

Smart speed control of BLDC motor using programmable logic controller

Abstract. This paper proposed a speed control technique for Brushless Direct Current Motor (BLDC) using a Programmable Logic Control (PLC) unit. The BLDC has been widely used in many industrial applications because of its excellent structure and high performance because it needs minor maintenance requirements. A PLC is an industrially hardened computer-based unit that performs discrete or continuous control functions in various processing plants and factory environments. A closed-loop control method has been developed to maintain the motor's speed within acceptable limits and equal to the reference speed. The speed signal has been taken from a tachometer that is coupled with the rotor of the motor. The simulation result of the PLC software (logo soft comfort) gives good results for the motor's speed control. The most crucial idea of this project is that the PLC will do almost all the control actions. That is, it will compare the reference with the measured speed, then this error will be fed to the PWM block inside the PLC program, and finally, the controller will generate the required sequence for the gating signal.

Streszczenie. W tym artykule zaproponowano technikę kontroli prędkości dla bezszczotkowego silnika prądu stałego (BLDC) przy użyciu jednostki programowalnego sterowania logicznego (PLC). BLDC jest szeroko stosowany w wielu zastosowaniach przemysłowych ze względu na doskonałą strukturę i wysoką wydajność, ponieważ wymaga niewielkich wymagań konserwacyjnych. PLC to przemysłowo utwardzona jednostka komputerowa, która wykonuje dyskretne lub ciągłe funkcje kontrolne w różnych zakładach przetwórczych i środowiskach fabrycznych. Opracowano metodę sterowania w pętli zamkniętej, aby utrzymać prędkość silnika w dopuszczalnych granicach i równą prędkości odniesienia. Sygnał prędkości został pobrany z obrotomierza, który jest sprzężony z wirnikiem silnika. Wynik symulacji oprogramowania PLC (logo soft comfort) daje dobre wyniki dla sterowania prędkością silnika. Najważniejszą ideą tego projektu jest to, że PLC wykona prawie wszystkie czynności kontrolne. Oznacza to, że porówna odniesienie ze zmierzoną prędkością, następnie ten błąd zostanie podany do bloku PWM w programie PLC, a na końcu sterownik wygeneruje wymaganą sekwencję dla sygnału bramkującego. (Inteligentna kontrola prędkości silnika BLDC za pomocą programowalnego sterownika logicznego)

Keywords: BLDC, PWM, LOGO and PLC.

Słowa kluczowe: BLDC, PWM, LOGO i PLC

Introduction

There are two main types of motors, the alternating current motor (A.C.) and direct current (D.C.), and the D.C. motor has several kinds that are separately excited, self-excited, permanent magnet, and BLDC. In our project, we use the BLDC motor.

The BLDC is a permanent magnet synchronous electric motor that is driven by DC electricity, and it accomplishes an electronically controlled commutation system (commutation is the process of producing rotational torque in the motor by changing phase currents through it at appropriate times) instead of a mechanical commutation system [1]. BLDC motors are one of the motor types rapidly gaining popularity. BLDC motor has been used extensively in industrial automation, aerospace, instrumentation, and automotive industries since the 1970s [2]. BLDC motors are preferred as small horsepower control motors due to their high efficiency, silent operation, compact form, reliability, and low maintenance [3].

BLDC is used for a wide variety of application requirements such as varying loads, constant loads, and positioning applications in the fields of industrial control, automotive, aviation, automation systems, health care equipment, etc. Some specific applications of BLDC motors are computer hard drives and DVD/CD players, electric vehicles, hybrid vehicles, and electric bicycles, industrial robots, Computer Numeric Controlled (CNC) machines, and simple belt-driven systems, and washing machines, compressors and dryers, fans, pumps and blowers, fuel pump control, electronic steering control, engine control and electric vehicle control [4, 5].

Comparison of BLDC with conventional D.C. motors

In a conventional (brushed) DC-motor, the brushes make mechanical contact with a set of electrical contacts on the rotor (called the commutator), forming an electrical

circuit between the D.C. electrical source and the armature coil-windings. As the armature rotates on-axis, the stationary brushes come into contact with different rotating commutator sections [6]. The commutator and brush-system form a set of electrical switches, each firing in sequence, such that electrical power always flows through the armature-coil closest to the stationary stator (permanent magnet). In a BLDC motor, the electromagnets do not move; instead, the permanent magnets rotate, and the armature remains static. This gets around the problem of how to transfer current to a moving armature. To do this, the commutator assembly is replaced by an intelligent electronic controller. The controller performs the same power distribution found in a brushed D.C. motor but using a solid-state circuit rather than a commutator. BLDC motors have many advantages over D.C. motors. A few of these are: High dynamic response, High efficiency, Long operating life, Noiseless operation, and Higher speed ranges [7].

