International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

December 2019	Issue 41	Volume 11	Number 4	Pages 57-62

WIRELESS ON-LINE MONITORING AND SPEED CONTROL OF PMDC MOTOR

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Abstract- Wireless on-line monitoring and speed control of permanent magnet direct current (PMDC) motor speed control with android application has been done in this study. First, PI (Proportion- Integral) control technique was applied to the speed of the motor by using 18F2550 microprocessor and android application which provides remote communication and monitoring for the system. The speed control and monitoring were designed by using sensors to succeed Bluetooth wireless remote system control. The display panel designed via android application displays the speed of PMDC motor on the screen. The proposed study has been verified via experimental prototype after some simulation results. It was observed that the proposed PI controlled PMDC motor with android application has wireless remote control and it has reached the most ideal and stable operating range as fast as possible with the simulation and experimental applications.

Keywords: PMDC Motor, Wireless, Monitoring, PI.

I. INTRODUCTION

PMDC motors are popular in some applications such as printers, floppy drives etc. due to their good characteristics, and high response performance [1]. When the direct current motor drivers are compared to the alternative current motor drivers, simplicities, cheapness of the DC motor driver circuits and low costs for maintenances of the brush and commutator are observed. In this way, the direct current motor has expanded the number of applications and this makes the direct current motor more advantageous in adjustable speed applications [2-4].

Controllable drivers which have faster processing can be designed with microcontrollers compared to analog drivers which have analog circuit elements and complex control charts. The designed digital drivers are smaller than the existing ones [5-6]. Small, fast, economical microcontrollers and power switching elements can be produced with help of the advances in semiconductor technology and so the control of direct current motor driver systems is more developed. Since direct current motor drivers are not expensive and complex, they are still widely used in many industrial applications requiring motor starting, stopping, braking and change of movement direction. Therefore, a direct current motor may be preferred to achieve the desired control with a low-cost microcontroller.

The rapid processing and stability have given particular advantages in industrial automation. The rapid development of communication technologies has increased the efforts for remote control and monitoring of systems by telephone or computer control. Since the new generation technological developments are more advanced than the existing systems, they have replaced the classical systems. These technological developments have made it mandatory to monitor as well as control.

In this study, it is provided to monitor and display the speed of PMDC motor with the interface software developed via Android operating system. In addition, a PI control method is used for speed control of PMDC motor. A H-Bridge driver circuit was used for drawing the PMDC motor. The applications such as speed regulations, direction control, braking which are made by using this driver card more efficient and more economical than others. After the simulation studies of the speed control of the modeled PMDC motor were completed, the experimental studies were carried out and the results were given. The android application which is used for PI control of the PMDC motor and speed monitoring consists of three sections. The settings which are related with PI control occur in the first page and settings of reference speed, K_p and K_i parameters are settled. In this section, the direction of rotation of the motor is also set. There are two separate buttons for starting and stopping the motor. The lower left section shows the number of data which are received. This number of data allows graph which is obtained to extend according to time. There are settings of the data numbers and options for whether the engine will stop when the data is completed in the setting section on the second page. The obtained data via HC-05 Bluetooth module as an on-line are shown graphically on the third page. The generated graph is the cycle – time graph. It is automatically generated with data which is taken from the processor and there are image enlargement and shift functions for detailed review. 18F2550 microprocessor which operates with 16 MHz oscillator frequency is used in the unit.

II. PMDC MOTOR AND DRIVER

H-bridge driver based PMDC motor can be modelled by connecting three simple electrical elements in series. The whole circuit and equivalent circuit of a PMDC motor is shown in Figure 1 [7].

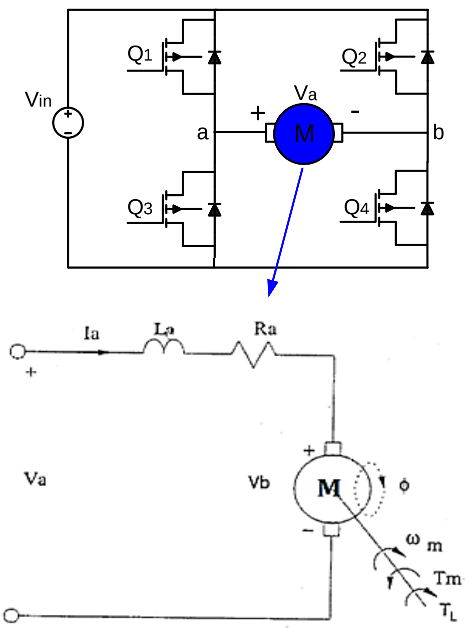

Figure 1. Mathematical model of PM DC motor

The equations of the PMDC motor are expressed by using Kirchhoff's law in the equivalent circuit, as:

