Trends in the Education of the Modern Power Electronics and Motor Drives

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Abstract – ***The paper shows the technical aspects in the education of the modern power electronics and motor drives. In the master degree course, as a part of the student laboratory work is used the medium Voltage Digital Motor Control (DMC) kit, DRV8412-C2, from Texas Instruments. The software available with the kit is completely open source, which allows students to create their own projects and thus to better understand the basics of applying digital signal processor (DSP) in power electronics and digital motor drive control. The Master's thesis results are reported in the paper, which consist of a new software realization for controlling DC motors with bipolar PWM and unipolar PWM in the same mode of the driver DRV8412 operation. This removes the need for hardware changes in the kit when training students the various methods of modulation. The experimental results are presented.***

Keywords – **Digital motor control, DC motor .**

I. Introduction

The paper examines some trends in the education of the modern power electronics and motor drives. Universal, brushed DC and stepper motors comprise the majority of motor applications given their low cost and simplicity of control. The use of the digital motor control allows more complex and more intelligent types of motor control [4]. The students in the field of power electronics and motor drives are expected to be good with hardware and software. They need to understand not only the principles of motor control, but also digital signal processing, as well as analog and digital circuitry. The students need to graduate with skills that make them easily marketable to potential employers [3].

To meet the high requirements and competencies that are placed on the students of the power electronics, in the master degree course, is used the Medium Voltage Digital Motor Control (DMC) kit, DRV8412-C2, from Texas Instruments (TI) as a part of the student laboratory work [4, 5].

The software available with the kit is completely open source, which allows students to create their own projects and thus to better understand the basics of applying digital signal processor (DSP) in power electronics and digital motor drive control as well as to prepare their Master's thesis.

The motor control techniques are realized using the TMS320F28035 microcontrollers and the DRV8412 Dual Full Bridge PWM Motor Driver. TMS320F28035 devices 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 DRV8412 are high performance, integrated dual full bridge motor drivers with an advanced protection system [5]. In the DRV8412 DMC Kit are included two brushed DC motors and 8-wire bi-polar stepper motor (Fig. 1).

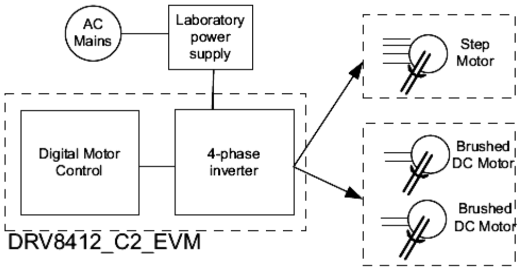

Fig. 1. Block Diagram for a Typical Motor Drive System Using

II. PWM Modulation Technique for Brushed DC Motor Control

The overall system implemention of a 2-axis brushed DC motor is depicted in Fig 1. In this system, current control of the brushed DC Motor will be demonstrated. The brushed DC motors are driven by the conventional H-bridge configuration (Fig. 2). With the flexibility of four switches, a number of different control methods (bipolar or unipolar) can be used to produce fourquadrant output voltage and current [1, 2]. The waveforms for bipolar PWM voltage switching are shown in Fig. 3.

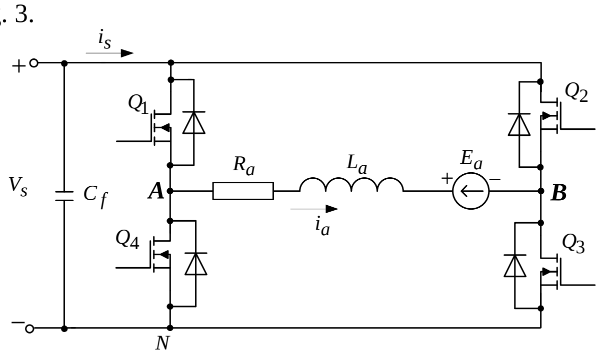

Fig. 2. Four-quadrant H-bridge converter

During the on-period for Q1 and Q3 $(0 \le t \le T_{on})$, when $v_a(t) = V_s$ (Fig. 2d)

$$V_S = R_a i_a + L_a \frac{di_a}{dt} + E_a \tag{1}$$

which yields

$$i_a(t) = \frac{V_S - E_a}{R_a}\left(1 - e^{\frac{-t}{\tau_a}}\right) + I_{a_{\min}} e^{\frac{-t}{\tau_a}} \tag{2}$$