BLDC's main disadvantage is the higher cost which arises from two issues. First, BLDC motors require complex electronic speed controllers to run. Brushed DC-motors can be regulated by a comparatively trivial variable resistor, which is inefficient and satisfactory for cost-sensitive applications [8].

Construction of a BLDC Motor:

Like any other electric motor, a BLDC motor also has a stator and a rotor. Here we will consider Stator and Rotor each separately from the construction point of view.

BLDC Stator: There are three types of the BLDC motor: Single-phase, Two-phase, and Three-phase. Stator for each class has the same number of windings. The single-phase and three-phase motors are the most widely used. The simplified cross-section of a single-phase and a three-phase BLDC motor is shown in Fig. 1. The rotor has permanent magnets to form two magnetic pole pairs and surrounds the stator, which has windings [4, 5].

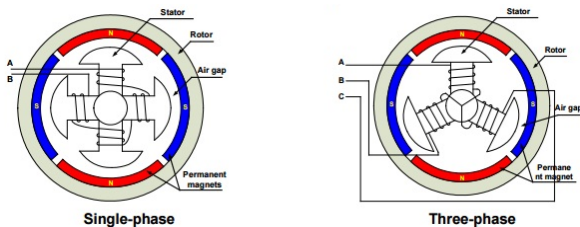


Fig. 1: Single-phase and three-phase BLDC motor

A single-phase motor has one stator winding wound either clockwise or counter-clockwise along each stator's arm to produce four magnetic poles as shown in the above figure. A three-phase BLDC motor has three windings. Each phase turns on sequentially to make the rotor revolve. BLDC Rotor: A rotor consists of a shaft and a hub with permanent magnets arranged to form between two to eight pole pairs that alternate between the north and south poles. Fig. 2 shows cross-sections of three kinds of magnets arrangements in a rotor.

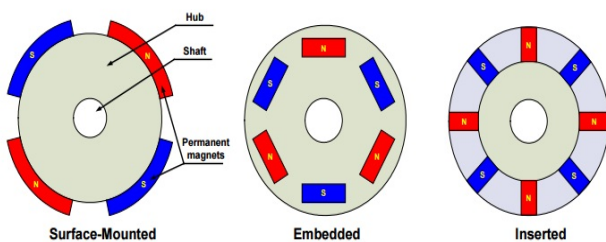


Fig. 2: Cross-sections of three kinds of magnets arrangements in a rotor

Speed Control of BLDC Motor

The speed control of the BLDC motor can be done by using PWM pulses by the microcontroller according to the programming done. PWM is a common technique for controlling electrical power for an electrical device. The average value of current and voltage fed to a load is controlled by turning on and off the switch between supply and load quickly. Similarly, the percentage of a duty cycle from the keypad is received by the microcontroller, and it gives the wanted output to switch the motor driver to vary the BLDC motor speed.

Using PID Controller, BLDC motors have been used in various industrial and domestic applications. Due to overweighing merits of this motor, there is a continuing trend to propose improved control schemes to enhance the motor's performance. Torque smoothness is essential for high-performance motion control applications, and obtaining an accurate and ripple-free instantaneous torque is of significant importance for BLDC motor.

Using PLC controllers

PLC is a programmable logic controller. This is also referred to as a commercial virtual P.C. tailored to manipulate manufacturing techniques, along with meeting traces or robot gadgets or any hobby that calls for high-reliability control and ease of programming and procedure fault diagnosis [9, 10]. They were extensively followed as excessive reliability automation controllers suitable for harsh surroundings. P.C is an instance for complex actual time device in view that output consequences need to be produced in reaction to enter situations with a limited time; in any other case, the unintended operation will result.

Practical Control Circuit

The proposed system is a closed-loop controller that uses the PLC as a comparator, PWM generator, and

sequence generator, as shown in Fig. 3. The BLDC motor's speed is measured using a simple tachometer; then, the speed signal is fed to a signal conditioning circuit, the output of this circuit is compared with the reference speed inside the PLC using the PLC analog comparator. This comparator is fed to the PWM circuit that will generate the required sequence to maintain the speed within the required limit.

