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Design and Implementation of BLDC Motor Speed Control Based on PI Regulator Using dspic30f4011 and IPM Inverter

***Abstract**. This paper proposed the speed control of brushless dc motor using PWM technique. In this study, we use a 16-bit Digital Signal Controller dspic30f4011 and the IRAMY20UP60B Intelligent Power Module as an inverter. In the proposed system three phase trapezoidal voltage is formed with six pulses signals generating using integrated PWM module of the dsPIC. The rotation speed control is constituted with the Proportional-Integral (PI) controller. The experimental results are wisely studied to prove that our proposed control and IPM inverter acquire a high performance to control the speed of the BLDC motor.*

***Streszczenie.** W artykule zaproponowano sterowanie prędkością obrotową bezszczotkowego silnika prądu stałego (BLDC) z wykorzystaniem modulacji PWM. Jako układ sterowania zastosowana 16-bitowy cyfrowy kontroler dspic30f4011, a jako falownik (komutator elektroniczny) wykorzystano inteligentny moduł mocy (IPM) IRAMY20UP60B. W proponowanym układzie trójfazowe napięcie trapezowe jest formowane za pomocą sześciu sygnałów generowanych za pomocą zintegrowanego modułu PWM układu dspic. Sterowanie prędkością obrotową jest realizowane za pomocą regulatora proporcjonalno-całkującego (PI). Wyniki eksperymentów potwierdzają, że proponowany przez nas układ sterowania i falownik IPM wykazuje wysoką wydajność do sterowania prędkością obrotową silników BLDC. (**Projekt i wdrożenie sterowania prędkością silnika BLDC w oparciu o regulator PI z wykorzystaniem dspic30f4011 i falownika IPM**)*

Keywords: Three-phase IPM inverter, dspic30f4011, PWM technique, BLDC motor, PI controller.
Słowa kluczowe: Trójfazowy falownik IPM, dspic30f4011, technika PWM, silnik BLDC, sterownik PI.
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Introduction

BLDC motors are largely used in several applications as fan, pump and actuator applications. These are also employed in household appliances such as, washing machines, DVDs, computer peripherals etc. Compared to a DC motor, BLDC motor is commutated by an electronic commutator using power semiconductor switches. Due to the absence of brushes and commutators, BLDC motors require less maintenance and operate much more quietly than DC motors. In BLDC motors, rotor magnets generate the rotor's magnetic flux, allowing BLDC motors to achieve higher efficiency; also it has many advantages like high efficiency, compact volume and less noise [1].

Therefore, BLDC motors may be used in high-end white goods (refrigerators, washing machines, air conditioner, etc.), high-end pumps, fans, and other appliances that require high reliability and efficiency. The main objective of this paper is to create a speed-closed loop BLDC driver using a Hall position sensor [2]. It serves as an example of a BLDC motor control system design using microchip microcontroller.

In this study, a three phase IRAMY20UP60B inverter is used. This IPM module delivers a high level of protection such as over-current, over-temperature protections and integrated under-voltage lockout function. It's also built with failsafe operation and along with short-circuits rated IGBTs [3]. This intelligent module is the best inverter for AC motor drive applications due to its excellent properties.

Many products of digital signal controllers and microcontrollers with integrated PWM module have been launched to the electronic market [1, 5]. Microchip produces power conversion and motor control chip families (PIC18F dspic30F, and dspic33F) is one of the most popular company's such a Motorola, Texas instrument, etc.

Practically, the PWM technique is one of the most important methods used to control several types of motors. We use this technique for generating three phase trapezoidal wave voltage for controlling the speed of the BLDC motor [2, 4]. The rotation speed control is constituted with the Proportional-Integral (PI) controller.

In this work, we propose using the Digital Signal Controller dspic30f4011 to design the three-phase PWM signals to control the speed of BLDC. The hardware model is neatly studied to show that our proposed control and IPM inverter obtain high performance [1, 4].

This paper deals with the design and development of the software of the Proportional-Integral (PI) to control the speed of the BLDC motor. The model used and the experimental results will be detailed in the next stages.

