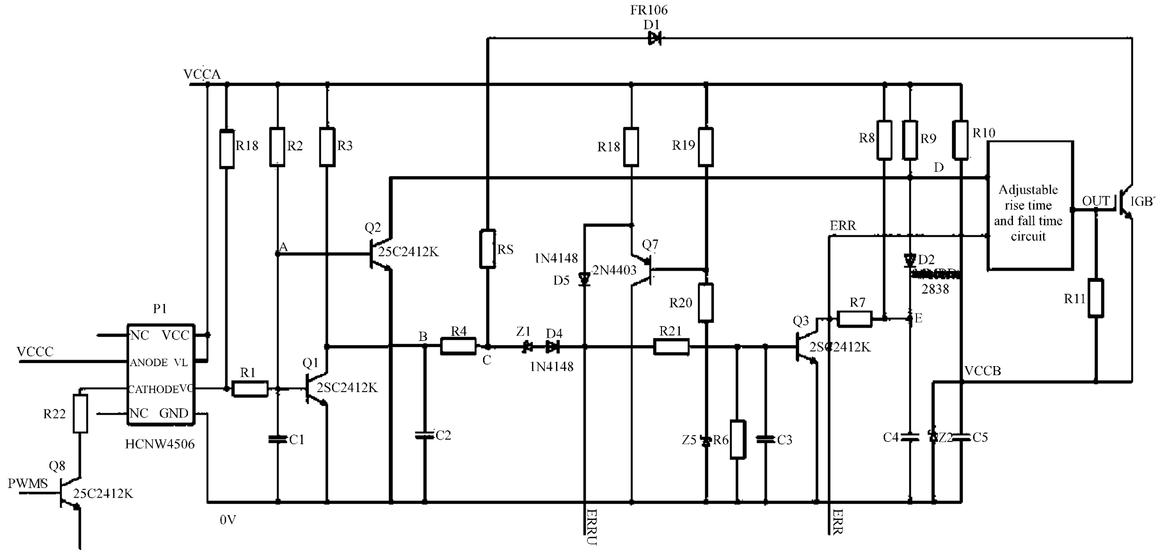

Fig. 3: Whole diagram of IGBT drive circuit

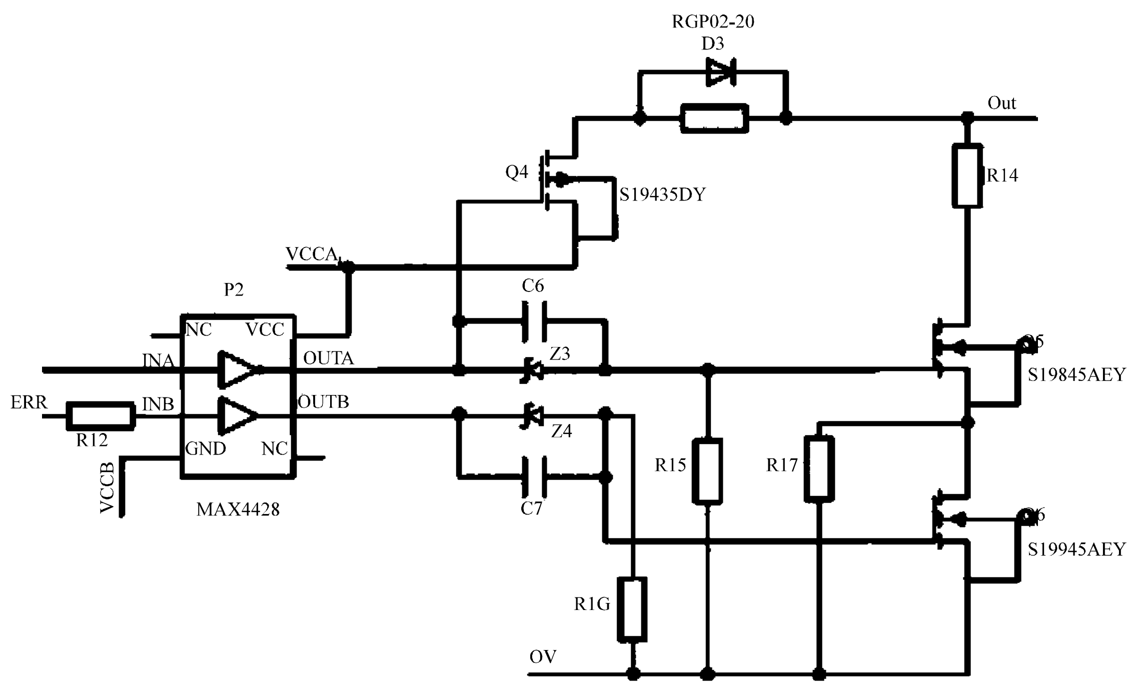

Fig. 4: Regulation circuit of turn-on and turn-off time of IGBT

as follows. In Fig. 3, when the drive signal PWMS is transmitted to the photocoupler P1, the photocoupler P1 will breakover and potential of point A is rapidly decreased to 0V and the transistor Q1, Q2 are cutoff. Q2 is turned off so that the potential of point D rises to the high level. In Fig. 4, the MOSFET device Q4 is turned on by the P2 inverting of point D. The power supply VCCA provides the current of IGBT through Q4 and the gate resistor R13, so that the IGBT can breakover rapidly. At time time, you can adjust the resistance of the resistor R13 to adjust the impedance of IGBT turn-off circuit and this can be indicated by the rising steepness of the drive pulse. Therefore, we can adjust the resistance of R13 to regulate the rise time Tr of conduction of IGBT. At the same time, the capacitor C2 charges through R3 from VCCA due to the cut-off of Q1.

The time constant τ_1 is calculated as following Eq. 1:

$$\tau_1 = R3 \times C2 = 2.42\ (\mu\ \text{sec}) \quad (1)$$

At this time, the time of point B potential rising from 0V to 13V (the breakdown voltage of the zener Z1) is calculated as following Eq. 2:

$$t_{13} = 20\ (1\text{-}e)^{-t/\tau 1} \quad (2)$$

In the Eq. 2, t = 2.54ìs. IGBT will be breakover after 1us delay and the voltage between the gate electrode and emitter of IGBT is 3V approximately. The potential of point B and C is about 8V below 13V due to the clamping of the diode D1. The voltage of voltage-regulator tube Z1 is 13V. Therefore, IGBT is not breakdown in common, transistor Q3 is non-conductive, the potential of point E is 20V, the diode D2 is turned off and the ERR signal is 20V.