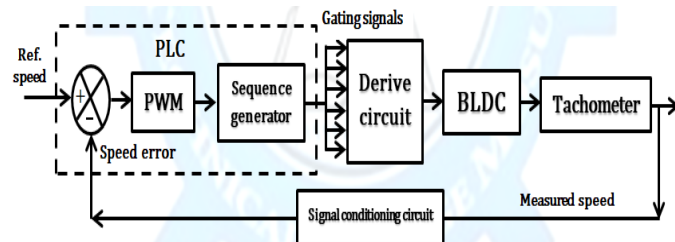


Fig. 3: Circuit Diagram for the proposed control system

BLDC type (PBT-GF40 SAE)

In this project, we used a BLDC to derive a Heater Fan Blower Motor for Toyota Land Cruiser UZJ200 200 Series crown reiz Prado see Fig. 4.



Fig. 4: BLDC motor

The motor specification for the used BLDC motor is shown in Table.1, these specifications are obtained using an RLC meter to get the phase resistance, and inductance and the other parameters are obtained from Toyota Land Cruiser UZJ200 VDJ200 200 Series Heater Fan Blower Motor.

Table 1: specifications for the BLDC motor

Rated voltage	12 volt
Rated torque	0.2 N.m
Rated velocity	3950 r/min
Rated current	5 A
Rated power	82 Watt
Torque coefficient	0.0475 N.m/A
Resistance phase	0.49 Ω
Phase inductance	0.16 mH
Number of poles pair	2

Siemens PLC type (LOGO!8 24CE)

As a controller, we used a Siemens product LOGO!8 24CE with an extension to increase the number of outputs. This type of PLC has many advantages as compared to other LOGO! Products. LOGO! 24CE, logic module, display PS / I / O: 24 V / 24 V / 24 V trans., 8 DI (4AI) / 4DO, memory 400 blocks, modular expandable, Ethernet integer. webserver, data log, standard micro S.D. card for LOGO! SOFT Comfort V8 or higher older projects executable. For many years, the LOGO! The logic module has secured a strong position when it comes to small automation applications. With LOGO! 8 there is a new generation on the market, one that focuses on communication and greatly enhanced performance. The easy entry into automation

technology nevertheless remains. Features

Because the central unit for the PLC has only four outputs and the proposed controller required six results to produce the required outputs for the gating signals. This product (LOGO! AM2) is connected directly to the central PLC unit mechanically and electrically. This extension has the following specifications from this catalogue.

Signal conditioning circuit

To make the output signal for the speed compatible with the PLC's inputs, the speed signal must be conditioned to a value suitable with the PLC requirements. The tachometer output that is mechanically connected to the motor is a sin wave signal; the PLC input must be D.C. voltage, so a simple rectifier circuit must be introduced as in Fig. 5. To ensure that the input voltage range to the PLC in the limit of (10-14 volt), a transformer is connected to produce a bridge rectifier.

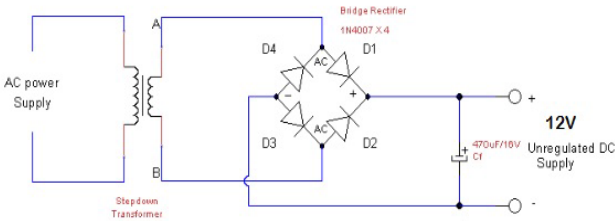


Fig. 5: LOGO! AM2 extension

PLC software

Most of our control activity in this project is achieved inside the PLC; to do so, a software program must be designed and implemented to perform the required performance of the PLC. As it is evident in Fig. 6, we used the function block diagram language and logo soft comfort program to design the PLC program, the reference signal (AI1) will be compared with the speed signal (AI2) they will enter to the analog comparator (BO12). This comparator must be set to deal with the error signal (we must set the maximum and minimum ranges that are coping with the actual signal). This error signal will be fed directly to the PWM block (BO13) also the same setting must be confirmed to this block also. According to the error, the PWM block will generate the required sequence to operate the on-delay timers and the asynchronous pulse generators that are output the gating signal according to the time setting that we insert on them to produce the required pulses to operate the BLDC motor. The block we used in this software will be explained in detail below.

