Evaluation of the Used PWM Techniques in the Control of Brushless DC Motors

Ivan Petrov Maradzhiev and Dilyana Marinova Ognyanova

Abstract – **At present the brushless DC motors find increasingly wider application, thus different methods for their control are developed. The paper presents varieties of pulse-width modulation applied in control of these types of motors. It is researched, analyzed and evaluated the energy exchange between motor and power source using the unipolar modulation of upper and lower transistors of voltage invertor, PWM_PWM and PWM_ON modulation. The load characteristics in each of examined PWM technics are researched, as well.**

Keywords – **Motor control, brushless motor, power electronics, modulations**

I. INTRODUCTION

In the dynamic life of modern society time and its optimal use is of great importance. It becomes possible by increasing the degree of automation of the surrounding environment. Automation helps in solving both specific and global problems, regarding the control of various mechanisms. The trend observed in modern automatic is the increase of share of brushless DC motors, such as low-power actuators, at the expense of AC motors. There are various power schemes and methods for power control. However, the requirement for modern automated systems is connected with higher efficiency and smaller electromagnetic interference. Brushless motor technology allows achieving it. These machines combine high reliability with high efficiency at lower price compared to brush DC motors in spite of the identical characteristics [1].

A specific feature of brushless DC motors is the requirement for invertor powering of their phase windings and feedback of the rotor position (Fig. 1). This is all needed to determine the moments of invertor commutation. Determination of rotor's position can be done with Hall sensors which are installed on the motor or without sensors by measuring back electromotive force (emf) generated in the stator windings during rotation of the rotor [1][2].

A three-phase brushless motor is powered by three-phase voltage system, in which voltages are shifted by 120^o from each other. The voltage applied to the phase windings of the motor can be expressed by Eq.1:

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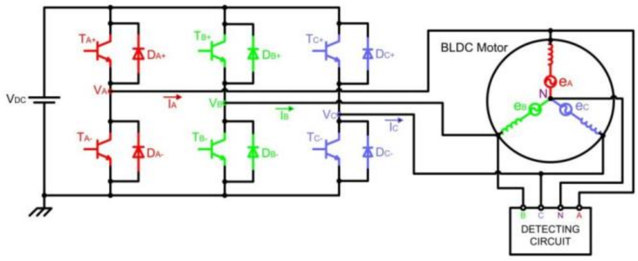

Fig. 1

$$V_a = Ri_a + L\frac{di_a}{dt} + e_a$$
$$V_b = Ri_b + L\frac{di_b}{dt} + e_b \qquad (1)$$
$$V_c = Ri_c + L\frac{di_c}{dt} + e_c$$

where: R - active resistance of the windings; i - current flowing through the windings; **e** - the generated back emf in the motor windings. That back emf can be expressed by Eq.2:

$$e_a = K_e + \phi(\Theta)\omega(t)$$
$$e_b = K_e + \phi\left(\Theta - \left(\frac{2\pi}{3}\right)\right)\omega(t) \qquad (2)$$
$$e_c = K_e + \phi\left(\Theta + \left(\frac{2\pi}{3}\right)\right)\omega(t)$$

where: K_e - voltage constant of the motor; ω - speed of rotation; ϕ - magnetic flux; Θ - position of the rotor [4][5].

Eq. 1 and Eq.2 shows that the speed of rotation of the motor depends on the value of the applied voltage to the motor windings [1]. So the adjustment of the rotational speed of the motor requires regulation of its voltage. Therefore for the control of brushless machines various PWM technics are developed, which adjust the average value of the applied voltage. This present report examines the most common modulations - unipolar modulation of upper and lower transistors of the voltage invertor, PWP-PWM modulation and PWM-ON modulation. In the research is used development system DRV8312-C2, which includes microcontroller and TMS30F28035 and DRV8312 Three-Phase PWM Motor Driver.

TMS320F28035 are part of the family of C2000 microcontrollers, which enable cost-effective design of intelligent motor controllers by reducing the system components and increasing efficiency. The DRV8312 is high performance, integrated three-phase motor driver with an advanced protection system [6][7]. Fig. 2 shows a block diagram of the system.