When the driving pulse does not input the photocoupler P1, the photocoupler P1 will be not turned on, the voltage of point A will rise, so that the transistor Q1 and Q2 will be turned on. When the transistor Q1 is turned on, the capacitor C2 will discharge rapidly through Q1. The potential of points B and C are clamped at 0V. The regulator tube Z1 is nonconductive and the transistor Q3 is turned off. ERR output high-level signal. The positive phase input enables the MOSFET device Q6 to turn on the output of P2. E point is still high potential, the diode D2 is turned off. At the same time, Q2 is turned on so that the potential of point D is decreased to the low level 0V and potential of point D outputs a high level 20V after the inverting of P2, Therefore, the MOSFET device Q4 is turned off and the MOSFETdevice Q5 is turned on by the voltage drop on the resistor R14. When the IGBT is in normal conduction and shutdown, the ERR signal 20V, so that the MOSFET device Q6 always conductive by the voltage drop in the resistor R16. Under a negative gate voltage, the IGBT gate discharges through resistor R14, the MOSFET device Q5 and Q6 rapidly. A voltage of-5V is added to the gate and the emitter of IGBT, so that IGBT can shutdown reliably. You can adjust the resistance of the resistor R14 to adjust the impedance of IGBT turn-off circuit and this can be indicated by the steepness of the decline off IGBT pulse fall time. Therefore, you can adjust the resistance of the resistor R14 to adjust the fall time of shutdown of IGBT. At the same time, of the diode D1 is off due to the rapid rise Uce.

