Design of Switching Power Converter of PMSM Power Driver for Hybrid Electric Vehicle

Ningzhi JIN
School of Electrical & Electronic Engineering
Harbin University of Science & Technology
Harbin 150040, China
E-mail: sharon0716@126.com

Xudong WANG
School of Electrical & Electronic Engineering
Harbin University of Science & Technology
Harbin 150040, China
E-mail: wxd6158@163.com

Hongwei GAO
School of Electrical & Electronic Engineering
Harbin University of Science & Technology
Harbin 150040, China
E-mail: ghw840@sina.com

Jinfeng LIU
School of Electrical & Electronic Engineering
Harbin University of Science & Technology
Harbin 150040, China
E-mail: ljf78118@163.com

***Abstract*—The power supply quality has a direct effect on the performance of motor driver as well as total HEV system. Generally, four separated integrated DC/DC converters are used for PMSM power drive, which don't meet the demand of low cost and small size for HEV. In this paper, firstly the input voltage from vehicle is chopped to 5VDC, and then full bridge switching power converter is applied to convert the power supply of 5V to four insulated DC power sources for IGBT switch in the three phase bridge inverter. As experimental results show, the switching power converter system will ensure the power supply quality when the input voltage from vehicle fluctuates in the wide range of 8-30VDC, and is also an efficient way to reduce the overall cost and size of HEV.**

Keywords- Switching power supply; DC/DC converter; Permanent magnet synchronous motor; Hybrid electric vehicle

I. INTRODUCTION

There are three key techniques for development of Hybrid Electric Vehicles (HEV): motor drive system, energy storage system and power train technology. The motor drive system is one of the most critical components. The power supply quality has a direct effect on the performance of motor driver as well as the total HEV system. Permanent Magnet Synchronous Motor (PMSM) is the first choice for HEV because of its simple structure, high power density and wide speed range [1-3]. The power supply system of PMSM driver provides not only power sources for active chips in the control unit, but also four insulated DC power sources for IGBT drive in the three phase bridge inverter. Generally, four separated integrated DC/DC converters are used for PMSM power drive, which results in an increase in overall cost and size and more difficulty in design of monolithic construction and quickly market development for HEV products [4-8].

II. THE OVERALL STRUCTURE OF POWER SUPPLY SYSTEM

In this paper, the power supply system is composed of input buck chopper, full bridge switching power converter, DC/DC converters in the control unit and under-voltage protection circuit etc., as shown in Figure 1.

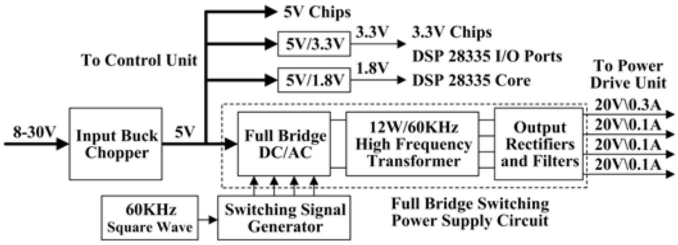


Figure 1.The overall structure of power supply system

The input voltage of power supply system is in the wide range of 8-30VDC, which facilitates the connection to the vehicle power bus. Firstly, it is converted to 5VDC by the input buck chopper. And then the power supply of 5V not only provides power sources at different voltage levels for active chips in the control unit such as DSP 28335, operational amplifiers etc., but also is converted to four insulated DC power sources by the full bridge switching power supply circuit for IGBT switch in the three phase bridge inverter. In this paper, full bridge switching power converter is introduced for PMSM power drive, which brings about a decrease in cost and size for the total HEV system.

III. INPUT BUCK CHOPPER

The input DC/DC converter consists of input filter, buck chopper and output filter circuit, as Figure 2 shows.

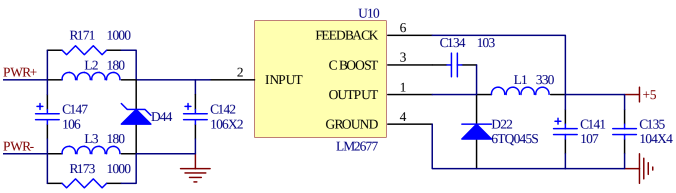
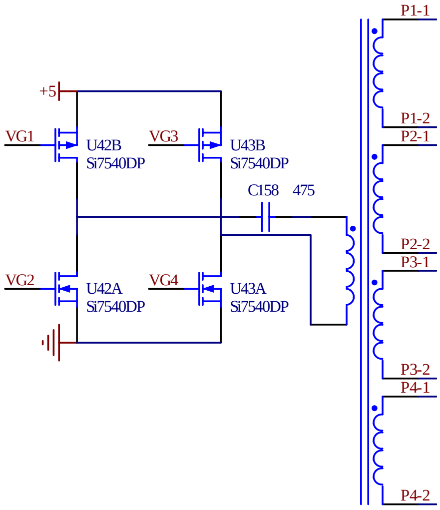