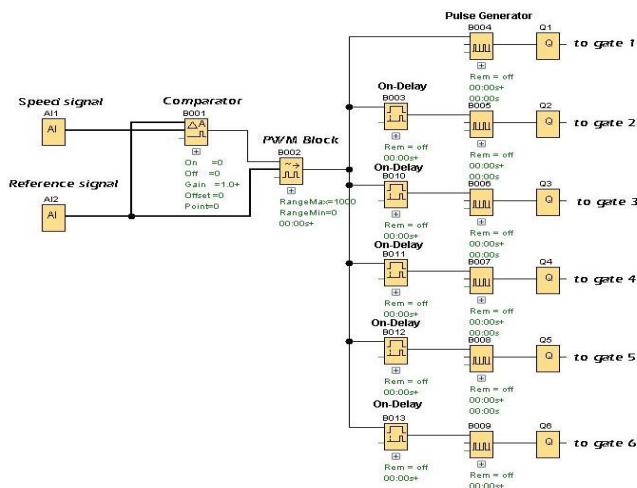


Fig. 6: The FBD program for the proposed controller PWM block

PWM:

As shown in Fig. 7, the PWM block has two inputs, the first one is the enable, and the second one is the analog signal modulated.

Pulse Width Modulator (PWM)



Short description

The Pulse Width Modulator (PWM) instruction modulates the analog input value Ax to a pulsed digital output signal. The pulse width is proportional to the analog value Ax.

Connection	Description
Input En	A positive edge (0 to 1 transition) at input En enables the PWM function block.
Input Ax	Analog signal to be modulated to a pulsed digital output signal.
Parameter	Gain Range of values: -10.00 to 10.00 Offset Range of values: -10,000 to 10,000 PT : Periodic time over which the digital output is modulated p : Number of decimals Possible settings: 0, 1, 2, 3
Output Q	Q is set or reset for the proportion of each time period according to the proportion of the standardized value Ax to the analog value range.

Fig. 7: PWM block

To set the PWM parameters, we must double click to the block, and Fig. 8 will appear; this will help us fix the ranges of this block.

Asynchronous pulse generator



Description of function

The pulse shape at the output can be modified by a configurable pulse/pause ratio.

Connection	Description
Input En	You enable/disable the asynchronous pulse generator with the signal at input En.
Input Inv	The Inv input can be used to invert the output signal of the active asynchronous pulse generator.
Parameter	T_H, T_L : You can customize the pulse width (T_H) and the interpulse width (T_L).
Output Q	Q is toggled on and off cyclically with the pulse/pause times T_H and T_L .

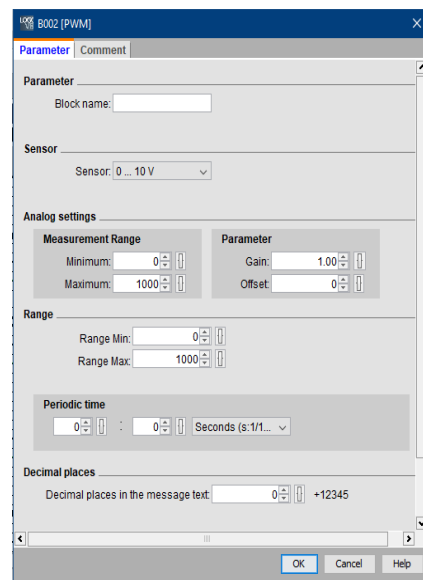


Fig. 8: PWM parameters setting

Comparator:

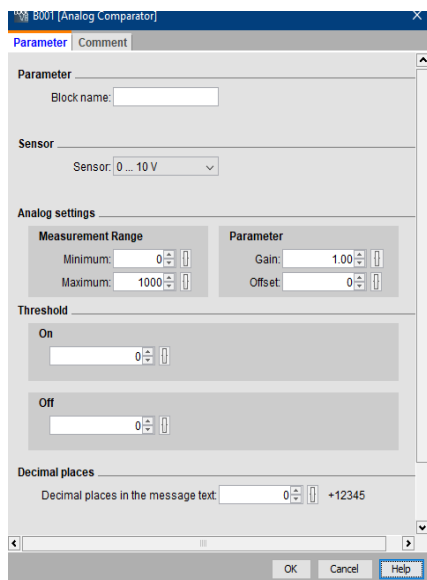
Fig. 9 is for the analog comparator That will compare between two analog signals and produce the error that will be fed to the PWM block.