$$V_b(t) = E_a = K_b \omega_m(t) \tag{1}$$

From Kirchhoff's circuit laws:

$$V_a(t) = R_a I_a(t) + L_a \frac{dI_a(t)}{dt} + V_b(t) \tag{2}$$

The torque developed by the motor is:

$$T_m(t) = J\frac{d^2\theta(t)}{dt} + B\frac{d\theta}{dt} = K_t I_a(t) \tag{3}$$

If the copper losses of the motor are neglected, the electrical output power of the motor is equal to the below equation;

$$P_e = E_a I_a = \omega_m T_m \tag{4}$$

$$T_m = B\omega_m \tag{5}$$

Description of parameters which are given for the system are given below.

V_a: Armature voltage, V;
R_a: Resistance of armature circuit, Ω;
L_a: Inductance of armature circuit, H;
E_a: The opposite electromotive force voltage, V;
ω_m: Motor angular speed, rad/s;
T_m: The torque developed by the motor, N.m;
J: Inertia moment, N.m;
T_L: Load torque, N.m.

The block diagram of the PMDC motor can be obtained as in Figure 2 with the help of the above equations. If Laplace Transform is applied to the above equation;

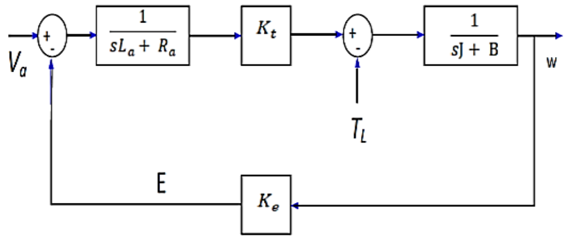

Figure 2. The block diagram of the PM DC motor

$$\omega(s) = \frac{K_v I_a(s) - T_L(s)}{J_s + B} \tag{6}$$

$$T_s = \frac{K_t/(L_a.J)}{s^2 + s\left(\frac{R_a}{L_a} + \frac{B}{J}\right) + \frac{R_a.B + K_e^{\,2}}{L_a.J}} \tag{7}$$

H-Bridge driver circuit is a power electronics driver circuit that allows a positive and negative voltage to be applied to a load by using a single power supply. H-Bridge circuit is generally used for some industrial applications [8] and also it is used for driving the direct current motors. The protection diodes are connected to protect the switches from the high voltage value that will occur in the direct current (DC) motor during transmission and cutting moments. For forward H-Bridge motor drive circuit (Figure 3), Q1 P channel and Q4 N channel MOSFETs are in transmission situation, Q2 P channel and Q3 N channel MOSFETs are in cutting situation. When Q1 and Q4 are in transmission situation together, the DC source voltage is seen at the motor terminals, and the armature current increases depending on this situation and so allows direct current motor to rotate in the forward direction.

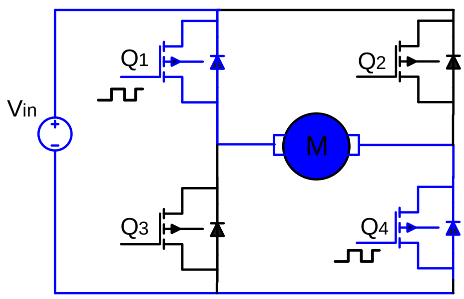

Figure 3. H-Bridge motor driver circuit for forward direction

In the opposite direction of the H-Bridge motor drive circuit (Figure 4), Q1 P channel and Q4 N channel MOSFETs are in cutting situation for the H-Bridge motor drive circuit are switched on, Q2 P channel and Q3 N channel MOSFETs are in transmission situation (Figure 4). The DC voltage is seen in the opposite direction at the motor terminals when the semiconductor switches Q2 and Q3 are in transmission situation together, and the armature current increases depending on this situation and so allows direct current motor to rotate in the opposite direction.