Figure 2.Input buck chopper

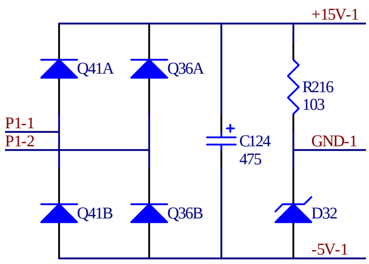
In the input filter circuit, L2, L3, R171 and R173 constitute a common mode choke used to filter the common mode EMI in input power bus from vehicle; D44 is a Transient Voltage Suppressor (TVS) used to protect devices against the damage of surge current and reverse input voltage [9, 10]. The buck chopper circuit consists of LM2677, a fly-wheel diode D22 and an inductor L1, where LM2677 is a switching step-down regulator with wide input voltage range of 8V-40V, high switching frequency of 260 KHz, maximum output power of 5V/5A and high efficiency up to 92%.

IV. CONVERSION PRINCIPLE OF FULL BRIDGE SWITCHING POWER CONVERTER

Full bridge switching power converters have both advantages of high voltage utilization ratio like push-pull converters and high withstand voltage like half bridge converters. It is composed of full bridge DC/AC conversion circuits, high frequency transformer and output rectifier etc., as shown in Figure 3.



(a) DC/AC conversion circuit and high frequency transformer



(b) One of output rectifier and filter circuits

Figure 3. Full bridge switching power converter

The full bridge DC/AC conversion circuit consists of four switches, where U42A, U43A are N-channel MOSFETs and U42B, U43B are P-channel MOSFETs. C128 is a blocking capacitor used to filter the DC component in the transformer primary winding. The output rectifier is a bridge uncontrolled rectification circuit with a capacitor filter. D32 is a voltage regulator diode of 5V used to separate the output voltage of 20VDC into +15V and -5V with respect to the emitter terminal of IGBTs, for the purpose of switching the high power devices on and off respectively.

Due to electromagnetic induction between the transformer primary and secondary windings, when U42B, U43A are in on-state and U43B, U42A are in off-state, the supply voltage of 5V is applied to the primary winding N_p, so there will be a positive voltage output across each secondary winding $N_{si}(i=1,2,3,4)$ in direct proportion to the turns ratio; when U43B, U42A are in on-state and U42B, U43A are in off-state, the supply voltage is reversely applied to N_p, so there will be a negative voltage output across N_{si} in direct proportion to the turns ratio... It goes round and begins again, which results in an alternating voltage outputs across each secondary winding. Consequently, four isolated DC voltages will be obtained after the alternating voltage outputs being rectified and filtered.

V. GENERATION OF SWITCHING SIGNALS FOR FULL BRIDGE SWITCHING POWER CONVERTER

Square wave generating circuit is applied to generate square wave VG with amplitude of 5V, frequency of 60 KHz, duty cycle of 50%, as Figure 4 shows.

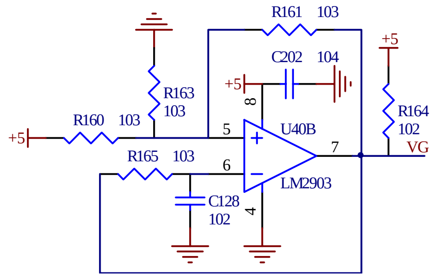


Figure 4.Square wave generating circuit

The four switching signals VG1-VG4 will be obtained from VG after logical conversion and dead time being inserted, as Figure 5 shows.

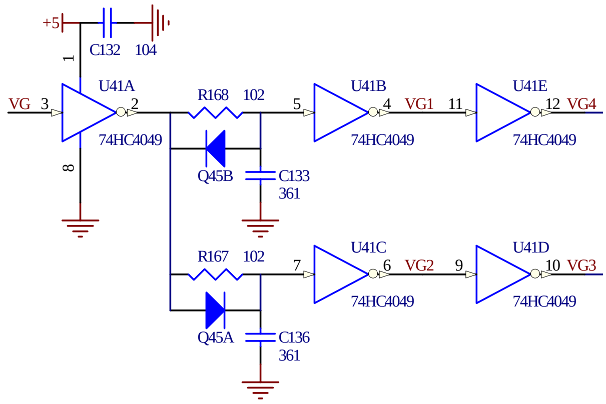


Figure 5.Switching signal generator

When VG1 is low and VG4 is high, U42B and U43A are turned on; when VG3 is low and VG2 is high, U43B and U42A are turned on. Dead time should be inserted in order to avoid the short circuit of DC source between upper and lower bridge-arms. Consequently, VG1 and VG3 will not turn low, and VG2 and VG4 will not turn high until dead time delay. The timing relationships between switching signals are shown in Figure 6.

