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Four-Quadrant Converter with the Insulated Gate Bipolar Transistors

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Abstract

A reversible D.C. drive system, which employs a four-quadrant converter with the insulated gate bipolar transistors (IGBT), is presented. The converter circuit employs a "half-bridge" configuration. The operation of the converter was tested at a command frequency of [1÷10]KHz. Except at very high power levels, the four-quadrant chopper has certain advantages such as high operational frequency, smooth and linear control, high efficiency and fast response.

Key words: *half-bridge chopper, IGBT gate drive circuit, PWM command, D.C. motor.*

Introduction

The appearance of power transistors with insulated gate IGBT (Insulated Gate Bipolar Transistor) lead to the necessity of redesigning the power converters structure from the point of view of the gate command and protection circuits [1], [2]. The IGBT advantages are: very high input impedance (voltage controlled device), low level of loses in conduction state, low switching loses, high operating frequency (up to 50KHz), simple protection circuits. They have also a wide area of application from the power point of view 5W÷500KW with a switching frequency over 25KHz, the currents being over 600A and the voltages around [1600÷1700]V. These parameters might become soon obsolete.

Taking into account ideas presented above, the author present in this paper a "half-bridge" converter designed using insulated gate bipolar transistors and dedicated to supplying the separately-excited D.C. motors.

Four-Quadrant Converter

Such D.C. supplies can be found in many industrial processes, e.g. transportation systems, chemical and steel plants etc. Except at very high power levels, the four-quadrant chopper has certain advantages such as high operational frequency, smooth and linear control, high efficiency and fast response [1].

The block diagram of the achieved control system is shown in figure 1. The converter is a "half-bridge" chopper with four-quadrant operation. The hardware configurations of the chopper where the snubber and gate drive circuits are also included.

The voltages $u_i(t)$ and $u_e(t)$ from the reversible chopper's input and output are presented in figure 2. On the hypothesis of perfect semiconductors use, the average value of the output voltage is given by:

$$U_m = \frac{1}{T} \cdot \int_0^T u_i(t)dt = U_n(2 \cdot \frac{t_1}{T} - 1) = U_n \cdot (2\varepsilon - 1) \qquad (1)$$

where:

T = the chopper period;
t_1 = the duration of conduction;
U_n = the motor's nominal voltage;
ε = the duty cycle.

From equation (1) it follows that for $\varepsilon = 50\%$, the voltage on the load circuit is purely alternative, the continuous component being zero. For $50\% < \varepsilon < 100\%$, the voltage applied is positive, continuous and it can be modified between 0 and U_n, for $0\% < \varepsilon < 50\%$, the voltage has the same limits, but in negative domain (fig. 2b).

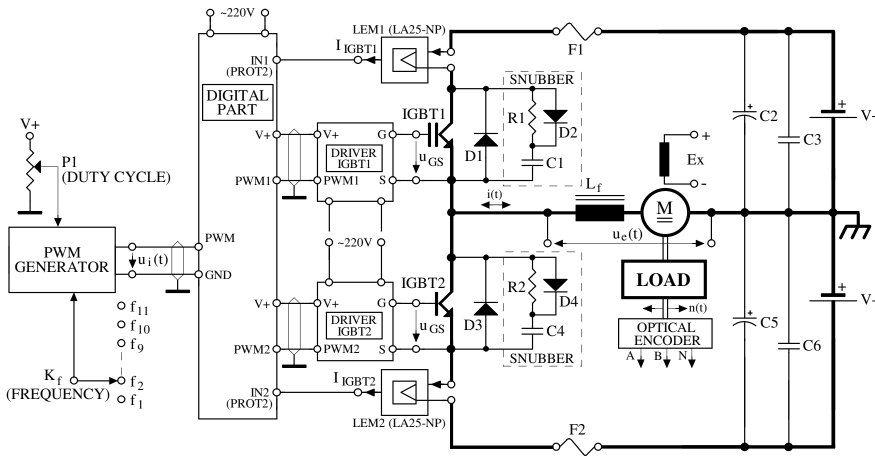
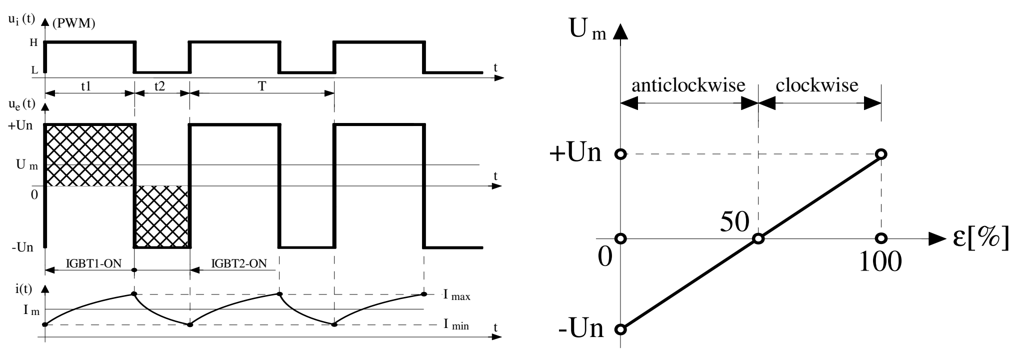