Analog comparator



Fig. 9: Analogue comparator block

To set the analog comparator parameters, we must double click to the block, and Fig. 10 will appear; this will help us develop the ranges of our block.



Connection	Description
Inputs Ax, Ay	Inputs Ax, Ay are two analog signals from the followings: <ul style="list-style-type: none"> AI1 to AI8 (*) AM1 to AM6 (if OBA6), AM1 to AM16 (if OBA7), or AM1 to AM64 (if OBA8) NAI1 to NAI32 (if OBA7 or OBA8) AQ1 and AQ2 (if OBA7), or AQ1 to AQ8 (if OBA8) NAQ1 to NAQ16 (if OBA7 or OBA8) The block number of a function with analog output
Parameter	Gain Range of values: -10.00 to 10.00 Offset Range of values: -10000 to 10000 On: On threshold Range of values: -20000 to 20000 Off: Off threshold Range of values: -20000 to 20000 p: Number of decimals Range of values: 0, 1, 2, 3
Output Q	Q is set or reset depending on the set thresholds.

* AI1 to AI8: 0 to 10 V corresponds with 0 to 1000 (internal value).

Fig. 10: Analogue comparator parameters settings

How to create the reference signal

The reference signal is created outside the PLC; a simple circuit is designed to produce a variable reference signal using a Voltage Divider Series Circuit. The two resistors are connected in series across the supply. As they are in series, the equivalent or total resistance, $R_{T.}$, is therefore equal to the sum of the two individual resistors: $R_1 + R_2$.

Also, being a series network, the same current flows through each resistor as it has nowhere else to go. However, the voltage drop given across each resistor will be different due to the resistors' different ohmic values. These voltage drops can be calculated using Ohm's Law

with their sum equal to the supply voltage across the series chain. So here in this example, $V_{IN} = V_{R1} + V_{R2}$.

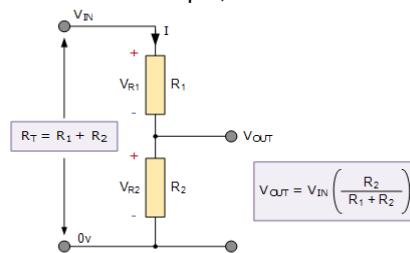
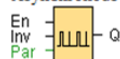


Fig. 11: simple potentiometer circuit

Sequence Generator:

In the PLC program, we used six pulse generator with different time setting to produce the outputs signal at the other time to create the other six gating signal to operate the motor at the required speed.

Asynchronous pulse generator



Description of function: The pulse shape at the output can be modified by a configurable pulse/pause ratio.

Connection Description

Input En	You enable/disable the asynchronous pulse generator with the signal at input En.
Input Inv	The Inv input can be used to invert the output signal of the active asynchronous pulse generator.
Parameter	T_H , T_L : You can customize the pulse width (T_H) and the interpulse width (T_L).
Output Q	Q is toggled on and off cyclically with the pulse/pause times T_H and T_L .

Fig. 12: Asynchronous pulse generator

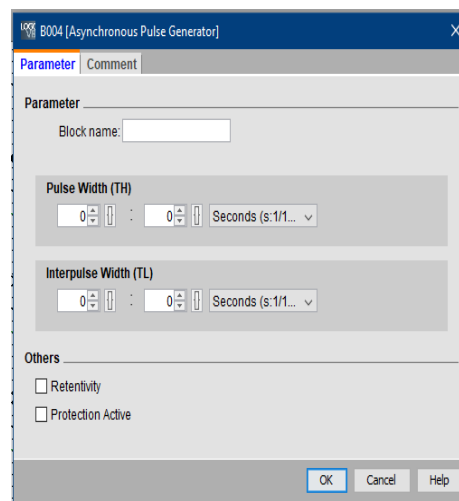


Fig. 13: Parameters setting for the asynchronous pulse generator

Derive circuit for the BLDC motor

The six outputs of the PLC will be fed directly to the six switch inverter via the opto-isolated circuit seen in Fig. 14.