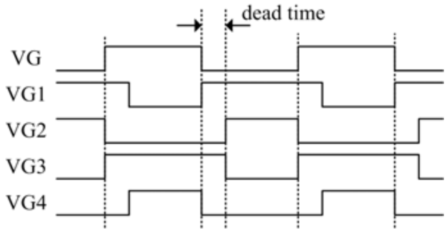


Figure 6.Timing relationships between switching signals

VI. INPUT UNDER-VOLTAGE PROTECTION CIRCUIT

The under-voltage protection will produce a lockout signal for PWM when the input supply voltage is lower than 6.6V, as shown in Figure 7, where PWR is the input supply voltage, VREF is the analog reference voltage of 3.3V and ERROR is the active-low lockout signal. The signal ERROR can be sent to DSP 28335 or certain circuits for PWM lockout.

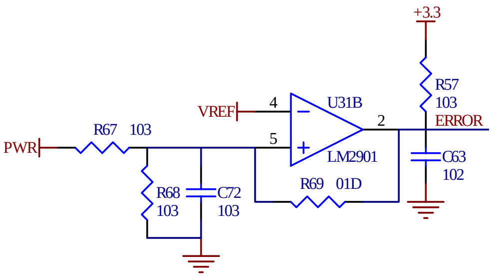


Figure 7.Input under-voltage protection circuit

VII. ANALYSIS OF EXPERIMENTAL RESULTS

The high frequency transformer in full bridge switching power converter is designed and applied as follows: the core material of R2KD ferrite and the core specification of EE25.4 are selected; the transformer operates at frequency of 60KHz within temperature rise of 25°C; the winding turns ratio is set as 1:4, where the primary winding is 6 turns, and each secondary winding is 25 turns considering the effect of on-state voltage drop of switching devices in the DC/AC converter and output rectifier; the rated output power is 12W, where one output is 20V/300mA and the other three outputs are 20V/100mA [11, 12].

The key design parameters of high frequency transformer are illustrated in Table 1.

Table 1.Design parameters of high frequency transformer

core material	R2KD ferrite core
core specifications	EE25.4
operating frequency	60KHz
allowable temperature rise	25°C
winding turns ratio	1:4 (6:25 actually)
rated output power	12W

The switching signals VG1 and VG2 between upper and lower bridge-arms in the full bridge converter are shown in Figure 8. The dead time inserted between VG1 and VG2 is about 1us, and the timing relationships are consistent with the analysis above.

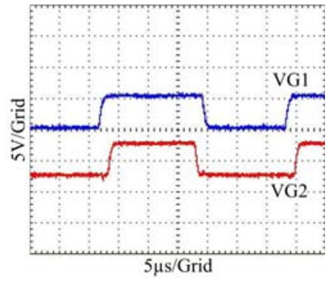


Figure 8.Switching signals VG1and VG2

Figure 9 and Figure 10 show the voltages across the transformer primary and secondary windings with full load. As shown in figures, the voltage amplitudes of each winding are 5V and 2V (decayed 10 times) respectively; the frequencies are both 60 KHz with duty cycle of around 50%; and there are no obvious glitches.

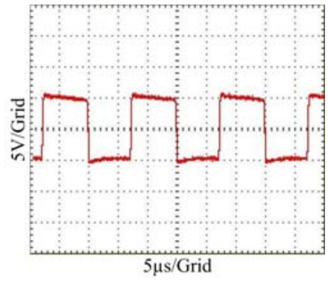


Figure 9.Voltage across primary winding

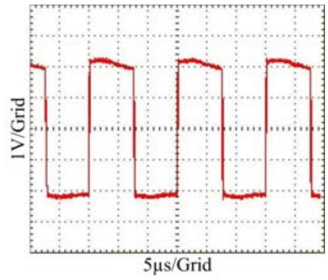


Figure 10.Voltage across one of secondary windings (decayed 10 times)

