

Teaching Stepper Motors and Brushed DC Motors Using the Medium Voltage Digital Motor Control Platform, Part I - Stepper Motors Control

Ivan Petrov Maradzhiev, Tsvetana Grigorova Grigorova and Svetoslav Tsvetanov Ivanov

Abstract – Development of the modern power electronics puts serious challenges to the teaching of the industrial electronics students, due to the complexity of the necessary knowledge and skills. In this paper we discussed the teaching methodology of stepper motors control, using Texas Instruments platforms and the main points of the students teaching process during the laboratory work.

Keywords – Stepper motors, Microstepping, Digital motor control

I. INTRODUCTION

Development of the modern power electronics puts serious challenges to the teaching of the industrial electronics students, due to the complexity of the necessary knowledge and skills. Experience shows that power electronics as a subject is not readily assimilated by students because of the different areas involved [1]. Although students expressed interest in power electronics integrated with digital controls and digital signal processor (DSP), the conventional teaching arrangement did not give them needed background and knowledge [3].

For the postgraduate students the laboratory experiments are very important part from the education and can help students assimilate the theoretical concepts of very complex subjects. In order to prepare students for the employers organizations requirements [2] we offered students an eligible course entitled "Electronic converters for motors control" as a part of the Master's program in "Electronics". Discipline is fundamental to the knowledge and skills of students in the field of power electronic circuits and devices for motor control (Stepper motors, Brushed DC, Brushless DC and AC motors). One major part of it is focus on digital motor control. The use of the digital motor control allows more complex and more intelligent types of motor control. During the last three years, we have seen a noticeable increase of student interest in this subject, as evidenced by the number of registered, which is more than 80% from all students from the Master's program in "Electronics".

I. Maradzhiev is with the Faculty of Electronics and Automation at TU- Sofia, Branch Plovdiv, 63 Sankt Petersburg Blvd, Plovdiv 4000, Bulgaria, E-mail: maradzata@yahoo.com

Tsv. Grigorova is with the Faculty of Electronics and Automation at TU- Sofia, Branch Plovdiv, 63 Sankt Petersburg Blvd, Plovdiv 4000, Bulgaria, E-mail: c_gr@tu-plovdiv.bg

Sv. Ivanov is with the Faculty of Electronics and Automation at TU- Sofia, Branch Plovdiv, 63 Sankt Petersburg Blvd, Plovdiv 4000, Bulgaria, E-mail: blueflam@tu-plovdiv.bg

In this paper we discussed the teaching methodology of stepper motors control, using Texas Instruments platforms. As a development environment was chosen the Medium Voltage Digital Motor Control (DMC) kit, DRV8412-C2, from Texas Instruments (TI), which provides a great way to learn and experiment with digital control of medium voltage motors. In the DRV8412 DMC kit are included two brushed DC motors and 8-wire bi-polar stepper motor [5].

The present report examines the implementation of one of the control methods for bipolar stepper motor - microstepping and the main points of the students teaching process during the laboratory work.

II. MICROSTEPPING OF BI-POLAR STEPPER MOTORS

At the beginning of the laboratory session, the teacher gives a brief explanation, presenting an overview of the experiment and the relation with the theory.

Stepper motors are a good choice when precise control of the movement is required. They are used for applications in which to control the rotation angle, the speed and position of the rotor are required. Their advantages have obtained their place in the various fields of the engineering, such as medical equipment, robotics, automotive and others. There are different methods to control stepper motors. One of them microstepping works on the principle of gradually transferring current from one winding to another. This is achieved by pulse-width modulating the voltage across the windings of a motor. The duty cycle of the signal charging one winding is decreased as the duty cycle of the signal charging the next winding is increased. The desired motion of a stepper motor is linear. Good implementations of microstepp drive strive to get as near to this linear motion as possible [4]. Figure 1 shows a waveforms of torque vs. rotor position for an ideal two-winding stepper motor [4].