Two pieces of BC337 NPN channel transistors are used for driving IRF9540 P channel MOSFET in the circuit of H-Bridge motor driver which consists of two pieces of IRF9540 MOSFETs and 2 pieces of IRF530 MOSFETs. IRF530 P channel MOSFETs are driven directly from the output of the microcontroller.

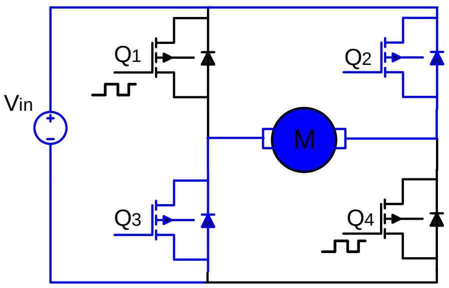

Figure 4. H-Bridge motor driver circuit for reverse direction

III. CONTROLLER DESIGN

A PI controller was used to control the speed of the PMDC motor for both simulation model and experimental prototype. C software language is used as software and PI control is used in the prepared circuit to determine the ideal and stable operating speeds of the direct current motor which has been selected. The motor in the system operates with 12 V and can reach a maximum speed of 10200 rpm. There are encoders which generate 48 cycles per revolution at the rear of the motor. The encoder is used for feedback and is connected to pin B0 of the processor which forms the external interrupt. HC-05 Bluetooth module is used for wireless connection. As shown in Figure 5, an error signal which is the difference between the reference value and real value is evaluated by the controller and transferred to the output. When the error signal $e(t)$ enters the PI controller, this signal is multiplied with the proportional effect gain (K_p) and the integral of the error signal is multiplied with the integral effect gain (K_i). PI control output is expressed as below [9];

$$y(t) = e(t) + K_i \int_0^t e(t)\,dt \tag{8}$$

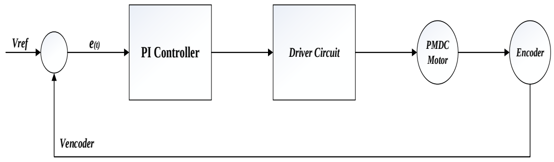

Figure 5. Speed control of direct current motor with PI control

The proportional gain (K_p) reduces the rise time and steady state error but does not completely eliminate it. Integral control (K_i) eliminates steady state error but adversely affects transient response. The effects of K_p and K_i coefficients of a closed loop system are realized according to Table 1.

In the closed loop system given above, the engine speed is set with the reference value. Thanks to the encoder which is used in the system, the changes in the engine speed is detected. The armature winding voltage or excitation winding voltage is changed according to the motor load condition so that the speed remains at the reference value. The system is efficient and reliable since the motor voltage is adjusted by helping of semiconductors.

PWM technique is widely used in many fields such as coding and decoding techniques in motor drives, power electronics, voltage regulators and telecommunications. Pulse Width Modulation is the most powerful method for controlling analog circuits with digital outputs and many microcontrollers which occur in industrial areas include PWM modules. This PWM module can be obtained by programming the frequency and ratio of signal.

The control of the square signal which will be generated can be modeled with a switch that is connected in series to a circuit [10]. The output of the PI controller is used as a comparator to produce PWM signals for driver. While switching frequency is determined with the help of microcontroller, the duty cycle of the signals is differing according to the comparator signal.

The direction of rotation of the motor is determined by entering the values of the rotation speed and the values of the K_p and K_i which will be used in PI control to the control screen and also first movement is given by pressing the start button. The PWM duty cycle is set to 350 for ensuring the first movement of the motor. PI control is performed in each cycle and the error rate and the completion time of the one cycle are determined by the information which is obtained from the Timer1 counter. The datas which are obtained from the generated PI update function and the ratio of the PWM dut cycle to be applied as a result of PI control are determined and applied to the system at the end of each cycle.

IV. RESULTS AND DISCUSSION

The proposed study has been verified via experimental prototype after obtaining some simulation results which were obtained via PSpice and Matlab/Simulink programs. The parameters of the PMDC motor are given in Table 1. These parameters are also used in the simulation model. In the simulation studies, speed control of direct current motor is tried to be obtained by using PI controller. The flowchart of the controller is given in Figure 6. Different PI controller' coefficients are used to observe the speed response oh the motor. Figure 7 is one of the examples.