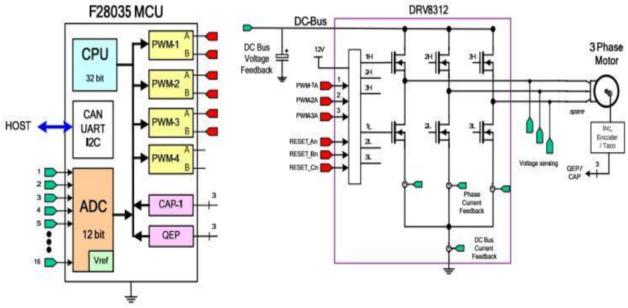

Fig. 2.

II. Types of Modulations Used for Control of Brushless DC Motors

A. Unipolar modulation of upper and lower transistors of the three-phase voltage inverter

Unipolar PWM is one of the most widely used modulation for electric drives. Its feature is that in the three-phase voltage inverter only the lower transistors of the inverter are modulated but the upper are permanently switched on (at a lower unipolar transistors, it’s opposite for upper unipolar modulation). Time-diagram of this type of modulation, and the synchronization with the sensors of position for one cycle of the algorithm of the phase shifting coils is shown at Fig. 3. In comparison with bipolar PWM in unipolar PWM the voltage pulsations are reduced by half. Unipolar PWM is also called "soft" switching modulation [3].

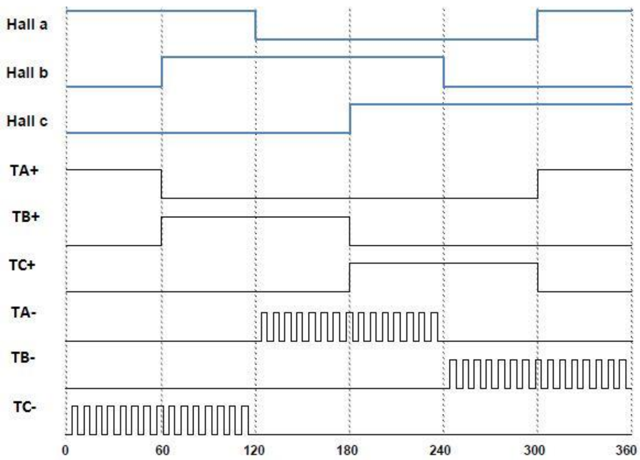

Fig. 3.

B. PWM-PWM modulation

This type of modulation is shown in FIG. 4. In its essence it is a symmetric PWM (PWM-PWM), at which complementary phased modulation is performed, phase A- transistors TA + and TA-; Phase B - TB + and TB-, and for phase C - TC + and TC- Fig. 1. The duration of modulation is 2 steps [2].

This technique of modulation is used in the low voltage power systems, and is characterized by small switching losses.

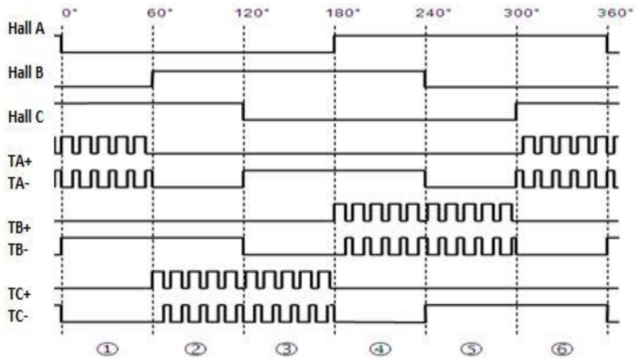

Fig. 4.

C. PWM-ON modulation

Mixed PWM (PWM-ON) is shown in Fig.5. When there is complementary, phased modulation for phase A- TA + and TA-; Phase B - TB + and TB-, and for phase C - TC + and TC-. The duration of the phased modulation is one step. Additional second step is uncontrolled (hard switching) [2].