Low power protection: When the power supply of driver protection circuit suddenly reduces to certain amplitude, this may cause some components of the circuit do not work properly and may have serious consequences. Therefore, the undervoltage protection unit is designed. In the undervoltage protection circuit, when the power supply of the drive protection cuircuit is normal such as 18-20V here the Q7 will be breakover by the voltage drop on R20 and Z5. R19 and R20 have equal resistance. Z5 is a stabilovolt tube of 17V. The fault signal ERRU is low, the transistor Q3 turns off and the drive circuit works normally. When the power supply VCCA reduces to 18V, the voltage drop on R20 and Z5 will not turn on Q7, the ERRU will be a high level of 20V and transistor Q3 will be breakover. Then the drive protection circuit turns off the IGBT softly and the output of the drive protection circuit will be blocked until VCCA is normal.

EXPERIMENT

In Fig. 5, the rising time Tr and fall time Tf are regulated by different resistance of R13 and R14. From Fig. 5, we can see the bigger resistance the larger rising

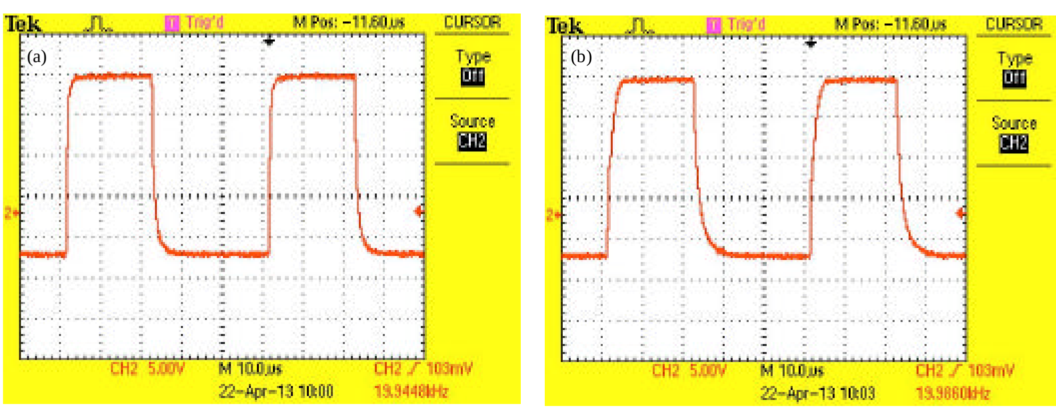

Fig. 5: Continue

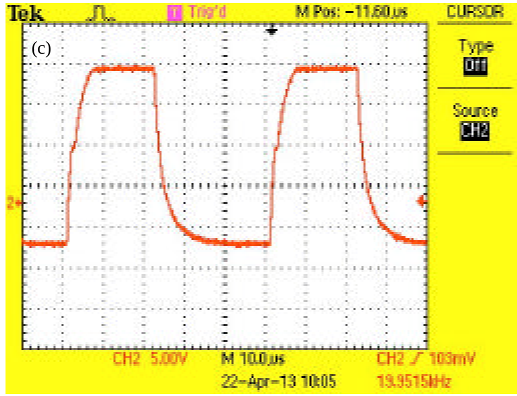

Fig. 5(a-c): Driver pulse of our board when R13, R14 are (a) R13, R14 = 7, (b) R13, R14 = 30 and (c) R13, R14 = 70