BLDC motor control structure

To control the phases for the six-step commutation, a three-phase IPM inverter is used to convert the DC power into three phase currents [7, 9], figure.1 show only the IGBTs part of the IPM inverter. To supply positive current to one of the phases, the switch connected to that phase at the high side needs to be turned on. And for negative current, the low side switch needs to be on. A constant voltage gets converted by the three-phase inverter to keep the motor at a constant speed. But to control the motor at varying speeds, we need to be able to adjust the applied voltage. One way of doing this is to use PWM. But we'll talk about this in more detail in the next steps.

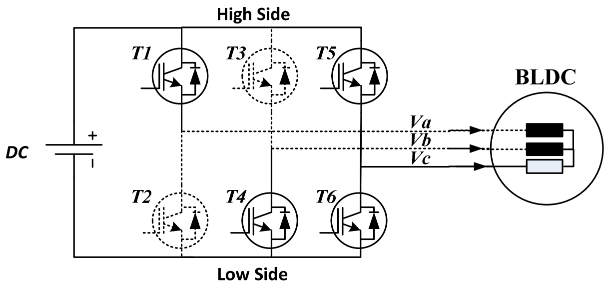

Fig.1. The IGBTs part of the IPM inverter

The Hardware block presented in figure 2 depict how the BLDC motor is driven using a dspic30f4011

PI Controller

Proportional-Integral PI controller is the most common part of PID regulator used to control feedback in modern engineering system. It should strictly speaking be called PI controllers, because we are not using the derivative action [8]. Block diagram of PI controllers in closed loop systems are shown in Figure 3. The control signal *u* is formed from the error *e*. The signal *rs* is called the reference signal. The parameters *Kp* and *Ki* are the proportional and integral gain respectively. *P* is the transfer function of the system controlled. The signal *y* is the processor output or the feedback. The input/output relation for *PI* controller is as (1).