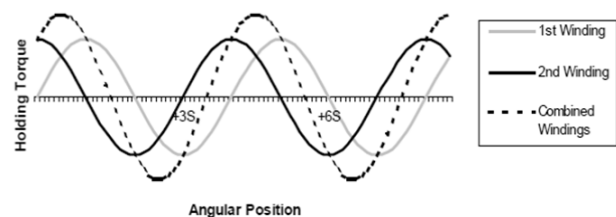


Fig.1. Torque vs. angular position for an ideal two winding motor

The torque curve for one winding of the ideal two winding stepping motor in Fig. 1 can be expressed by the following equation:

$$T_1 = H \sin \left(\frac{\pi}{S} \theta \right) \quad (1)$$

$$T_2 = H \cos \left(\frac{\pi}{S} \theta \right), \quad (2)$$

where: T_1 – torque of the first winding; H - holding torque; S – step angle, [rad]; θ – shaft angle, [rad].

In an ideal motor, the torque produced by each winding is proportional to the current in that winding. As a result, if we want to hold the motor rotor at the angle θ , we can do so by setting the currents through the motor windings to the values given in Eq. 3 and Eq. 4.

$$I_1 = I_{MAX} \sin \left(\frac{\pi}{2S} \theta \right) \quad (3)$$

$$I_2 = I_{MAX} \cos \left(\frac{\pi}{2S} \theta \right), \quad (4)$$

where I_{MAX} is maximum current through the motor windings.

A. The Medium Voltage Digital Motor Control (DMC) kit description

At the beginning of the laboratory work, students are given a tutorial that guides them through the hardware description, the experiments and the actions to be performed in each step.

Fig.2 shows the block diagram of the DRV8412 evaluation kit (DRV8412-C2-KIT). It consists of the DRV8412 motor driver, a C2000 Piccolo F28035 MCU controlCARD, example software, code development environment (Code Composer Studio) and the motor.

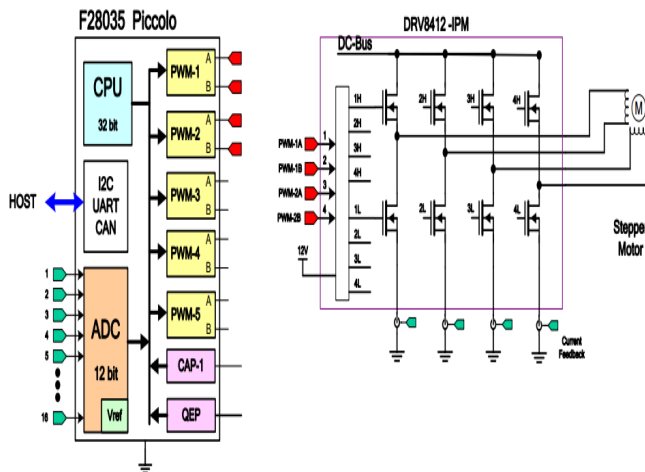


Fig. 2. Stepper motor drive implementation

This system demonstrates current-controlled microstepping of a bi-polar stepper motor. The stepper motor is driven by a H-bridge, which is provided by the DRV8412 Dual Full-Bridge PWM Motor Driver IC. The Piccolo F28035 MCU controlCARD generates four pulse-width modulation (PWM) signals, two for each motor phase. Two phase currents of each motor phase are measured from the H-bridge and sent to the F28035 device

through four analog-to-digital converters (ADCs). In addition, the DC-bus voltage is measured and sent to the F28035 through an ADC [5].

This highly integrated, robust motor control and driver solution allows developing for stepper motors.

For the proper work we put Mode Jumpers as follows: M1=H, M2 = M3 = L (mode 2 of DRV8412). This mode means: dual full bridges or four half bridges with OC latching shutdown. The software available with the kit is completely open source and allows both to be studied from the students and to be modified. Furthermore, there is a possibility to change the motor control algorithm, and can be choose between modes microstepping with different sizes of step, quarter step, half step and a full step. Thus, students acquire practical skill and obtained knowledge about the most common methods for the stepper moors control. Also, students can change the base electrical frequency of pulses, references voltage and current for the used motor.

Except the development board the necessary equipment includes a personal computer with an installed development environment Code Composer Studio v6.0, the oscilloscope and current probe.