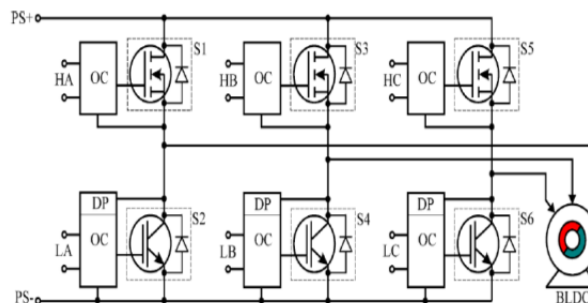


Fig. 14: Derive circuit for the BLDC motor

Our practical derive circuit is seen in Fig. 15; it is consisting of:

- Six Power MOSFET of type IRFP 460 A that have a Drain-to-Source Breakdown Voltage equal to 500 volt and Continuous Drain Current of 20 A
- Six opto-isolated integrated circuits of type 4N35, as is seen in Fig. 16.
- Different values of resistance.



Fig. 15: Practical derive circuit

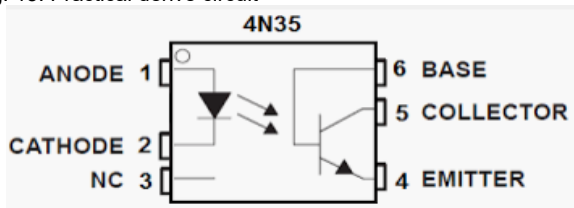


Fig. 16: 4N35 Optocoupler

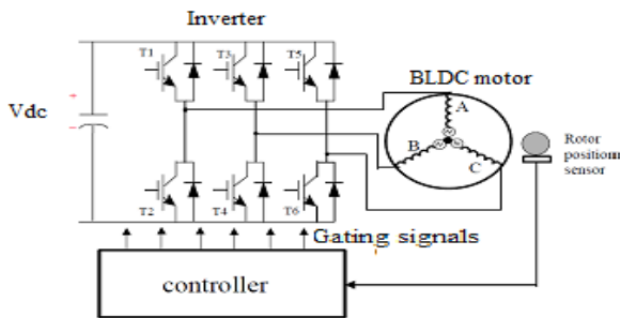


Fig. 17: Derive circuit for the BLDC motor

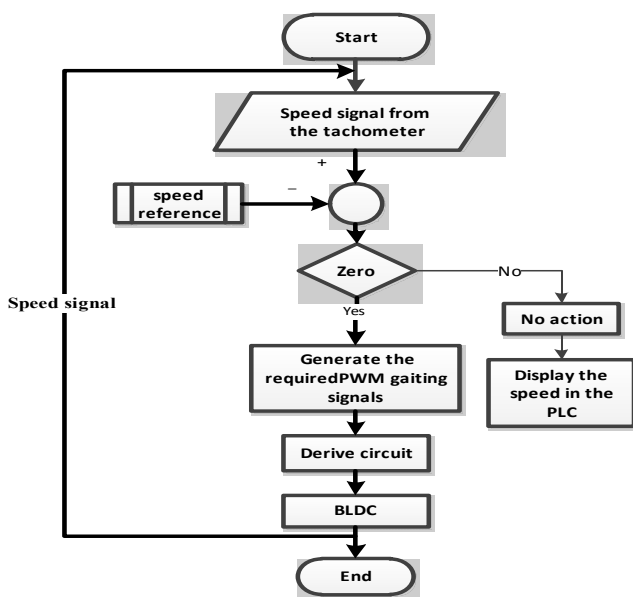


Fig. 18: software flowchart Results

The output of the PLC is fed to the Optocoupler I.C. via the resistance as a potential divider then if the input of the Optocoupler is high, the gate of the transistor in the 4N35 will derive the Vcc (5 volts D.C.) to the gate of the IRFP 460 power misfit then it will derive the 12 volt D.C. to the terminals of the motor as it clear in Fig. 17.

Program flow chart

This section will consider the PLC program flowchart (see Fig. 18) to clear the sequence of operations for the proposed control system.

In this project, our order is seen in Fig. 19. If we get the PLC, we will have to read the output waveforms of the derive pulses current that will be out of the PLC, and it may be as in Fig. 20. The step response of the motor speed must be drawn, and simple calculations must be done, as shown in Fig. 21.