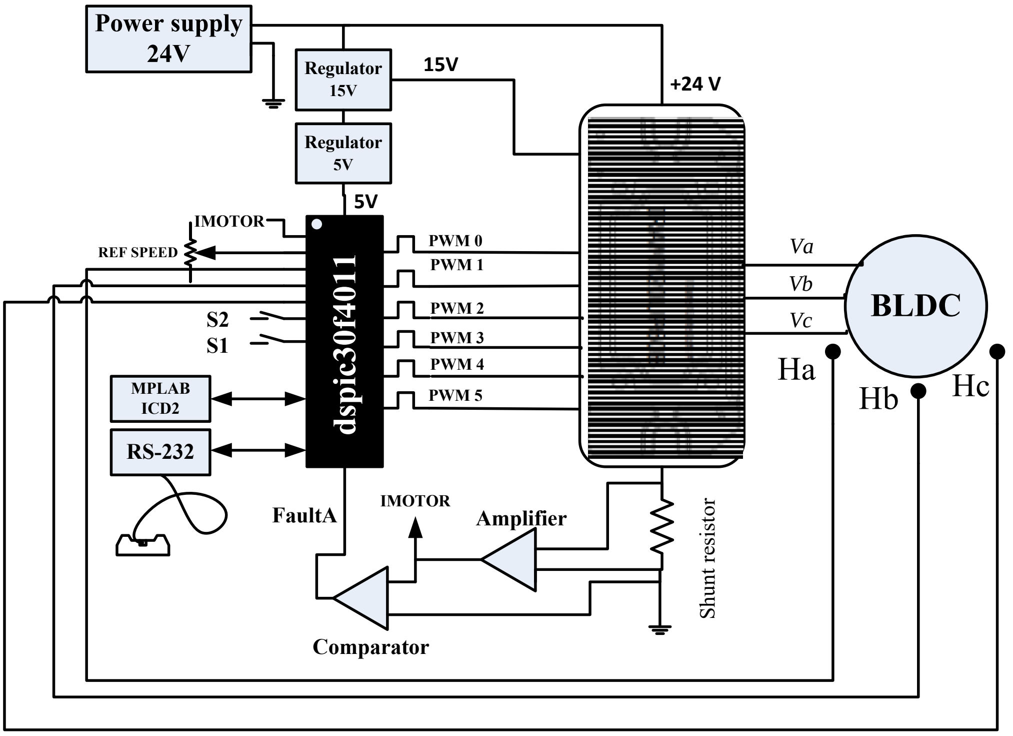

Fig.2. Hardware block diagram

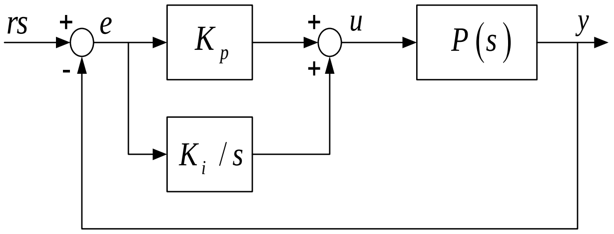

Fig.3. Closed loop system with PI controller

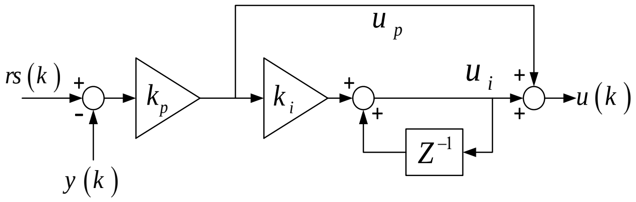

Fig.4. Typical PI controller block

(1) $$u = k_p e + k_i \int_0^t e(\tau)d\tau$$

For the hardware implementation, we used the following equations:

(2) $$u_p(k) = error(k) = k_p\left[rs(k) - y(k)\right]$$

(3) $$u_i(k) = u_i(k-1) + k_i\left[error(k)\right]$$

(4) $$u(k) = u_p(k) + u_i(k)$$

Where *u(k)* is the controller output, *up(k)* is the proportional output, *ui(k)* is the integral output, *rs(k)* is the reference command in step *k* and *y(k)* is the speed feedback. It should be noted that all signals are expressed in step *k*.

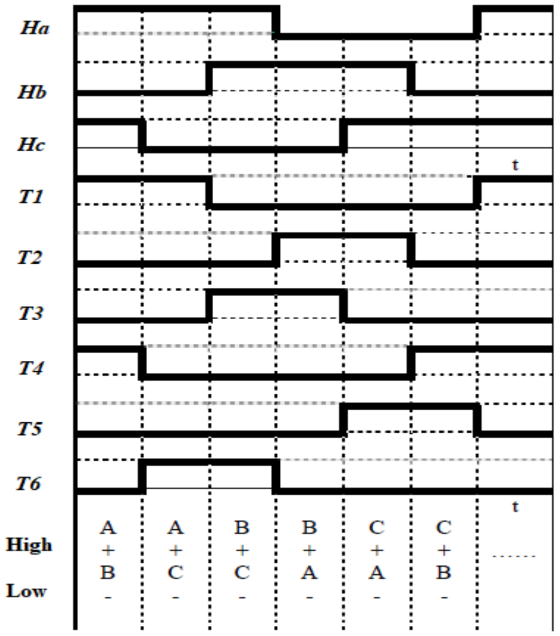

Fig.5. Switches sequence of PWM and sensor signals

Switches Sequence and PWM

The rotor position given by Hall Effect sensors provides correct commutation information to the power devices in the inverter bridge as shown in Table1. In Figure 5, the switches sequence and corresponding conduction phase of each winding is more clear [10].

Table.1. Truth table of gate state and Hall Effect sensors

[illegible]	Hall sensor			Phase A		Phase B		Phase C	
	Ha	**Hb**	**Hc**	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**
1	0	0	1	0	0	0	1	1	0
2	0	1	0	0	1	1	0	0	0
3	0	1	1	0	1	0	0	1	0
4	1	0	0	1	0	0	0	0	1
5	1	0	1	1	0	0	1	0	0
6	1	1	0	0	0	1	0	0	1

Design of BLDC Motor Controller

In this part we will explain how the dspic30f4011 is used to control the speed of BLDC motor using a PI controller. To measure the actual speed, TMR3 is used as a timer to trigger a full electric cycle. Since we are using a 4 pole motor, two electrical cycles result in a mechanical cycle [6].

