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D.C. DRIVE SYSTEM USING FOUR-QUADRANT CHOPPER

BY

CIPRIAN AFANASOV*

“Ştefan cel Mare” University of Suceava,

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Abstract. This paper presents the study of an electric drive system for D.C. motor speed control, with separate excitation using a full bridge chopper type structure and asynchronous control strategy which function in four quadrants of the system. Paper shows an electric drive system reversible for driving a D.C. motor, with separate excitation. D.C. motor operation is allowed in all four quadrants because it is powered by a chopper composed of IGBT transistors. The chopper is made in the “full-bridge” configuration type. The operation of chopper was tested for command frequencies between 1 and 10 kHz. The advantages that provides the realized drive system are: operating at high frequency, the yield is high, the control is linear, the response is fast. To study the operation of the D.C. motor in all four quadrants was made an electric drive that contains: the power circuit, logical control of transistors, signal interface boards. Control system of the D.C. motor allows its rotation in both directions and energy recovery braking load.

Key words: asynchronous control; D.C. motor; four-quadrant chopper; *H*-bridge converter.

1. Introduction

The tendency of power electronics system is to become more and more compact and smaller, fact that leads to an increased switching frequency. An increase of switching frequency has the effect of decreasing the mass of the magnetic core of the transformer (Kazimierzuk & Czarkowski, 1995; Steigerwald, 1998). When the switching devices like MOSFET or IGBT

* *e-mail*: aciprian@eed.usv.ro

perform hard switching, the higher switching frequency increases, the much switching losses are generated. Also according to that, the whole system efficiency go down. So, to solve this problem, many soft switching converters that employ resonant networks have been proposed. But in the two stage inverter systems, although the converter stage performs soft switching, if the inverter stage performs hard switching, the whole system efficiency will be decreased (Jung *et al*., 2008).

Once with the use of IGBT (Insulated Gate Bipolar Transistor) power transistors was needed a redesign of the converter structure. The changes occurred relates at the command of the gate and to protection circuits (Mohan *et al*., 1989; Williams, 1987; Băluță, 2004).

The advantages offered by an IGBT transistor would be the followings:

a) losses in conduction state are very low;
b) losses in switching state are low;
c) the input impedance is very high;
d) operating frequency can reach up to 50 kHz;
e) the protection circuits are relatively simple.

The application area of IGBT power transistors is very wide, they are used mostly for power between 5 W and 500 kW to a switching frequency about 25 kHz and the voltages nearby 1,700 V.

Taking into account the ideas mentioned above, we present in this paper a ”full-bridge“ converter type designed using IGBT transistors used to supply the separately-excited D.C. motors.

Any D.C. machine needs to operate be supplied with D.C. voltage. Typically this voltage has to be produced starting from the A.C. supply voltage.

D.C. machines usually are not satisfied with a voltage obtained by simple filtration and recovery, requiring a continuous variation of it. Continuous change of the supply voltage can be realized by changing the A.C. voltage through autotransformers before rectifier or after rectifier A.C. voltage through static converters in commutation.

Modern devices that are equipped with power supply on the principle of PWM switching are known in the literature under the names of *Chopper* or *Switch Mode Power Supply*.

The chopper's used to adjust the speed in the field of electric traction facilitates regenerative braking of D.C. machine.

This is the reason for which the chopper's is widespread.

The advantages offered by chopper's are: low time response; small size; low weight; flexibility in the command; increased performance.

2. Four-Quadrant Chopper and Asynchronous Control Strategy

The four-quadrant chopper used for drive the D.C. motor is made by connecting conveniently of a four single-quadrant choppers connected in a *H*-bridge.

In antiparallel with each single-quadrant chopper is connected a diode.

This circuit configuration allows current circulation from the source to the D.C. motor, and from the machine to the power supply in the case of the generator regime.

If is analysed the eq. of power, $P_e = U_e I_e$, (U_e – output voltage; I_e – output current) it results that the four-quadrant chopper allows power circulation in both directions

By changing the direction of current, I_e , leads to getting a bidirectional converter and by changing the polarity of voltage, U_e , leads to getting a reversible converter.

In Fig. 1 is represented the topology of the converter with IGBT transistor. It is composed of two arms, *A* and *B*, each one built up with two transistors.