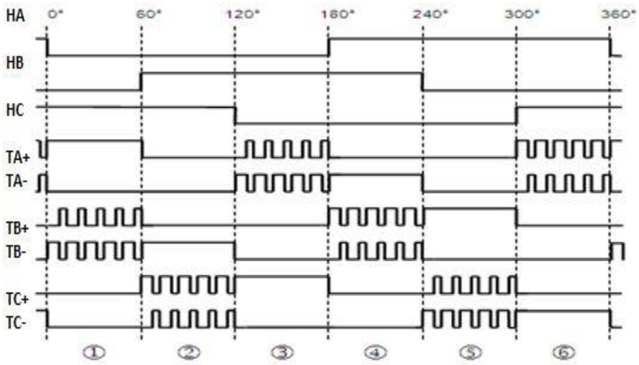

Fig. 5.

The high side power device is chopped in 1/6 fundamental period and duty ratio is derived from the speed reference. Similar control signal is applied to the low-side power device with 180º shift. These control signals are applied to the other two phases with 120° shift. As the high-side device is with chop control, the associated low-side power device is triggered by the inverse signal of chop control.

It is used in low powerful electric drives, in order to reduce commutation losses and therefore thermal losses, and electromagnetic noise, as well.

III. Experimental Results

The experimental results are made by the DRV8312-C2 evaluation board and brushless DC motor type DT4260-24-055-04 (24V, 55W). The speed of the motor is set to 1500rpm. The frequency of the PWM signals is 20 kHz. The control signals are fed to the PWM_X and RESET_X inputs of the DRV8312 chip [6][7]. By using the principle of operation of the three-phase driver, modulation techniques described above are realized and tested.

A. Waveforms of the supply current for different types of PWM

On Fig. 6 are shown waveforms of the current consumed from the supply source and a PWM signal to one of the RESET inputs of the driver. These waveforms are for unipolar modulation of upper transistors.

A specific feature is the appearance of negative peaks of the current consumed by the power source on each 120 electric degrees.

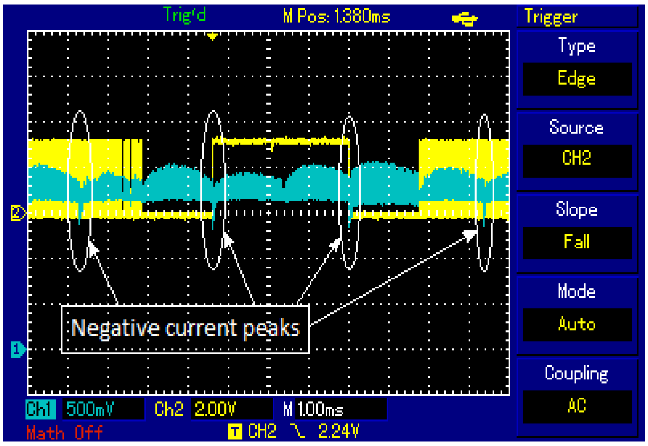

Fig. 6. Supply current (trace1), RESET_B signal (trace2) for unipolar upper transistors modulation

These negative peaks are caused by stored energy in motor windings inductance Eq. 3. They appear when two lower transistors of the inverter change their conditions.

$$W_L = \frac{I^2 L}{2} \qquad (3)$$

From the moment of switching off a bottom transistor until the moment of switching on the other bottom transistor, the energy in the phase inductance changes its polarity. The energy that is stored in inductance becomes negative and returns to the power source, using the built-in reverse diodes of the MOSFET transistors in the three-phase voltage inverter.This process is illustrated in Fig. 7.

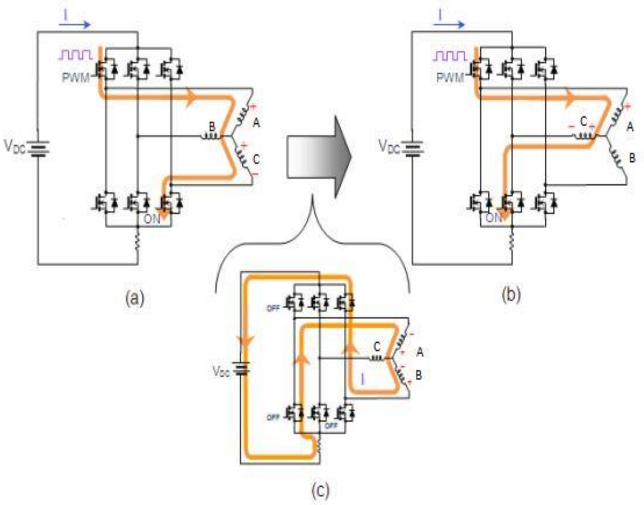

Fig. 7.