Table 1. The parameters of PM DC motor

Parameters	Values	Units
Armature inductance	7×10^{-6}	Henry (H)
Armature resistance	0.41	Ohm (Ω)
Rotor inertia (J)	42×10^{-5}	N. m2
Viscous friction coefficient (B)	0.00034	N.m/rad/s
Moment coefficient (K_t)	0.0191	N.m/A
Voltage coefficient (K_v)	0.02	V/A-rad/s
Friction moment	0.049	N.m

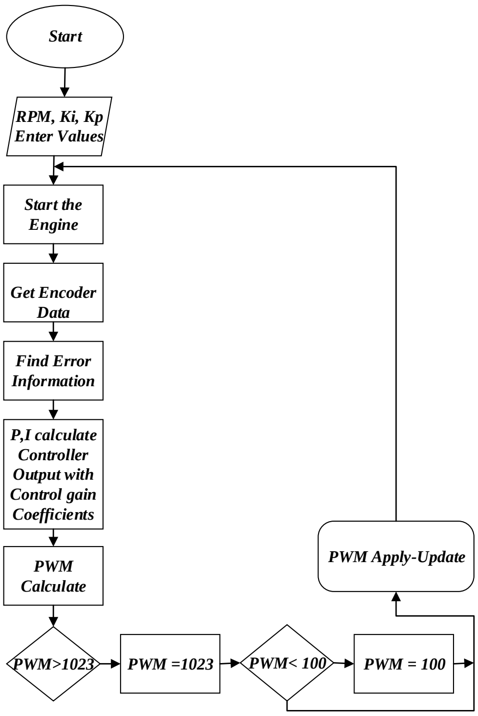

Figure 6. The flowchart of the controller

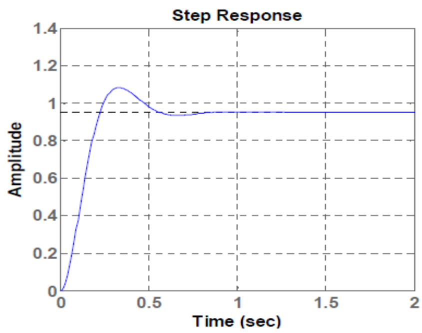

Figure 7. Speed responses of the motor under different gains of PI

Except for Simulink, PSpice software was also used to simulate the whole system. Figure 8 shows the PSpice simulation model. The PWM outputs for driving circuit produced in PSpice is given in Figure 9.

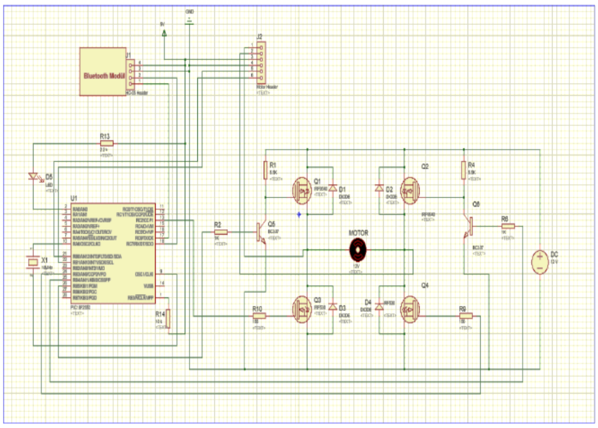

Figure 8. PSpice model of the system

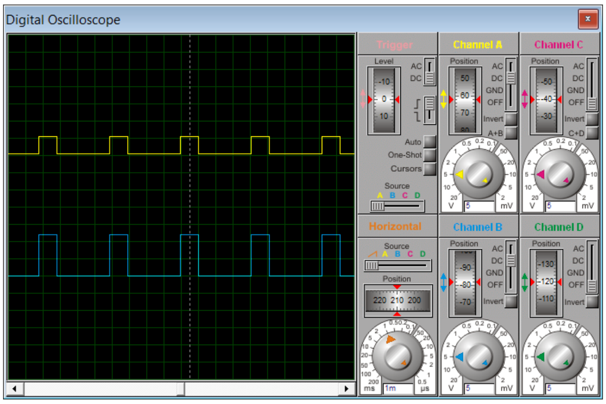

Figure 9. PWM outputs produced in PSpice model

After the simulation studies, the experimental prototype has been done to observe the experimental results. The experimental setup is given in Figure 10. The experimental prototype includes two parts. First is the PMDC motor and driving circuit with microcontroller. The second part is the Android application which is applied via a hand phone.