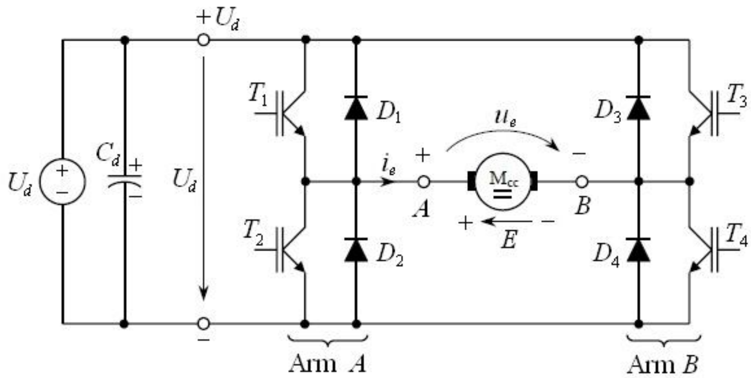


Fig. 1 – Full bridge D.C.–D.C. converter with IGBT transistors.

The four transistors of chopper are controlled simultaneously in all four quadrants. In the case of PWM control strategy with an asynchronous voltage switching, are controlled individually each transistors from *H*-bridge.

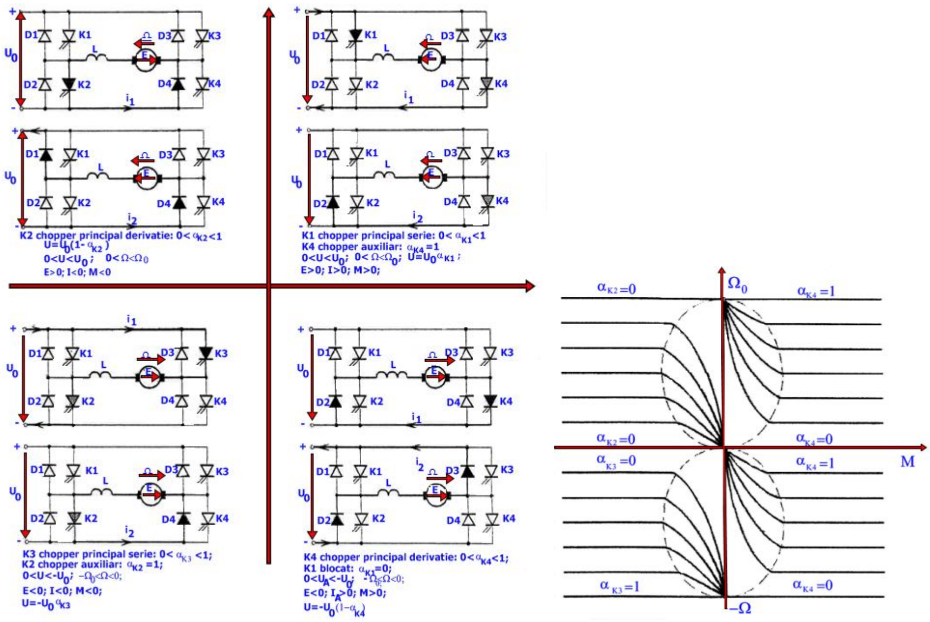
Thus in first machine's quadrant is running as a motor in direct motion and speed control is made through the command of chopper K_1; the chopper K_4 is in constantly conducting state and K_2 and K_3 choppers are blocked.

The speed will be maximum when duty cycle of chopper K_1 is 1 and minimum when duty cycle of chopper K_1 is 0. In the sequence of K_1 conduction state, current flows on the route +, K_1, L, rotor, K_4, –.

Current increases exponentially while loading the inductances from the rotor circuit. In the lock sequence of K_1 current through the motor keeps the meaning, decreasing exponentially over time, due to energy that is stored in inductances on route: K_4, D_2, L, rotor.

In the second quadrant, machine operates in generator regime, under the action of potential type resistant torque. In this case K_2 is the main chopper and the speed is adjusted by changing the duty cycle of chopper K_2.

In Fig. 2 these paths are presented for PWM control strategy with an asynchronous voltage switching.



a *b*

Fig. 2 – *a* – Currents trails of the four-quadrant chopper and asynchronous control strategy; *b* – mechanical characteristics.

A disadvantage of the controlled synchronous chopper is the most complex command because must be independent controled each of the four choppers to be in the four quadrants.

Another disadvantage is the presence of interrupted conduction current, that leads to nonlinear characteristics in all four quadrants.