Fig. 1. Block diagram of D.C. drive system.



a. *b.*

Fig. 2. Logic timing diagram for "half-bridge" converter.

IGBT Gate Drive Circuit

For the IGBT command, a positive voltage is needed for charging the input capacity at the transistor's switching on. The switching-off can be done with a negative voltage [1], [2].

The main problem for the switching on is the assurance of a sufficient current during the period of the switching on in order to charge the input capacity in an imposed time. The IGBT switching off begins immediately after the gate-source voltage becomes zero. The switching speed is again limited by the discharging slope of the input capacity through the driver circuit. In figure 3 it is presented the electric schematic for the IGBT gate drive circuit [3].

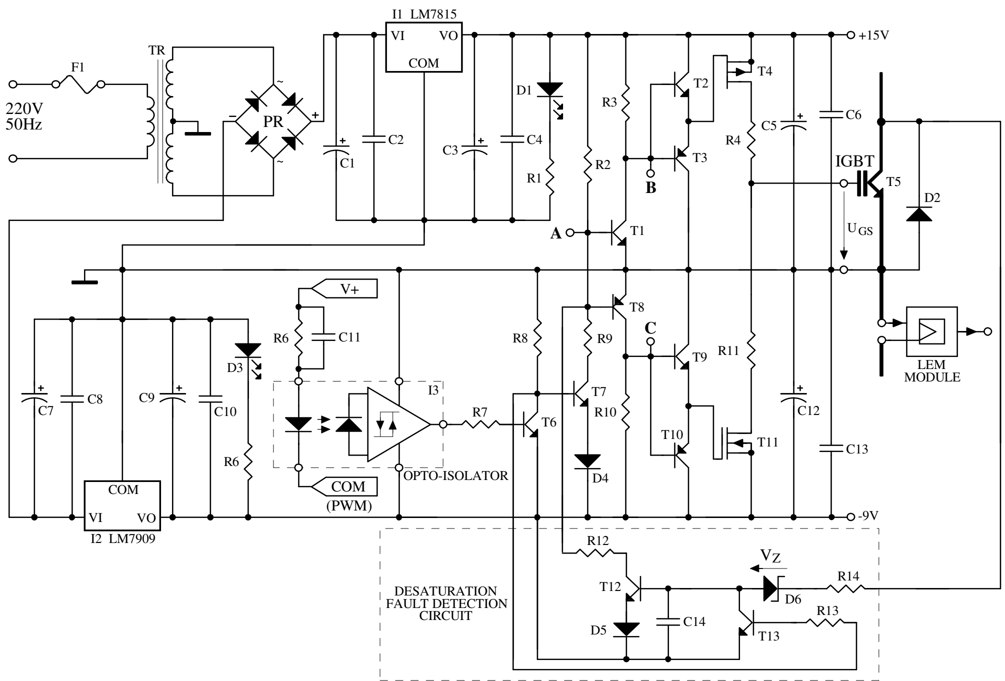


Fig. 3. IGBT gate drive circuit.

The IGBT can be found as a single component per device or as a module with one, two or six discrete components in the same device, the recovering diodes being included in most of the cases. The author used a module with one IGBT, without diode IRGBC40F (160W, 600V, 49A, International Rectifier), which offers flexibility, the user having the possibility to choose any of schematic [7].

The galvanic isolation between the gate drive circuit and the digital command part is provided by a HP2212 optocoupler (Hewlett Packard). Among the features of this optocoupler, it can be mentioned here: TTL, LSTTL and CMOS compatible, propagation time better than 150ns, wide supply range (4.5 to 20 volts), low input current (1.6mA) [5].