PIC-18F2550 microprocessor which works with 16 MHz oscillator frequency is used for the microcontroller. The circuit configuration of the 18F2550 microprocessor is given in Figure 11. There are two PWM generators which have 10-bit resolution and they are used to drive MOSFETs in our motor driver circuit. The used PMDC motor operates with 12 V voltage and can reach a maximum speed of 10200 rpm. There is encoder which generate 48 cycles per revolution at the rear of the motor. The encoder is used for feedback and is connected to pin B0 which forms the external interrupt of the processor. HC-05 Bluetooth module is used for wireless connection. PI control is performed in each round and the error rate and completion time of one round are determined by the information that is obtained from Timer1 counter. The data which are obtained from the generated PI update function and the PWM duty cycle ratio to be applied as a result of PI control are determined and they are applied to the system at the end of each cycle.

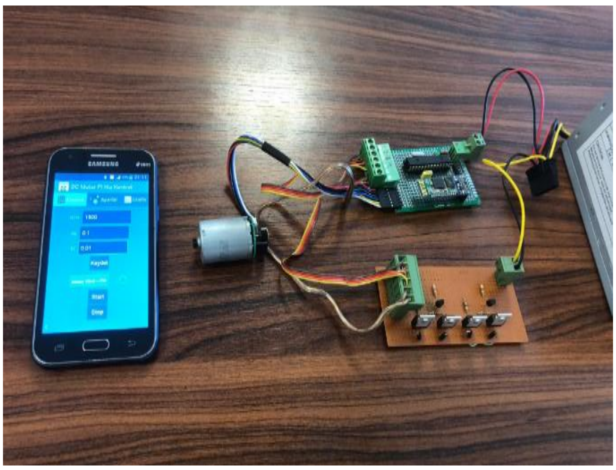

Figure 10. The experimental prototype

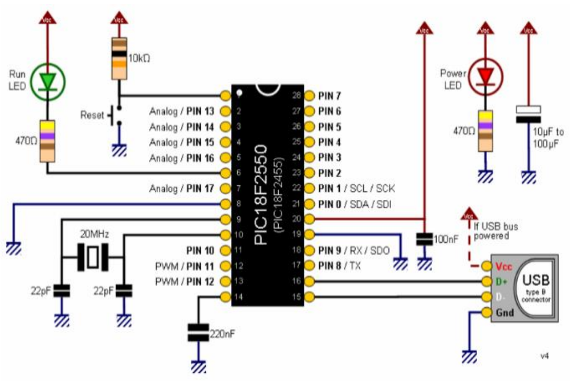

Figure 11. 18F2550 microprocessor and its circuit

Motor drive circuit tests were performed before using the Android-based interface. The PWM signals generated by the PIC microprocessor were passed through the driver circuit and applied to the H-bridge circuit. Some results are shown in Figure 12.

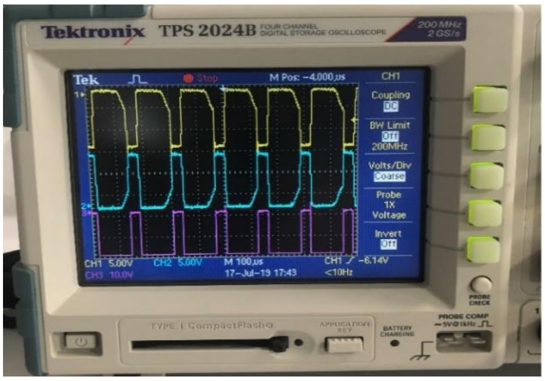

Figure 12. Scope records of driver circuit outputs for H-Bridge (V_M, V_{DS2}, V_{DS3})

Android application was used to monitor and display the speed of PMDC motor. The android application that is used for PI control of PMDC motor consists of three parts. The first page contains the settings for the PI control and settings are done for the reference cycles, K_p and K_i parameters. In this section, the direction of rotation of the motor is also set. There are two separate buttons for starting and stopping the motor (Figure 13).