3. The Structure of Control Circuit for IGBT Power Transistors

3.1. PWM Generator Realized with Discrete Circuits

Triangular and rectangular voltage generator applied to the oscillator are produced by two operational amplifiers LM741 under one integrator and one comparator with hysteresis (Fig. 3). Triangular voltage obtained in the first operational amplifier output will be applied to a comparator LM339 performing modulation in duration. In this way was made rectangular voltage generator to control the power transistor switch converter (National Semiconductor, 2002). The resistance of potentiometer P_1 sets the frequency of the PWM signals and the resistance of potentiometer P_2 sets the filling factor of the signals. The output voltage of this type of PWM signal generator is connected to the power switch transistor gate in four-quadrant chopper and asynchronous control strategy. Control of IGBT transistor is made with four signals: PWM_K_1, PWM_K_2,PWM_K_3, PWM_K_4.

For the electrical connection order to be performed between the signal generator and IGBT transistors was necessary to make an interface board that ensuring electronic link between the command and force.

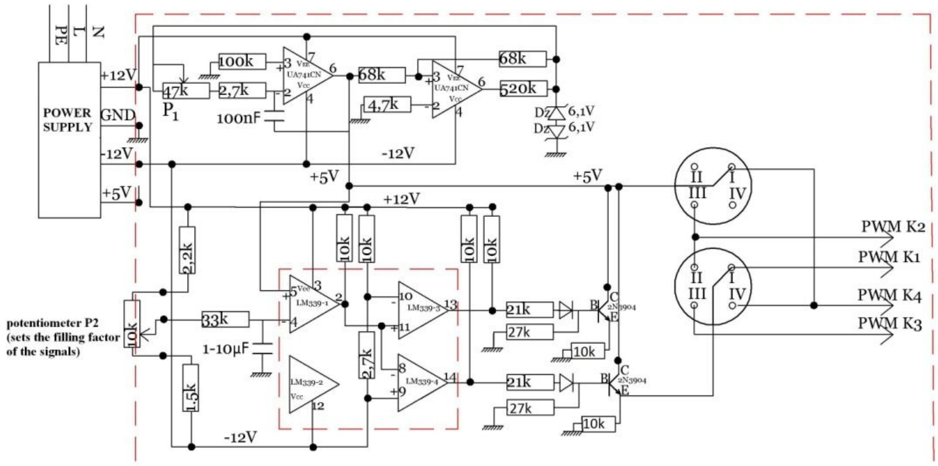


Fig. 3 – Control circuit scheme for PWM generator with an asynchronous voltage switching strategy.

3.2. PWM Signal Adjustment Circuit BOARD 2s SKYPER 32 PRO R

PWM control signals of power transistors are sent to the two drivers by means of an interface plate that provides the following functions:

a) PWM signals are galvanically insulated;

b) enables the establishing control mode for different configurations of transistors IGBT inverter;

c) raise the drivers IGBT control signals from 5 V to 15 V;

d) reports optically presence of the control voltage;

e) reports optically the state of IGBT drivers;

f) provides link with power sources of different circuits;

g) provides start and stop of ATX type switching sources used in the power circuits.

Galvanic insulation between control and force was made with performance optocouplers that have the ability to work at a frequency of several hundred kHz. Since the output of the optocoupler is low was designed a circuit that raises to 15 V signals; this value is necessary to the input PWM of IGBT drivers.

Due to the facilities offered by the family of modules SEMIX and having the desire to realize a high power chopper which shall be used in different configurations we have used for its construction, two IGBT modules of the range SEMIX2s, IGBT modules with the name SEMIX302GB126HDs.

The characteristics of this family lead to the realization of a compact inverter with low inductance. If the D.C. circuit is made so that the routes of connecting wires have as little inductive character as possible, the spikes that occur in the process of switching the IGBT transistors will be significantly reduced. Due to the direct connection of the PWM driver to the power module is obtained an optimal control of transistors and electrical noise and losses on connection wire and connectors are removed. Using the family modules SEMIX, entire design of the inverter is simplified significantly.

To control the two IGBT modules SEMIX302GB126HDs type, we chose an IGBT driver offered by the company SEMIKRON. Driver's name is SKYPER 32 PRO R, and it is a professional version and top of the range of the drivers for IGBT modules type chosen (Hermwille, 2004).