B. Projects Organization

The project is built up into three levels, with each level test modules and software is checked for the proper operation of the hardware [6]. The platform allows change and adjustment of various parameters in real time. The project can be configured in Stepper-Settings.h header file and can range from whole stepping to 128 microsteps/step.

```

define BUILDLEVEL LEVEL1

#define WHOLE_STEPPING 2
#define HALF_STEPPING 3
#define QUARTER_STEPPING 4
#define MICROSTEP_8 5 //8-microsteps
per step
#define MICROSTEP_16 6 //16-microsteps per step
#define MICROSTEP_32 7 //32-microsteps per step
#define MICROSTEP_64 8 //64-microsteps per step
#define MICROSTEP_128 9 //128-microsteps per step
#define MICROSTEPS HALF_STEPPING
// Define the system frequency (MHz)
#if (DSP2803x_DEVICE_H==1)
#define SYSTEM_FREQUENCY 60
#elif (DSP280x_DEVICE_H==F2808)
#define SYSTEM_FREQUENCY 100
#endif
// Define the ISR frequency (kHz)
#define ISR_FREQUENCY 10
// Select the motor
#define Motor 1
// Define the base quantites
#define BASE_VOLTAGE 66.32 // Base peak phase voltage
(volt), maximum measurable DC Bus
#define BASE_CURRENT 7.2 // Base peak phase current
(amp), maximum measurable peak current
#define BASE_FREQ 200 // Base electrical frequency
(Hz)

```

Here is reported some examples, included in the development kit. Fig. 3 shows diagram for the whole

project. Level 1 of the project verifies the target independent modules, duty cycles and PWM update. The results, which are illustrated correspond to 128 microsteps/step.

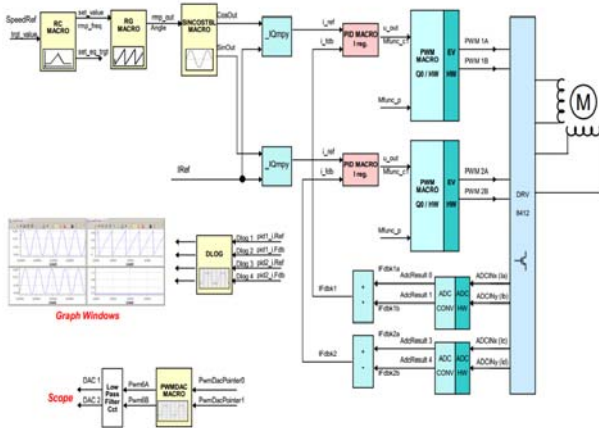


Fig.3. System Build Block Diagram

At first level of the project the motor is disconnected. In this level students test the sin/cos table module (SINCOSTBL_MACRO) and PWM generator (PWM_MACRO). For these purpose the reference speed SpeedRef value and voltage Vref across the motor are specified. Depending on SpeedRef value RG_MACRO module via RC_MACRO produce discrete angle. SINCOSTBL_MACRO module takes that discrete angle as input and outputs the sin and cos of that angle from a look-up table. The outputs of the SINCOSTBL_MACRO are then scaled by Vref to obtain the desired amplitude. The range of the angle input is dependent on the desired number of microsteps per step.

The students can be monitored the outputs of the SINCOSTBL_MACRO and RG_MACRO using the graph windows of the Code Composer Studio 6.0 (CCS) as shown at Fig. 4

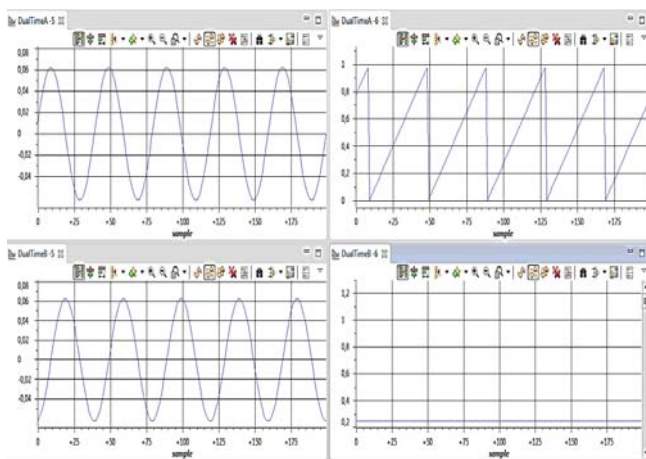


Fig. 4. CCS 6.0 Graph Windows for BUILDLEVEL = 1

The outputs of the SINCOSTBL_MACRO are scaled by Vref and then specified to the PWM_MACRO. The duty cycle of the PWM outputs should vary sinusoidally at the frequency specified by SpeedRef.

Then students check the PWM test points on the board to observe PWM pulses (PWMA and PWMB for Phase A and PWMC and PWMD for Phase B), as shown in Fig.5.