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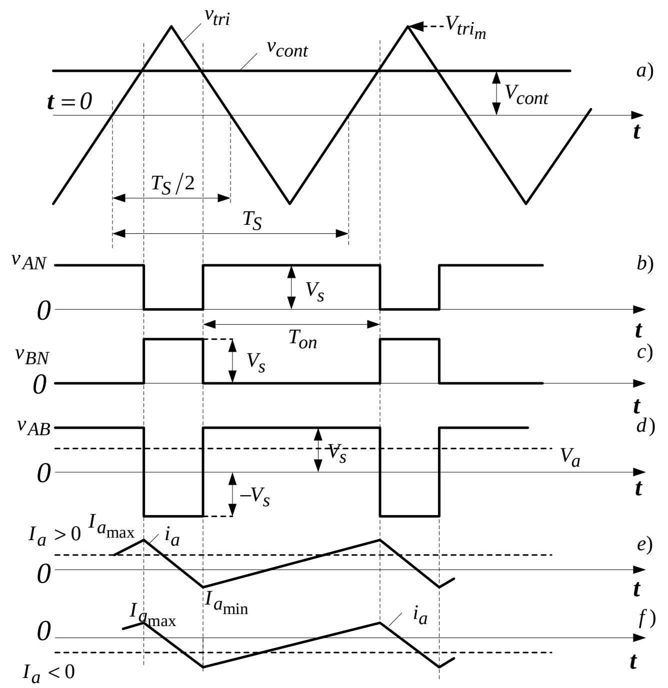

Fig. 3. PWM with bipolar voltage switching

During the on-period for Q2 and Q4 **(**$T_{on} \le t \le T_S$ **)**, when $v_a(t) = -V_S$

$$-V_S = R_a i_a + L_a \frac{di_a}{dt} + E_a \tag{3}$$

which, gives

$$i_a(t) = -\frac{V_S + E_a}{R_a}\left(1 - e^{\frac{-t}{\tau_a}}\right) + I_{a\max} e^{\frac{-t}{\tau_a}} \tag{4}$$

The initial conditions $I_{a\max}$ and $I_{a\min}$ are determined by using the steady-state boundary conditions:

$$I_{a\max} = \frac{V_S}{R_a} \cdot \frac{1 - 2e^{-DT_S/\tau_a} + e^{-T_S/\tau_a}}{1 - e^{-T_S/\tau_a}} - \frac{E_a}{R_a} \tag{5}$$

$$I_{a\min} = -\frac{V_S}{R_a} \cdot \frac{1 - 2e^{-(1-D)T_S/\tau_a} + e^{-T_S/\tau_a}}{1 - e^{-T_S/\tau_a}} - \frac{E_a}{R_a}, \tag{6}$$

where D – duty ratio ($D = T_{on}/T_S$ **);** τ_a - load time constant**;** E_a - back EMF.

The average output voltage V_a is

$$V_a = (2D - 1)V_S . \tag{7}$$

The F28035 is being used to generate the four pulse width modulation (PWM) signals needed to drive the DRV8412. Two input currents of each motor are measured from the H-bridge and they are sent to the F28035 via four analog-to-digital converters (ADCs).

Using the included project in the kit is generated one PWM sequence that appears on the output PWM-A or the output PWM-B depending on the motors rotation. With the resulting signals unipolar and bipolar PWM technique for motor control can be accomplished, which is determined by the operating mode of the driver. A disadvantage is that in order to use one or the other method of PWM hardware switching has to be performed.

As mention above, the software available with the kit is completely open source and in the paper is presented the releasing of the different modulation strategies (4-Quadrant Bipolar and 4-Quadrant Unipolar technique) for brushed DC motors. The software for controlling one DC motor with bipolar PWM and the other DC motor with unipolar PWM in the same mode of the driver DRV8412 is developed. This removes the need for hardware changes in the kit when training the various methods of modulation.

It is assumed that two motors are connected to the device (Fig. 4). This build verifies the multi-axis concept which is two DC motors running simultaneously with current control. For the operation mode is selected mode 1 of DRV8412 (M1 = M2 = M3 = 0), therefore the control algorithm should be done so as to generate control signals for each side of the bridge circuits. The control method of the bipolar PWM is applied to the motor connected between the outputs A and B of the driver DRV8412, i.e. motor 1. The control method of the unipolar PWM is applied to the motor connected between the outputs C and D of the driver DRV8412, i.e. motor 2.