The proposed gate drive circuit achieves the voltage bipolar command of the insulated gate bipolar transistor T_5. The circuit contains two complementary MOS transistor T_4 with P-cannel IRF9540 (U_{DS}=-100V, $R_{DS(ON)}$=0.2Ω, I_D=-19A, P_D=150W) and T_{11} with N-cannel IRF540 (U_{DS}=100V, $R_{DS(ON)}$=0.077Ω, I_D=28A, P_D=150W) [8]. When the P-cannel transistor is switched on the IGBT is commanded with a positive voltage (+12V) and the N-cannel transistor is switched on the IGBT is switched off with a negative input voltage (-9V). The command of the MOS transistors is achieved with complementary bipolar transistors: T_2 (npn) and T_3 (pnp) on one hand and T_9 (npn) and T_{10} (pnp) on the other hand. The transistors T_6 and T_7 are used for the amplification of the signal obtained of the optocoupler's output.

Figure 4 shows the electric schematic of the digital command part. Two complementary PWM signals, PWM1 and PWM2, with "dead time" are achieved by a simple combinational logic (fig. 5). The "dead times" were obtained using the monostables I_1 and I_2 (MMC4047) and the R_TC_T assigned circuits.

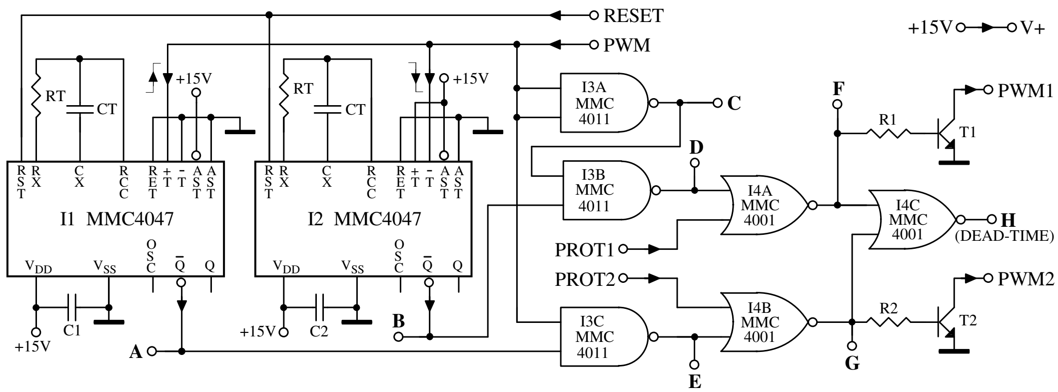


Fig. 4. Logic block diagram for digital command part.