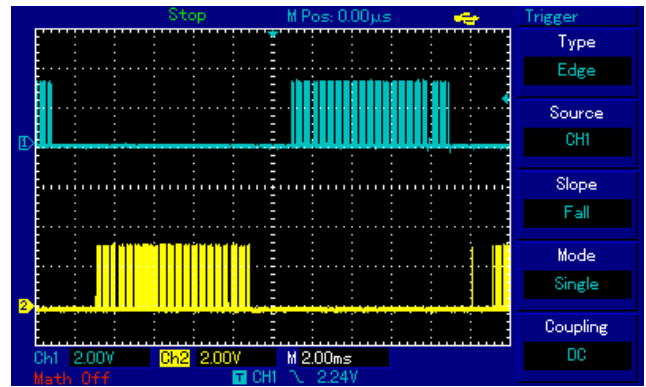


Fig. 5. 1 -PWMA and 2 -PWMB switching waveforms

After the Level1 incremental build is completed successfully, the motor is connected to the board. In this level verifies the analog-to-digital conversion [6]. In the software, the key variables which can be adjusted are VRef (for changing the motor voltage in per-unit) and SpeedRef (for changing the motor electrical speed in per-unit).

The motor starts spin slowly. In the CCS watch window can be monitored the generated references sin and cos signals and currents through the two phase motor windings as shown in Fig. 6. The top two graphs show the cos and sin voltage waveforms that are being generated. The bottom two graphs show the corresponding ADC sampled current waveforms. It is shown that the current waveforms are different from sin waveforms.

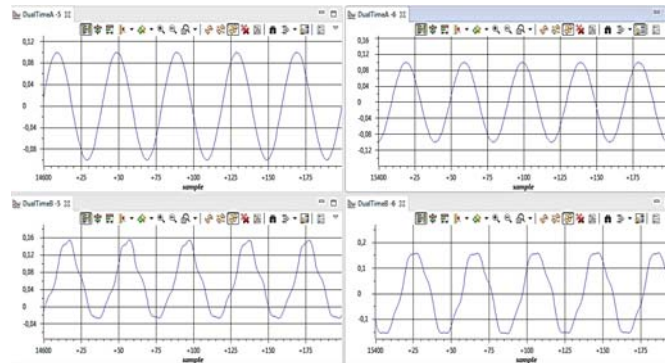


Fig. 6. Build Level 2 graph showing generated sinusoidal voltages and current feedback

Fig. 7 illustrates the phase A current.

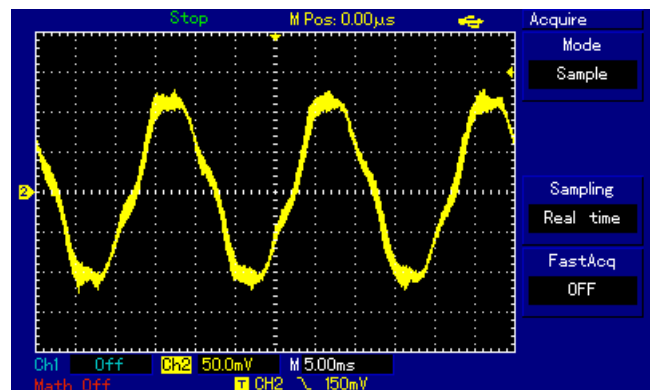


Fig. 7. Phase A current

The Level 3 section verifies the current regulation performed by PID_REG3 module. This module is consisted from two PID controllers. To confirm the operation of current regulation, the gains of these two PID controllers are necessarily tuned for proper operation. This can be configured in Steper.c:

```
// Initialize the PID_REG3 module for I
pid1_i.Kp = _IQ(2.16);      //for 24V DC bus
pid1_i.Ki = _IQ(T*128.1);
pid1_i.Kd = _IQ(0/T);
pid1_i.Kc = _IQ(0.006);
pid1_i.OutMax = _IQ(0.95);
pid1_i.OutMin = _IQ(-0.95);

pid2_i.Kp = _IQ(2.16);      //for 24V DC bus
pid2_i.Ki = _IQ(T*128.1);
pid2_i.Kd = _IQ(0/T);
pid2_i.Kc = _IQ(0.006);
pid2_i.OutMax = _IQ(0.95);
pid2_i.OutMin = _IQ(-0.95);
```

In this project build two quadrature sinusoidal motor currents are dynamically regulated by using PID_REG3 module. The steps are explained as follows: Set values for Iref (for changing the motor current in per-unit) and SpeedRef (for changing the motor electrical speed in per-unit). Figure 10 shows the graphs for this build level. The top two graphs show the commanded cos and sin current waveforms. The bottom two graphs show the corresponding current feedback waveforms. If PID gains are adjust properly, the feedback currents will track the commanded currents.