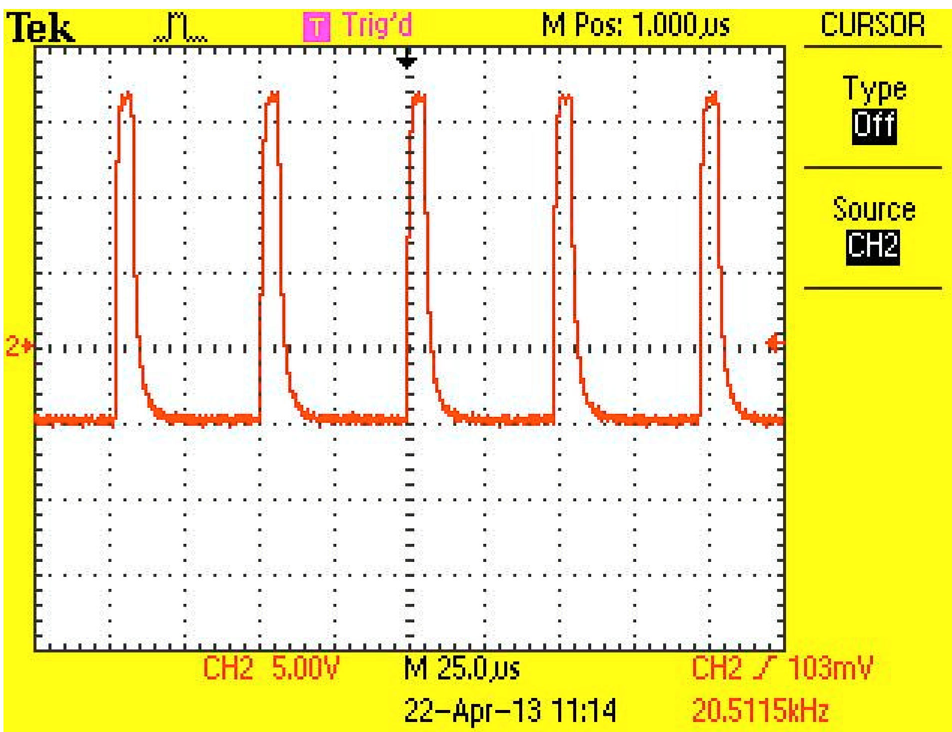

Fig: 6. Soft turn-off diagrams of drive circuit

and fall time. The gradient of rising and falling edige of driver pulse is larger when R13 = 7 and R14 = 7 than R13 = 30, R14 = 30 and R13 = 70, R14 = 70.

The drive plate stops working when the power supply is 15% less than the standard value. At the same time, the driver board can realize overcurrent protection and the specific waveform is shown in Fig. 6.

CONCLUSION

The rise time Tr of breakover and fall time Tf of shutdown are important parameters for IGBT driver. They are different due to the different specifications of IGBT as well as types of applications. We design a special circuit to adjust them. According to experiment, the circuit can adjust the rising time Tr and fall time Tf flexibly. Therefore, the improved driver board can be used to many IGBT. Moreover, other protection circuits and a soft-close part are designed, which make the driver board more reliable.

REFERENCES

Han, Y., 2013. A pedagogical approach for modeling and simulation of switching mode DC-DC converters for power electronics course. TELKOMNIKA Indonesian J. Electr. Eng., 10: 1319-1326.

Hemmer, R., 2009. Intelligent IGBT drivers with exceptional driving and protection features. Proceedings of the 13th European Conference on Power Electronics and Applications, September 8-10, 2009, Barcelona, Spain, pp: 1-4.

Herzer, R., S. Pawel and J. Lehmann, 2002. IGBT driver chipset for high power applications. Proceedings of the 14th International Symposium on Power Semiconductor Devices and ICs, June 4-7, 2002, Santa Fe, NM., USA., pp: 161-164.

Li, C.T., C.H. Du, H.B. Xu and Y. Luo, 2012. The study of submerged arc welding power based on DSP. Adv. Mater. Res., 487: 186-191.

Li, C.T., X.B. Zhang, Y. Luo and C.H. Du, 2011. Designing of CO_2 inverter welding power for the mode of full-bridge and IGBT based on DSP. Applied Mech. Mater., 80-81: 730-736.

Wang, S., 2013. Permanent magnetic synchronous motor control system based on ADRC. TELKOMNIKA Indonesian J. Electr. Eng., 11: 3439-3444.

Zhang, M., J. Zhu and W. Liang, 2000. The effectiveness of protection for IGBT and proper use of EXB840/841. Electrotech. J., 10: 47-49.

Zhang, W., 2013. The electromagnetic interference model analysis of the power switching devices. TELKOMNIKA Indonesian J. Electr. Eng., 11: 167-172.