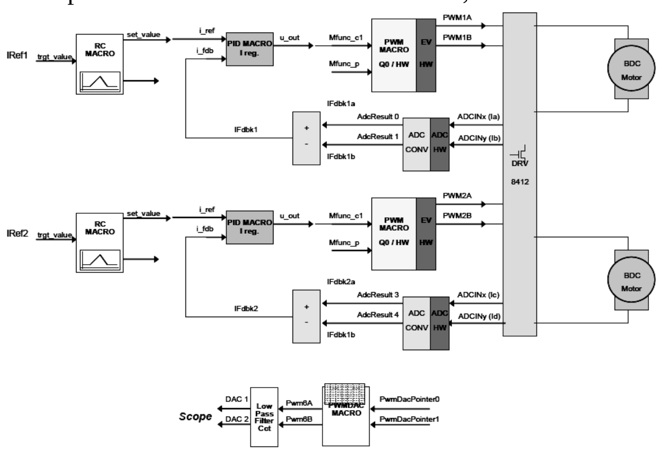

Fig. 4. Incremental System Build Block Diagram

The triangle carrier signal which is used to perform PWM sequences digitally represents the increase of the value of the counter TBCTR from 0 (0x0000) to a given value for a time equal to a half-period of the modulated signal (TBPRD), which is set by the function **PWM_Macro**, and depends on the output of the PID controller, and therefore the reference current IRef. Since ePWM module works with the frequency of the processor core, so in the span of time TBPRD the value, which the TBCTR counter reaches, is the value recorded in the register TBPRD.

A. PWM with unipolar voltage switching

PWM with unipolar voltage switching, in classic view, is realized as follows (Fig. 5): a triangular waveform is compared with the control voltage v_{cont} and $-v_{cont}$ for determining the switching signals for leg A and leg B, respectively. A comparison of v_{cont} with v_{tri} controls leg A transistors, whereas leg B transistors are controlled by comparing $-v_{cont}$ with v_{tri}.

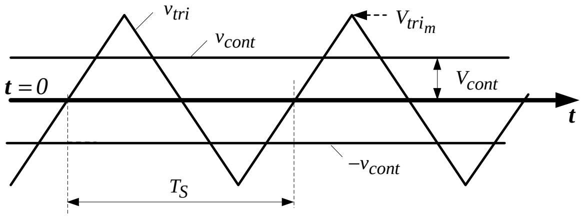

Fig. 5.

The triangle carrier signal in our project is generated as follows(Fig. 6): the equivalent of a zero will be considered half of the maximum value that the counter TBCTR reaches, i.e. one half from TBPRD. Compared to this level there should be two symmetric control signal v_{cont} and $-v_{cont}$, which are generated ePWM2A and ePWM2B, respectively. The values of these control signals are recorded in the registers CMPA and CMPB.

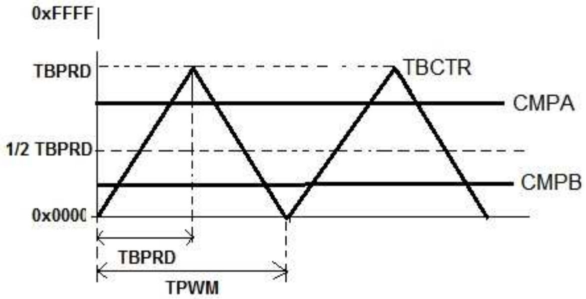

Fig. 6.

As we will use the value of CMPA register for the generation of signal ePWM2A and CMPB register for the generation of signal ePWM2B, it is necessary in the initialization of ePWM module to make appropriate initialization of the action qualifier control registers (AQCTLA and AQCTLB), determining what operation will be carried out with the output signals, thus reaching the value of the counter TBCTR with one of the two registers.