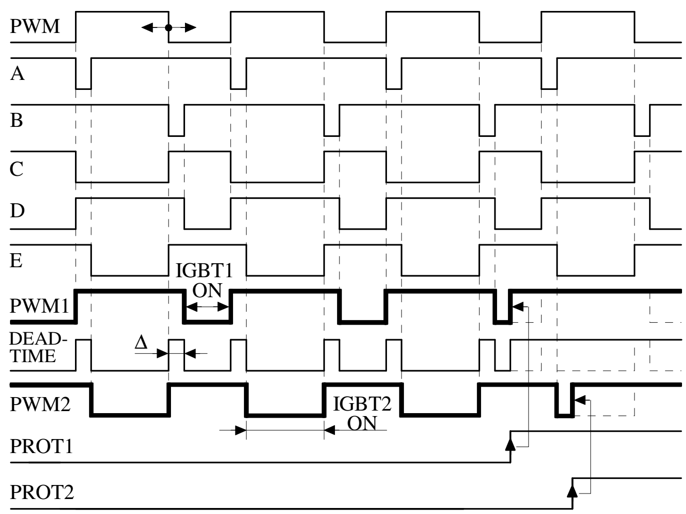


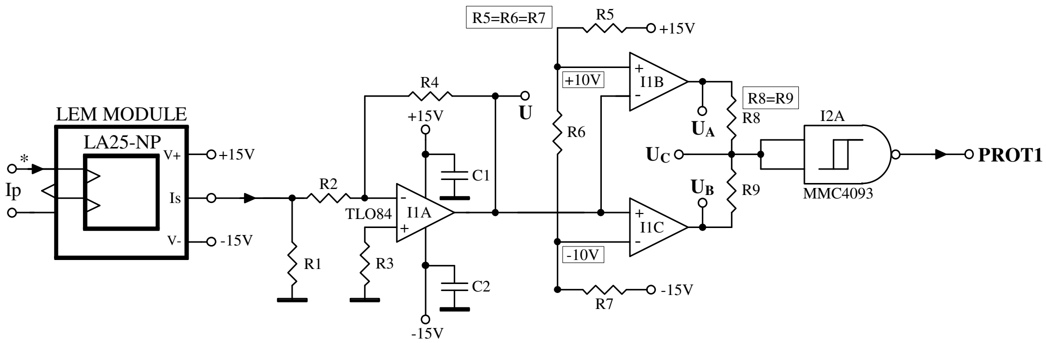
Fig. 5. Logic timing diagram for digital command part.

The main elements of the overload protection circuits are two Hall transducers-LEM modules, which have very high performances (fig. 6) [3], [6]: the electronic measurement of currents: D.C., A.C., impl., etc., with galvanic isolation between the primary (high power) and the secondary (electronic) circuits; global precision: ±10% of nominal current; response time: better than 1µs; bandwidth: 0÷150KHz; linearity: better than 0.1%.

The output of each current measurement channel contains two CMOS signals for protection (PROT1, PROT2), which become active when the current through IGBT overpass the imposed limit for each sense.

Experimental Laboratory System

The experimental research was performed in Electrical Drives Laboratory from the Electrical Engineering Faculty, Technical University "Gh. Asachi" of Iaşi, where it was achieved an electrical drive system using separately-excited D.C. motor. In figure 7 is presented the general view of developed system [4].



U	U_A	U_B	U_C	PROT1
(-15V; -10V)	+15V	-15V	0V	H
[-10V;+10V]	+15V	+15V	+15V	L
(+10V; +15V)	-15V	+15V	0V	H

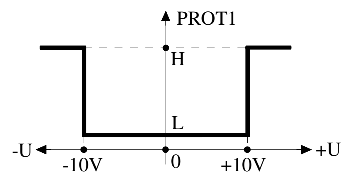


Fig. 6. IGBT protection circuit.

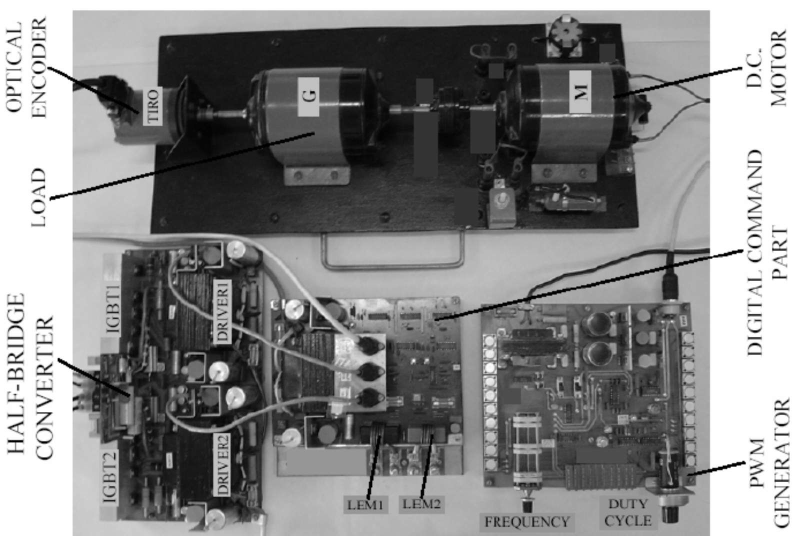


Fig. 7. The experimental laboratory system.

The electric motor uses permanent magnets and is loaded using an identical machine, which operates in a braking mode.

In figure 8 there are presented the command complementary PWM signals for the case of a working frequency of 5 KHz. The imposed ”dead-time“ is 25μs.

The figures from 9 to 11 present the armature voltage and current waveforms under the following working conditions: working at clockwise electrical drive motor, ε=90% (fig. 9); resting motor, ε=50% (fig. 10); working at anticlockwise electrical drive motor, ε=10% (fig. 11).