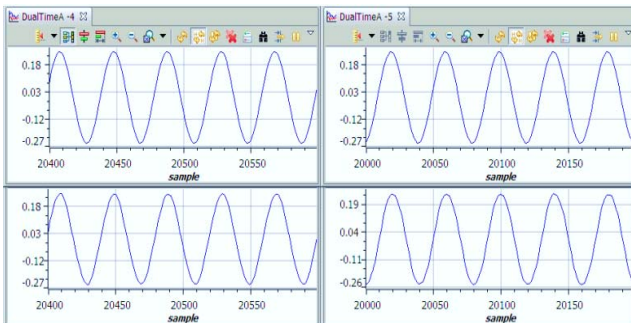


Fig.8. Build Level 3 graphs of commanded and regulated motor currents

Fig. 9 illustrates the phase A current.

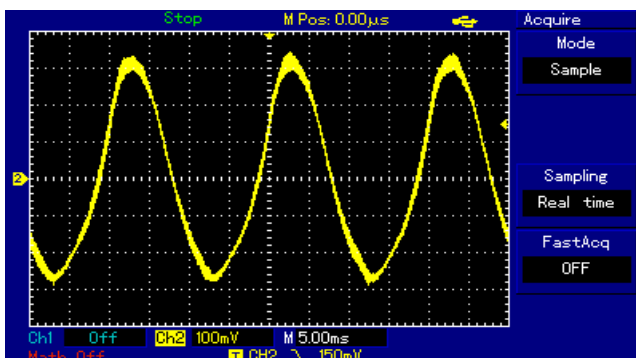


Fig. 9. Phase A current

As mentioned above, the development environment allows the testing, the study and comparison to other methods for control of the stepper motors, i.e. microstepping with different sizes of step, quarter step, half step and a full step.

The laboratory works are organized so that after investigation of these different control methods, the students made conclusion about their advantages and disadvantages.

III. CONCLUSION

Development of the modern power electronics puts serious challenges to the teaching of the industrial electronics students, due to the complexity of the necessary knowledge and skills. Although students expressed interest in power electronics integrated with digital controls and digital signal processor (DSP), the conventional teaching arrangement did not give them needed background and knowledge.

As a development environment was chosen the Medium Voltage Digital Motor Control (DMC) kit, DRV8412-C2, from Texas Instruments (TI), which provides a great way to learn and experiment with digital control of medium voltage motors. The present report examines the implementation of one of the control methods for bipolar stepper motor - microstepping and the main points of the students teaching process during the laboratory work.

REFERENCES

- [1]. J. Martinez, F Soto, E. Jodar, J. Villarejo, and J. Roca-Dorda, "A New Approach for Teaching Power Electronics Converter Experiments," IEEE Trans. Education, vol. 48, no. 3, pp. 513-519, Aug. 2005
- [2]. P. Yakimov, *Teaching Basic Skills in Embedded Systems Using Open-source Platforms*, L. International Scientific Conference on Information, Communication and Energy Systems and Technologies ICEST 2015, 24 - 26 June 2015, Sofia, Bulgaria (in press).
- [3]. R. Ahmed, A. R .Ofoli, *Teaching Power Electronics Converter Experiments that Integrates Fuzzy Logic Approach*, American Society for Engineering Education, 2011, AC 2011-305
- [4]. R. Condit, D. Jones. *Stepping Motors Fundamentals*, Microchip Technology Inc, 2004.
- [5]. DRV8412-C2-KIT Hardware Reference Guide. Texas Instruments. <http://www.ti.com/lit/ug/tidu314/tidu314.pdf>
- [6]. Microstepping of Bi-polar Stepper Motor. Texas Instruments. ftp://ftp.ti.com/pub/dml/DMLrequest/Christy_FTP-10-30-12/controlSUITE/development_kits/DRV8412-C2-KIT_v131/Stepper/~Docs/Microstepping.pdf