One of DC voltage outputs and its ripple with full load are shown in Figure 11 and Figure 12. The two curves in Fig. 11 show the potentials at two output terminals with respect to the emitter of the corresponding IGBTs, with amplitudes of +15V and -5V, used to respectively drive the high power devices to switch on and off. As Figure 12 shows，the output voltage ripple is lower than 100mV, that is to say, the ripple coefficient of the output voltage is no more than 0.5%。

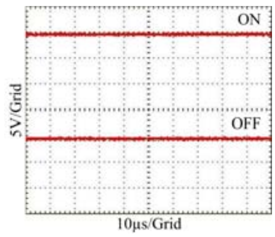


Figure 11.One of DC voltage outputs

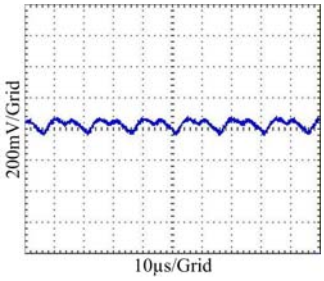


Figure 12.Output DC voltage ripple

VIII. CONCLUSION

Design of switching power converter system of PMSM power driver for HEV has following characteristics: (1) the input voltage of power supply system is in the range of 8-30V, which can be conveniently connected to the vehicle power bus; (2) the switching power converter system will ensure the power supply quality when the input voltage from vehicle fluctuates in the wide range of 8-30V; (3) the design scheme of full bridge switching power converter, instead of four separated integrated DC/DC converters, is an efficient way to reduce the overall cost and size, and will be beneficial to the design of monolithic construction and quickly market development for HEV products.

ACKNOWLEDGMENT

My deepest gratitude goes first and foremost to Professor Xudong Wang, my supervisor, for his constant encouragement and guidance. He has walked me through all the stages of the writing of this paper. Without his consistent and illuminating instruction, this paper could not have reached its present form. Second, I would like to express my heartfelt gratitude to Professor Kunmei Du and Hanying Gao, who led me into the world of power electronics, and gave me their help and time in helping me work out my problems during the difficult course of the paper. Last, my thanks would go to my beloved family for their loving considerations and great confidence in me all through these years.

REFERENCES

[1] William Cai, "Starting engines and powering electric loads with one machine," IEEE Industry Applications Magazine, pp.29-38, Nov./Dec.2006.

[2] T.J.M. Miller, "Brushless permanent-magnet and reluctance motor drives," Oxford, UK: Oxford Science Press, 1989.

[3] N. Bianchi, S. Bolognani and B.J. Chalmers, "Salient-rotor PM synchronous motors for an extended flux-wakening operation range," IEEE Trans. Ind. Applicat., vol. 36, no. 4, pp. 1118-1125, July/Aug.2000.

[4] Arnold N.Alderman, "'Powering up' for the 21st. century: the power supply industry in major transition," The 15th. Conference of China Power Supply Society, pp.1-7, 2003.

[5] Chen Wenjie, Yang Xu and Yang Shuanke, "A design of discrete components based integrated power modules," Proceedings of the CSEE, vol. 23, no. 12, pp.104-110, 2003.

[6] Wang Xinggui, Zou Yingwei, and Liu Jinlong, "Characteristics study of power electronic integrated module used for SMPS," Power Electronics, vol. 38, no. 2, pp.51-53, April 2004.

[7] Sun Tiecheng, Tang Pinghua, Gao Peng and Liu Hongpeng, "Novel full-bridge ZVT PWM DC-DC converter," Proceedings of the CSEE, vol.26, no.6, pp. 83-88, Mar.2006.

[8] Wang Xinggui, Zou Yingwei, and Liu Jinlong, "Modeling and control of full-bridge DC/DC switching power supply," Power Electronics, vol. 41, no. 7, pp.51-53, July 2007.

[9] He Junping, Chen Wei and Jiang Jianguo, "Model & analysis on common-mode conducted EMI of a switched mode power supply," Proceedings of the CSEE, vol.25, no.8, pp.50-55, Apr.2005.

[10] Meng Jin, Ma Weiming, Zhang Lei and Zhao Zhihua, "Method for analysis and modeling of conducted EMI in Switching power converters," Proceedings of the CSEE, vol.25, no.5, pp.49-54, Mar.2005.

[11] Keith Billings, "Switchmode power supply handbook," 2nd. ed., Beijing, China: Posts & Telecom Press, pp.387-427, 2006.

[12] Lotfi A.W., Wilkowski M.A., "Issues and advances in high-frequency magnetics for switching power supplies," IEEE Proceedings, vol.89, no.6, pp. 833-845, 2001.