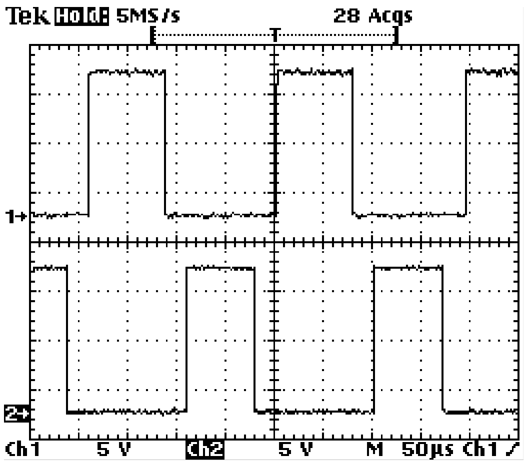


Fig. 8. Control complementary PWM signals.

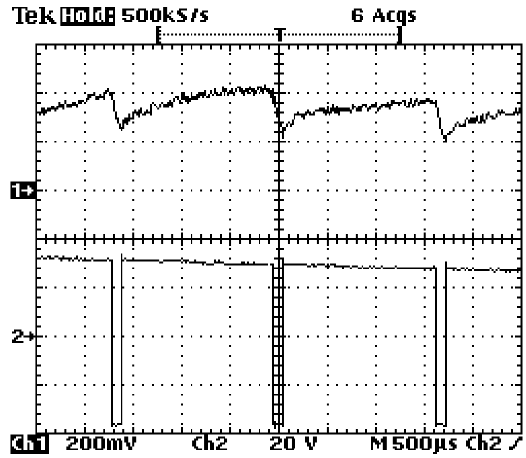


Fig. 9. Armature voltage and current waveform (clockwise).

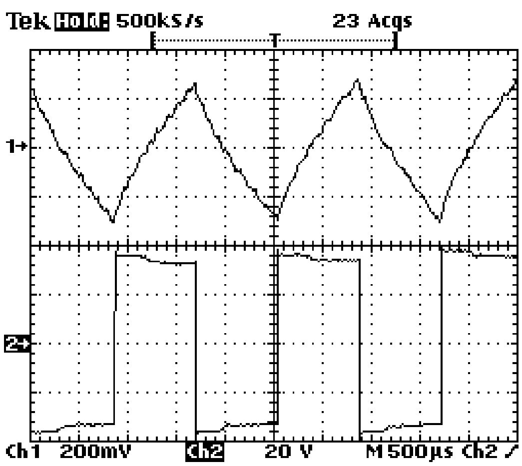


Fig. 10. Armature voltage and current waveform (resting motor).

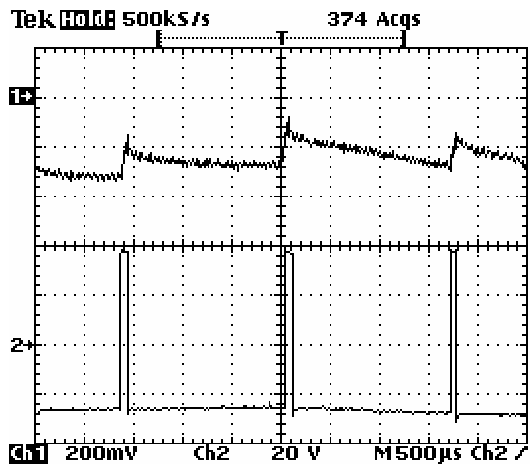


Fig. 11. Armature voltage and current waveform (anticlockwise).

Conclusions

Power electronics is nowadays one of the most dynamic field of engineering. The applications of power electronics are more and more diversified and focuse especially on electric power conversion (converters). The modern solution involve new power semiconductor devices with high performances, dedicated command circuits which achieve multiple specific functions and new control techniques. Thus, the converters structure is much simplified, their volume and weight decrease, they become cheaper and more robust. Furthermore, the conversion quality increase and the disturbances against power supply networks and environment decrease.

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Convertor reversibil cu tranzistoare bipolare cu grilă izolată

Rezumat

Se prezintă un convertor reversibil de tip "semipunte" realizat cu tranzistoare bipolare cu grilă izolată (IGBT). Comanda bipolară în tensiune a IGBT-ului se realizează cu un circuit de comandă conceput cu componente discrete, protecţia la suprasarcină cu traductoare cu effect Hall (Module LEM), iar semnalele PWM complementare cu "timp mort" sunt generate de un bloc digital realizat cu circuite CMOS.