If T seconds is the time of an electrical cycle, the speed is given as:

$$\omega = 60\left(p / 2T\right) \tag{5}$$

Where *p* is the number of poles of the motor. And the speed is with rpm.

Figure 6 shows the simplified diagram of the control with PI controller and the flow chart is also shown in figure 7.

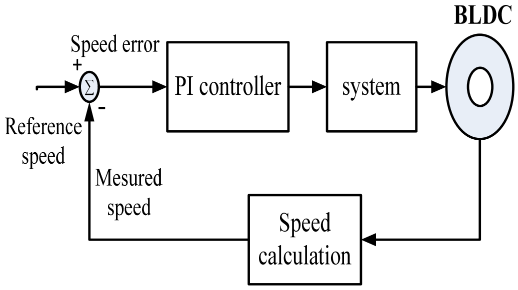

Fig.6. System structure of the speed PI control

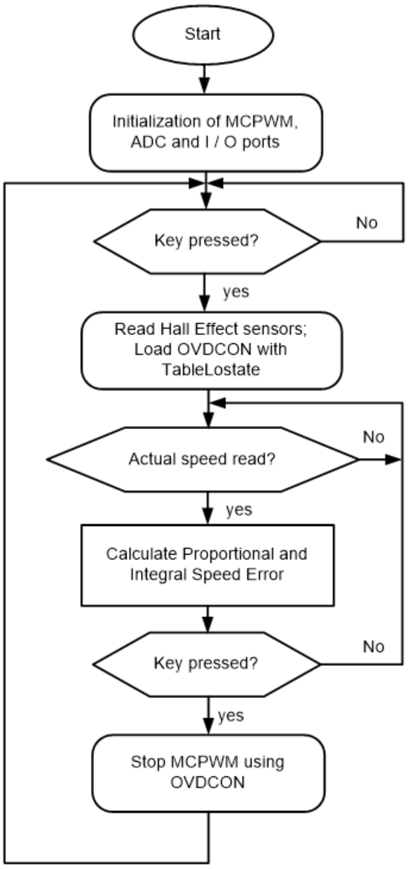

Fig.7. Flowchart of the speed PI control

In the closed-loop control technique, the main difference is that the pot is used for setting the speed demand. Where

$$\mathrm{PDCx} = \mathrm{KP}\left(\mathrm{P\ Speed\ Error}\right) + \mathrm{KI}\left(\mathrm{I\ Speed\ Error}\right) \tag{6}$$

Using the MCPWM module

As shown in figure 8, the value loaded into the OVDCOND register is determined by the Hall sensor and the switching sequence. When the PWM should be active, the corresponding OVDCOND bit is set to "1" and vice versa.

To vary the motor speed, in addition to the OVDCONx registers, the PWM duty cycle registers must also be calculated and reloaded according to the set speed [7, 11].