The value of these registers is set as follows:

EPwm2Regs.AQCTLA.all = (CAU_SET + CAD_CLEAR);
EPwm2Regs.AQCTLB.all = (CBU_SET + CBD_CLEAR);

Thus if CMPA > TBCTR ePWM2A signal will be in a high level, and similarly if CMPB > TBCTR ePWM2B signal will be in the high level. If CMPA < TBCTR and CMPB < TBCTR output signals will be in the lower level. The problem here is getting the values CPMA and CMPB, so that they are symmetric towards the half TBPRD value. The value recorded in CMPA register is actually a signal which is obtained based on the current setpoint value and the current through the motor, resulting in the feedback control. To obtain an accurate value for the CMPB register, so that it is symmetrical to the CMPA the following equation is proposed:

$$\text{CMPB} = \text{TBCTRmax} - \text{CMPA} = \text{TBPRD} - \text{CMPA} \quad (8)$$

In Fig. 7 the switching signals generation for this modulation is proposed. The two control signals are equating continuously.

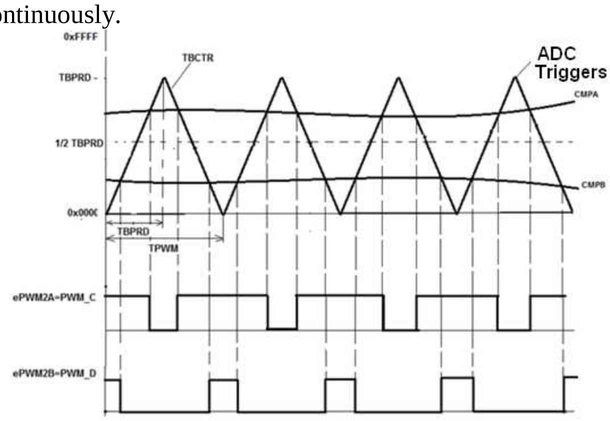

Fig. 7. Unipolar PWM control signals

B. PWM with bipolar voltage switching

For the realization of bipolar PWM necessary ePWM1 processor module to simultaneously generate two PWM sequences (ePWM1A and ePWM1B). These two signals are connected to the inputs and PWM_A PWM_B of DRV8412. Both control signals must be opposite, so as to switch both pairs in the bridge circuit, i.e. they are inverted relative to one another. In the classic bipolar PWM signals for generating ePWM1A and ePWM1B used triangular signal from the register TBCTR of ePWM1 module and the value of the register CMPA. For the proper generation of the control signals it is necessary for both register and AQCTLA AQCTLB to be initialized as follows:

EPwm2Regs.AQCTLA.all = (CAU_SET + CAD_CLEAR);
EPwm2Regs.AQCTLB.all = (CAU_ CLEAR + CAD_ SET);

Thus, if CMPA > TBCTR ePWM1A signal will be in the high level and ePWM1B signal will be in a low level. If CMPA < TBCTR ePWM1A signal will turn in low and ePWM1B in high level, respectively.

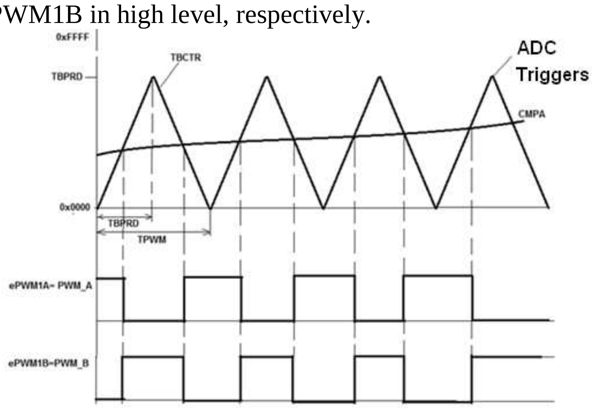

Fig. 8. Bipolar PWM control signals

III. Experimental results

The experimental results are made by the default PWM frequency 10kHz.

Fig. 9 shows ePWM2A (trace1) and ePWM2B (trace2) signals, which are generated with unipolar PWM for D=0.75.

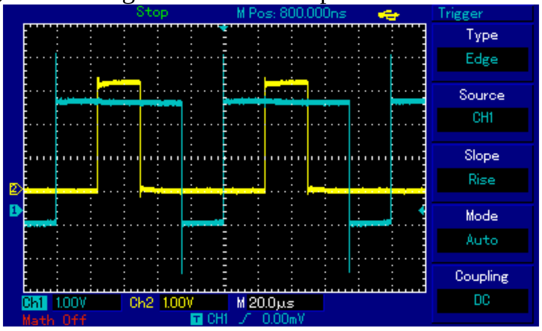

Fig. 9. ePWM2A (trace1) and ePWM2B (trace2) signals

Fig. 10 illustrates the output voltage (trace1) and the output current (trace2) with unipolar PWM for same D=0.75.