3.3. Power Circuit of Full Bridge Four-Quadrant Chopper

The power circuit is composed from a constant voltage source and a four IGBT transistors connected in full bridge. Voltage source is made of a single-phase bridge rectifier and two 4,700 μF capacitors (450 V) series. We used two capacitors connected in series in order to be created an artificial neutral point. The connection to the neutral is necessary for some control strategies of the D.C. motor.

The four-quadrant chopper is realized by using two arms of semiconductor elements in modular form. Each arm includes two high power IGBT transistors which, in turn, are connected in antiparallel with a diode. Nominal current of IGBT transistor is 200 A in the case of long-term use regime, and a maximum current of 300 A for a time of 10 s. Nominal voltage of transistors is 1,200 V. Same voltage and current values are also valid for diode.

4. Experimental Results

Experimental testbench in order to verify the operation of the full bridge chopper and PWM control strategy with an asynchronous voltage switching is shown in Fig. 4.

In figures below are presented waveforms for voltages and currents taken from the full bridge chopper at different values of the filling factor.

In Fig. 5 is represented on channel 1 the reference voltage in the form of a triangular signal on pin 6 of operational amplifier UA741. This signal is designed to establish the frequency of PWM control signal. From the sample 3 of oscilloscope was taken voltage command signal, that is designed to determine the filling factor of the PWM signal. By comparison of the two signals described above, we obtain the control signal of the IGBT transistor, signal that can be seen on channel 2 of the oscilloscope.

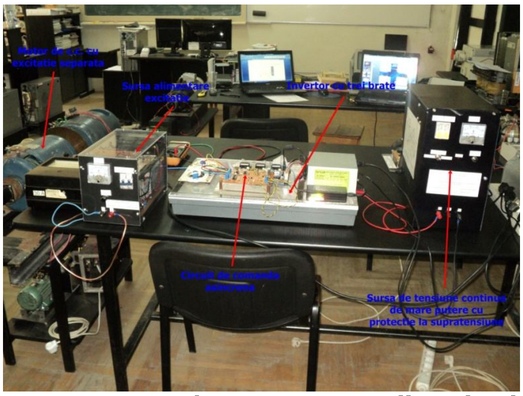


Fig. 4 – Image with montage practically realized.

In the case of Fig. 6 *a* is represented the control voltage taken from terminals 13 and 14 of the integrated circuit LM339. It is noted that the dead time of the control voltage of the transistors T_1, T_3 and the input to the conduction of the transistors T_2, T_4 is 0. After the implementation of the dead time, with a circuit consisting of an *RC* group and a signal inverter, we have obtained a guard time of 14 μs (Fig. 6 *b*).

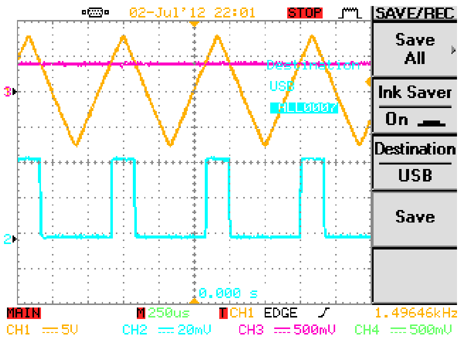
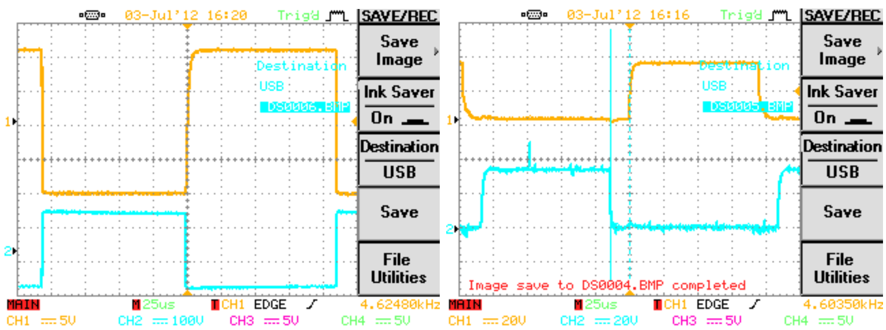