On Fig. 8 are shown waveforms of the current consumed from the supply source and a PWM signal to one of the RESET inputs of the driver. These waveforms are for unipolar modulation of lower transistors.

Again, there are negative peaks in the form of the total current. The cause is the same as described above with the difference that occurs when commutation between two upper transistors happen.

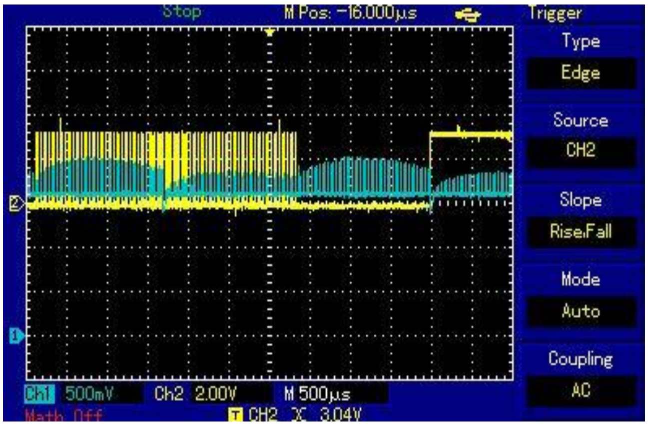

Fig. 8. Supply current (trace1), RESET_B signal (trace2) for unipolar lower transistors modulation

On Fig. 9 are shown waveforms of the current consumed from the supply source and a PWM signal to one of the RESET inputs of the driver when PWM-PWM modulation is tested. With this type of modulation of the transistors, the negative peaks of the total current are seven times greater than its peaks in unipolar modulation. The process of generation of these peaks is identical like in unipolar modulation of top transistors. These peaks are main cause of generation of electromagnetic noise. Also, when the battery power supply is used such negative peaks are not conducive to the battery.

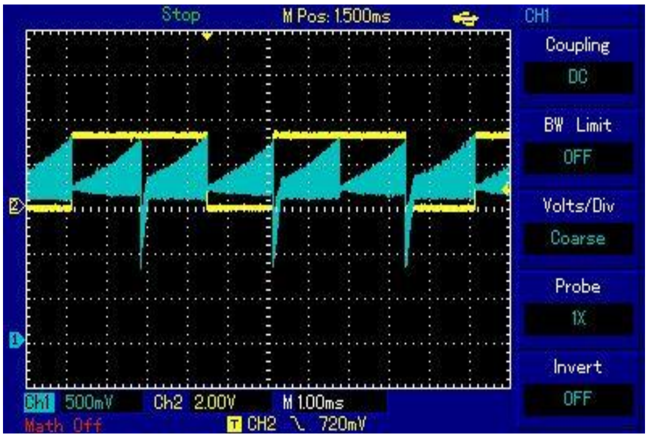

Fig. 9. Supply current (trace1), RESET_B signal (trace2) for PWM-PWM modulation

On Fig. 10 are shown waveforms of the current consumed from the supply source and a PWM signal to one of the PWM inputs of the driver when PWM-ON modulation is tested. At this type of modulation of the transistors, it’s clearly seen that there are no negative peaks in the form of the current consumed from the power source.

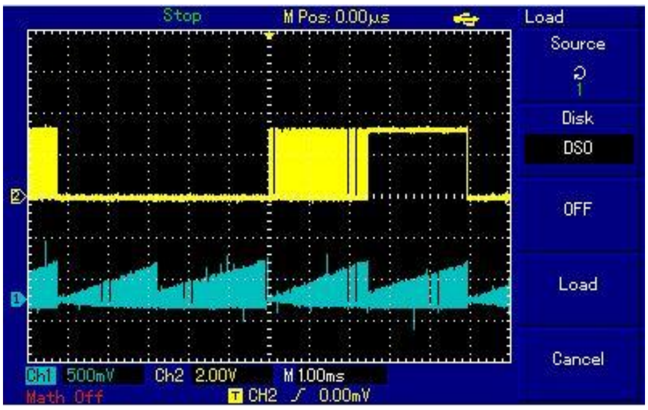

Fig. 10. Supply current (trace1), PWM_B signal (trace2) for PWM-ON modulation

This leads to less-electromagnetic noise. This modulation is suitable for use with battery power supply.