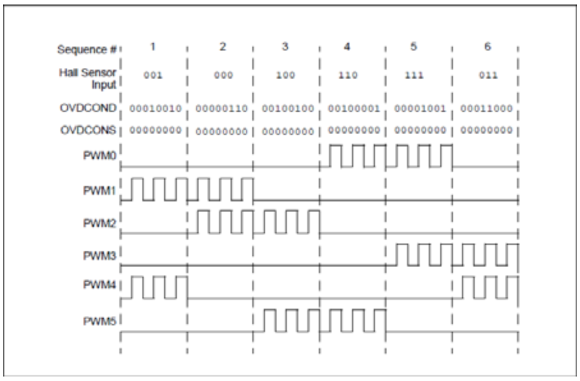

Fig.8. PWM OVDCOND output

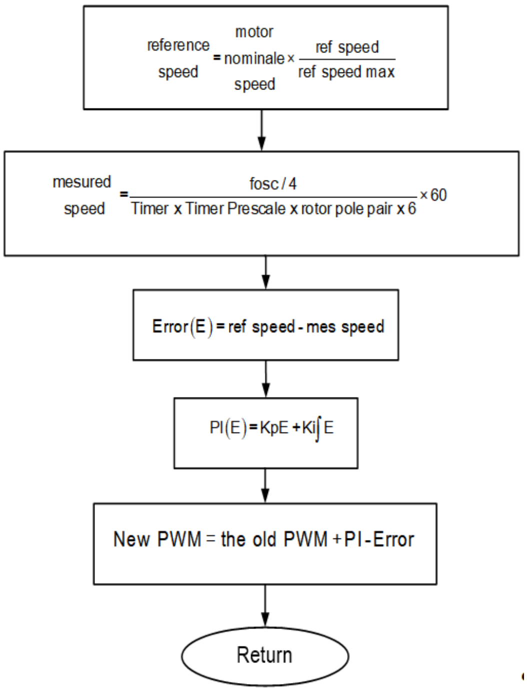

Fig.9. Simplified flowchart for calculating the speed error and updating the PWM duty cycle

Speed error calculation

The difference between the reference speed value and the actual speed value gives the speed error. The error can be positive or negative, indicating that the speed is above or below the set reference. This error is transmitted via a PI algorithm to amplify the error [6, 8]. The amplified error is used to readjust the PWM duty cycles initially calculated according to equation 7.

$$\text{PWM duty cycle} = \frac{\text{Motor rated voltage}}{\text{DC bus voltage}} \times \frac{\text{PTPER} \times 4}{\text{max speed reference}} \times \text{speed reference} \tag{7}$$

A simplified flowchart of calculating the speed error and updating the PWM duty cycle is shown in Figure 9.

Experimental results

To implement and test the speed control technique for a three phase BLDC motor, various hardware and software stages are prepared. In all experiences we used an outrunner BLDC motor, 350 W, 36 V. Figure 10. For the power stage a three phase IRAMY20UP60B inverter is used as shown in figure 11. This IPM module delivers a high level of protection such as over-current, over-temperature protections and integrated under-voltage lockout function. It's also built with failsafe operation and with short-circuits rated IGBTs. Figure 12 shows the controller board that contains the digital signal processor dsPIC30F3011. Hall sensor feedback is also used to calculate the motor position. For improving the response of the system, PI controller is incorporated. For data acquisition we used a digital oscilloscope.