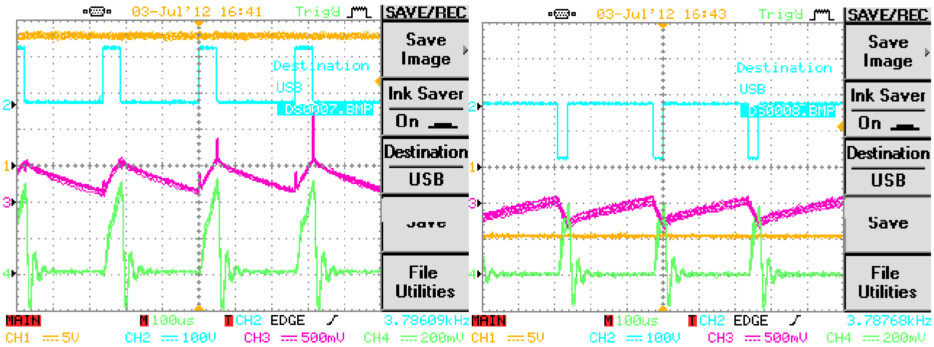
Fig. 5 – Small filling factor of PWM signal.



a *b*

Fig. 6 – *a* – Control signals without dead time; *b* – PWM signals with dead time.

In Figs. 7 *a* and 7 *b* is represented on channel 1 the motor speed, on channel 2 the voltage at the motor terminals, on channel 3 current through the motor and on channel 4 the current drawn from the source.



a *b*

Fig. 7 – Power signals of the chopper:
a – when speed is positive; *b* – when speed is negative.

First figure is obtained when operating the machine in quadrants I and II, where speed is positive, and second when we operating the machine in quadrants III and IV.

5. Conclusions

Having in view the experimental determinations the following conclusions are drawn:

1. The control circuit provides with success the transition of the machine in another quadrant from the motor regime to generator one.

2. For this type of chopper command is complex because you must independently control that each of the four chopper is in the four quadrants.

3. A disadvantage is the presence of interrupted conduction current, which leads to nonlinear characteristics in all four quadrants.

4. The use of converter in an application is requested by a task that must be operate, in its turn, also in four quadrants.

REFERENCES

Băluță Gh., *Acționări electrice de mică putere*. Edit. Politehnium, Iași, 2004.

Hermwille M., *Plug and Play IGBT Driver Cores for Converters*. Power Electron. Europe, *2*, 10-12 (2006).

Jung D.Y., Ji Y.H., Kim J.H., Won C.Y., Jung Y.C., *Soft Switching Boost Converter for Photovoltaic Power Generation System*. Power Electron. a. Motion Control Conf., September 2008. EPE-PEMC 2008, 1929-1933.

Kazimierzuk M.K., Czarkowski D., *Resonant Power Converters*. J. Wiley & Sons, NY, 1995.

Mohan N., Undeland T.M., Robbins W.P., *Power Electronics: Converters, Application and Design*. John Wiley & Sons, New York, 1989.

Steigerwald R.L., *A Comparison of Half-Bridge Resonant Converter Topologies*. IEEE Trans. Power Electron., **3**, *2*, 174-182 (1988).

Williams B.W., *Power Electronics: Devices, Drivers and Applications*, John Wiley & Sons, New York, 1987.

* * * *Application Manual Power Modules*. SEMIKRON International, 2011.

* * * http://www.SEMIKRON.com

* * * *SEMiX® IGBT Modules for Fast, Solder-Free Assemblies*. SEMIKRON Internat. GmbH, Nürnberg, Deutschland, 2011.

* * * *Op Amp Circuit Collection*. National Semiconductor, Application Note 31, September 2002.

* * * *Trench IGBT Modules SEMiX302GB126HDs*. Rev. 27 – 02.12.2008 © by SEMIKRON.

SISTEM DE ACŢIONARE DE CURENT CONTINUU CARE UTILIZEAZĂ UN CONVERTOR ÎN PATRU CADRANE

(Rezumat)

Se prezintă un sistem de acţionare electrică pentru controlul vitezei motorului de curent continuu cu excitaţie separată care utilizează în circuitul de forţă o structură de tip punte *H*. Strategia de control a punţii *H* este una asincronă, aceasta permiţând funcţionarea în patru cadrane a sistemului. Convertorul realizat este bidirecţional şi reversibil. Funcţionarea convertorului în patru cadrane este condiţionată de tipul cuplului rezistent de la arborele motorului care trebuie, la rândul său, să lucreze în patru cadrane. Pentru cazul specific al unui reglaj de viteză cu motor de curent continuu, acţionarea electrică permite rotirea rotorului în orice direcţie şi există de asemenea posibilitatea recuperării energiei de frânare a mişcării.