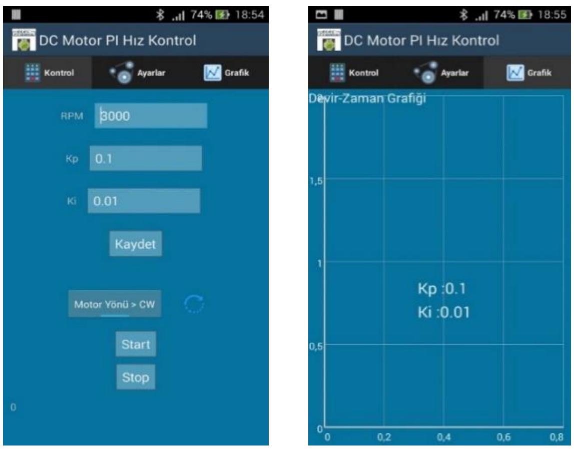

Figure 13. The android application interfaces

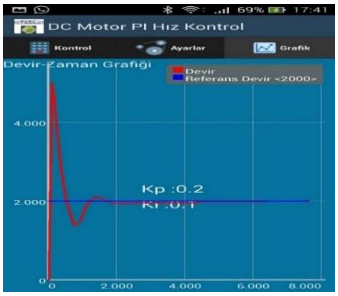

Figure 14. Results for 2000 rpm at K_p: 0.1-0.2 and K_i: 0.01-0.1

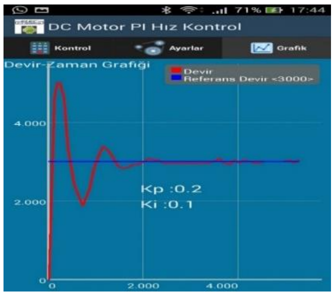

Figure 15. Results for 3000 rpm at K_p: 0.1-0.2 and K_i: 0.01-0.1

The left section of the interface shows the number of data which are received. There are options for setting of the number of data and options for whether the motor will stop when the data is completed in the settings section on the second page. On the third page, the data that are obtained via HC-05 Bluetooth module is shown graphically. The generated graph is the cycle - time graph. It is automatically generated with data that is received from the processor and includes image enlargement and shift functions for detailed review. The direction of rotation of the motor is determined by entering the rotational speed of the PMDC motor and the K_p and K_i values to be used in PI control to control screen and the first movement is given by pressing start button.

When the system is energized, the PMDC motor starts and the motor speed increases to the reference speed value and remains constant at this value. As the reference speed increases, the average amplitude of the PWM signal that is applied to the direct current motor increases. Conversely, as the reference speed of the motor decreases, the average amplitude of the PWM signal that is applied to the motor decreases. There is feedback PI controller in the system, so the system responds automatically to the direct current motor speed to follow the reference speed and to generate the appropriate PWM signal. The experimental setup was operated for the motor speed of 2000 and 3000 rpm under the same PI coefficients values. The results are given in Figures 14 and 15, respectively.

Referring to the graphs shown in Figures 14 and 15, it is seen that the PMDC motor speed has high peaks before reaching the reference speed. This is due to the fact that the rated speed of the motor used is high (10200rpm) and its inertia is very low. In addition to this the operating of the motor without load causes these peaks. Choosing a more suitable motor and operating under load will eliminate this problem.

V. CONCLUSIONS

The experimental verification of a PMDC motor speed control and monitoring the speed of PMDC motor with the interface software developed via Android operating system has been done in this study. The PI control technique was applied to the speed of the motor by using android application which provides remote communication and monitoring for the system. The speed control and monitoring were designed by using sensors to succeed wireless remote system control. The proposed study has been verified via experimental prototype after some simulation results which were obtained via Matlab/Simulink and PSpice programs. It was observed that the proposed PI controlled PMDC motor with android application has wireless remote control and it has reached the most ideal and stable operating range as fast as possible with the simulation and experimental applications.

In the experimental setup PIC-18F2550 is used as microcontroller and PWM signals are applied to the H-Bridge drive circuit of direct current motor through. It is seen from the practical results that the speed values of the direct current encoder motor speed control circuit, which is designed by using PI controller, are dependent on both reference speed values and the response of PI controller. It is also observed that the designed system become stable in approximately 1.5-2 seconds depending on K_p and K_i values which are given at 1500-3000 rpm.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Scientific Research Fund of Van Yuzuncu Yil University, Van, Turkey (YYU-BAP) for the financial support of this research with project number of FYL-2018-6733.

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BIOGRAPHIES

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