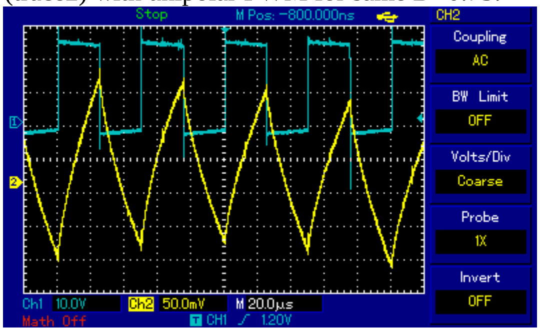

Fig. 10. Output voltage (trace1) and output current (trace2)

Fig. 11 shows ePWM2A (trace1) and ePWM2B (trace2) signals, which are generated with unipolar PWM for D=0.25.

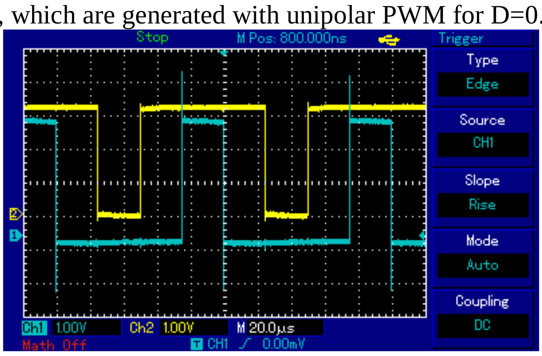

Fig. 11. ePWM2A (trace1) and ePWM2B (trace2) signals

Fig. 12 shows ePWM1A (trace1) and ePWM1B (trace2) signals, which are generated with bipolar PWM for D=0.75.

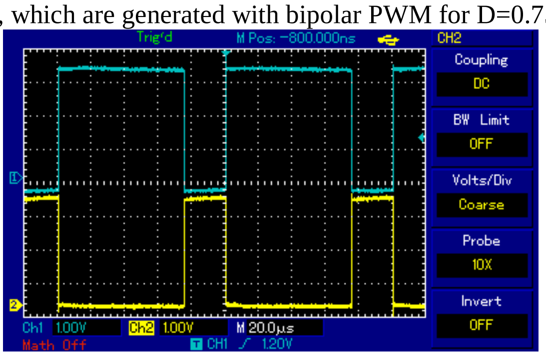

Fig. 12. ePWM1A (trace1) and ePWM1B (trace2) signals

Fig. 13 shows output voltage (trace1) and output current (trace2) with bipolar PWM for D=0.75.

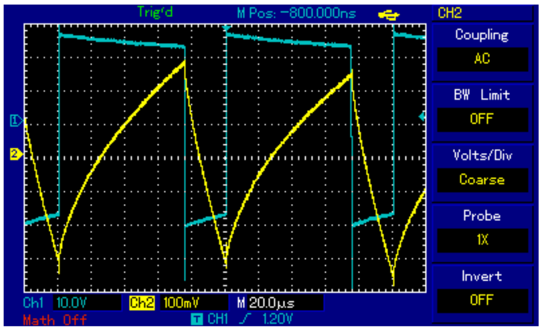

Fig. 13. Output voltage (trace1) and output current (trace2)

If the switching frequency of the switches is the same in these two PWM strategies, then the unipolar voltage switching results in better output voltage waveform and in a better frequency response, since the output voltage frequency is doubled and the ripple is reduced (Fig. 10 and Fig. 13).

In experimental testing of the control algorithms, it was found that when changing the current reference the response of the digital control system is 6,65μsec. When changing the conditions of motor operation with the proposed algorithm, the system will react to timing functions for PID, PWM modules, number of cycles for updating the condition and ADC conversion. This response time is 5,15μsec.

IV. Conclusion

The paper presents the realization of different modulation strategies (4-Quadrant Bipolar and 4-Quadrant Unipolar technique) for brushed DC motors, using DMC kit, DRV8412-C2, from Texas Instruments as a part of the student laboratory work. The Master's thesis results are reported in the paper, which consist of a new software realization for controlling DC motors with bipolar PWM and unipolar PWM in the same mode of the driver DRV8412 operation. This removes the need for hardware changes in the kit when training students the various methods of modulation. The experimental results are presented.

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