B. Load characteristics

Load characteristics of the motor are made with the modulation techniques described above. For that purpose, brushless motor is connected to another DC motor type NISCA MM5475B, who works in generator mode and serves as a load. The speed of the brushless motor without load is set to 1500 rpm. Torque-speed characteristics are shown on Fig. 11.

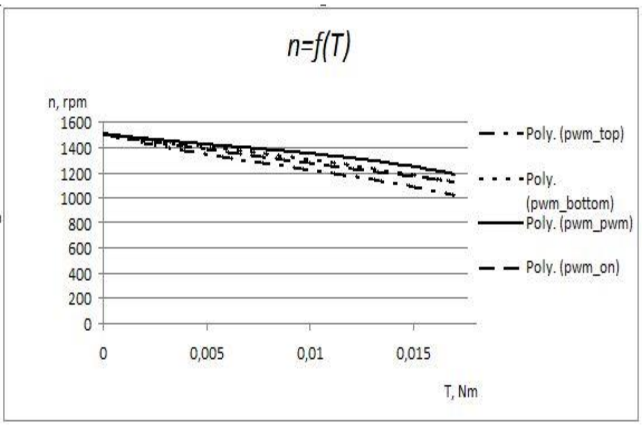

Fig. 11. Torque-speed characteristics of four types of modulations

It is noticeable, that the load characteristic by using PWM-PWM modulation is hardest. For this method of modulation when the load is 17mNm the speed of the motor drops by 310rpm. The softest load characteristic is obtained by using unipolar modulation of top transistors. In this case with the same load the speed drops by 500 rpm. The load characteristics by using unipolar modulation of lower transistors and PWM-ON modulation are identical.

C. Evaluation of current consumption from the power source

Along with the load characteristics for four types of modulation the current consumption from the power supply is measured. The change of the current by increasing the load of the motor is shown in Fig. 12.

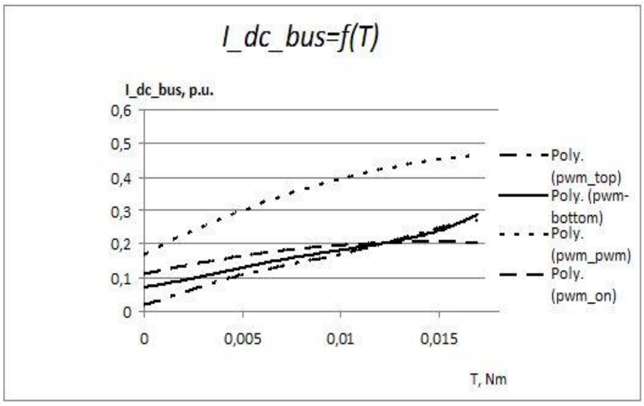

Fig. 12.

The value of current is given in relative units compared to the maximum motor current. It is noticeable that the PWM-PWM modulation consumes approximately twice as large current compared to the PWM-ON modulation. This is the reason for the hard load characteristic of the PWM-PWM modulation.

IV. CONCLUSION

The presented four types of modulation techniques used in control of brushless DC motors demonstrate different behavior in terms of current consumed from the power source. The experiments show that the unipolar modulation of upper or lower transistors leads to generation of negative peaks on the total current on every 120 electric degrees. These negative peaks are especially large in PWM-PWM modulation. This is the main disadvantage of these types of modulation, because negative current peaks are source of electromagnetic noise. In contrast, PWM-ON modulation has no such negative current peaks. Furthermore the research proved that the PWM-PWM modulation is suitable for use in bigger loads at the expense of the current consumed from the power supply, while PWM-ON modulation is suitable for use in battery-powered electric drive and also in environments where there are increased requirements in terms of electromagnetic noise.

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