Fig.10. Outrunner BLDC motor, 36 V/350 W

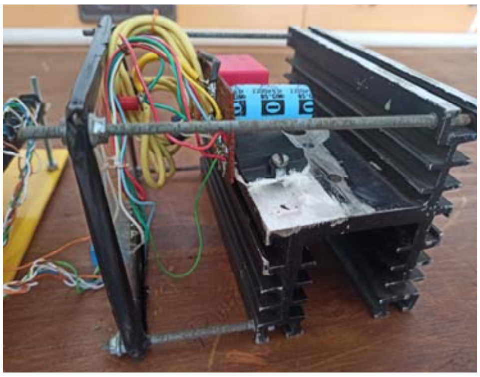

Fig.11. Three phase IRAMY20UP60B IPM inverter

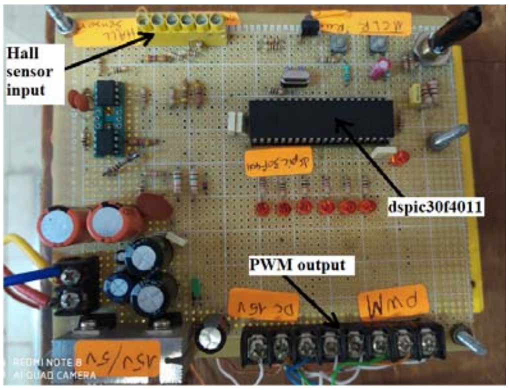

Fig.12. Main control board

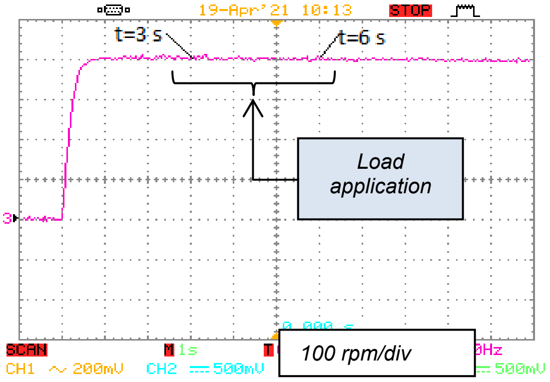

Fig.13. Speed response of constant reference of 400 rpm with load disturbances

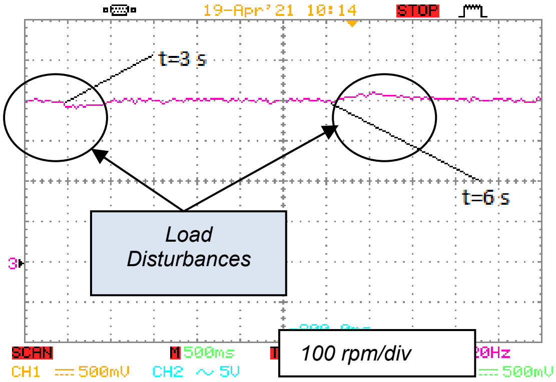

Fig.14. Speed responses of constant reference of 400 rpm with load disturbances (ZOOM)

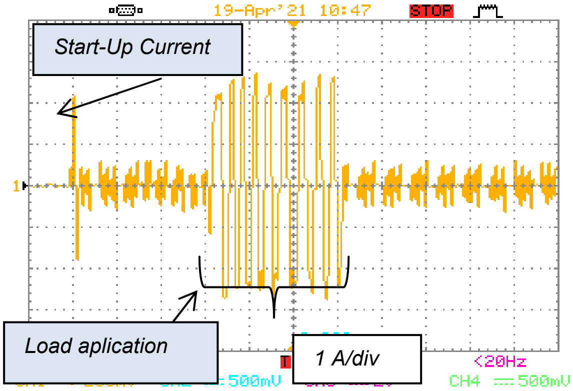

Fig.15. Phase current response with load disturbances

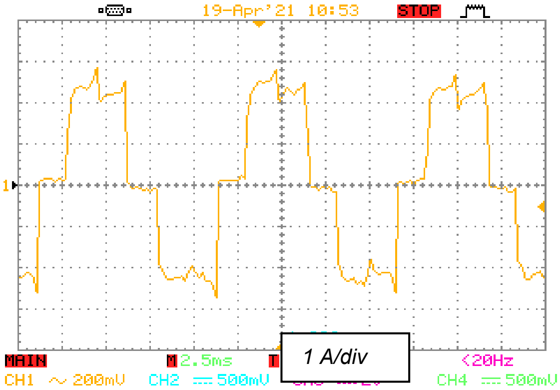

Fig.16. Phase current response when load is applied (ZOOM)

To demonstrate the capability of the PI controller, random external load disturbances are applied to BLDC at a constant speed. The disturbances are applied approximately at 3 and 6s. Figure13 shows the response of constant reference speed of 400 rpm with load application between 3 and 6s. The zoom of this speed response when load is applied is presented in figure 14. As for the figure 15 and figure 16, they show the response of the phase current when starting-up the motor and then in the field of application of the load. Also the load application interval zooms of respectively. For the PI controller parameters, we have selected the proportional gain value *Kp* = 7 and integral gain value and *Ki* = 0.00325.

Conclusion

In this paper we present the speed control method of BLDC motor using dspic30f4011 and IPM inverter. The PI controller proves the capability to modulate the speed with feedback of Hall Effect sensors. The experimental results are wisely studied to prove that our proposed control and IPM inverter acquire a high performance to control the speed of the BLDC motor. The performance evaluation has been verified with normal start-up followed by torque application.

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