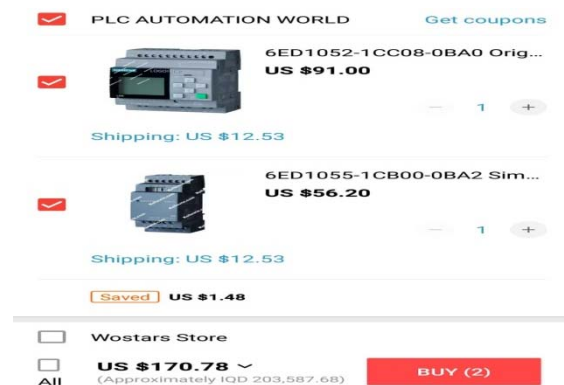


Fig. 19: PLC order checklist

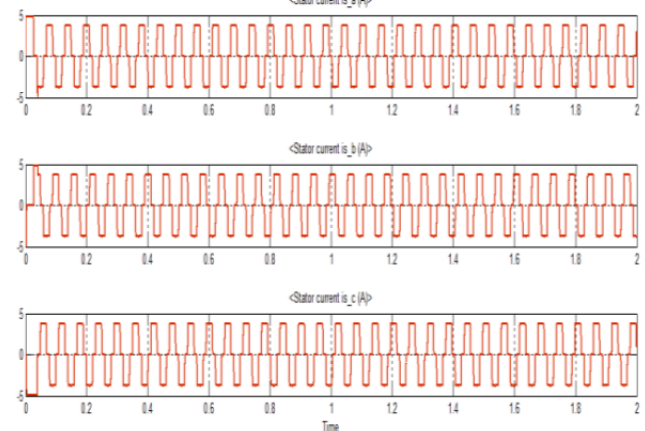


Fig. 20: load current of the BLDC motor

The suggested models may be used to simulate the dynamic as well as steady state performance of a faulty and non-faulty motor [11-13]. After completing the design of the control circuit, some parameters which have been described the performance of this circuit must be calculated from the step response; these parameters are:

- damping ratio (ζ).
- natural frequency (ω_n) in radian/second
- Percent overshoot P.O. = $100e^{-\zeta\pi/\sqrt{1-\zeta^2}}$ (1)
- Time to peak overshoot (T_p) = $\frac{\pi}{\omega_n\sqrt{1-\zeta^2}}$ in second. (2)
- Settling time (T_s) = $\frac{4}{\zeta\omega_n}$ in second (for 2% criteria) (3)
- Steady-state error (e_{ss}). (4)

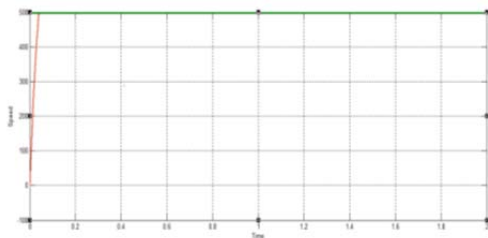


Fig. 21: Speed response of the BLDC motor

Potentiometer calculations

In this simple voltage divider example, the voltage developed across R2 was found to be 9 volts. But by changing the value of any one of the two resistors, the voltage can, in theory, be any value between 0V and 12V. This idea of a two resistors series circuit in which we can change either resistor's weight to obtain a different voltage output is the basic concept behind the potentiometer's operation. The step changes response to the system reference signals is used for testing the performance of the controller [11].

The difference this time with the potentiometer is that to obtain different voltages at the output, the total resistance, R.T. value of the potentiometer resistive track does not change; only the two resistances' ratio formed either side of the wiper as it moves. Thus, the potentiometer's movable wiper provides an output that varies between the voltage at one end of the track and that at the other, usually between maximum and zero, respectively, A practical example for potentiometer used in our project

$$RT=R1+R2$$

$$RT=250\Omega+750\Omega=1000\Omega \text{ OR } 1K\omega$$

Conclusions and Future Work:

The proposed control technique that uses the PLC to produce the error signal for the motor speed using the PLC analog comparator, and using the PWM block inside the PLC software and finally made these PWM in sequence using the sequence generator in the software to out the required gating signal for the six switches, all of these achievements for the PLC is consider as a novel work to overcome the complexity of the electronic circuits (i.e., the comparator, PWM circuit, and the pulse generator signals for the switches). Also, the flexible structure for the prosed circuit made it very easy to implement in many modes of operation for the speed control (i.e. produce many speed configurations, reveres the speed of operation and finally this circuit can be implemented for many motors together not for one motor). This circuit can be easily maintenance and operated for the technical operator in the factory by simple training course.

For future work, this circuit can be used the ethernet com in the PLC to control the operation of the motor also to monitor the operation of the motor (its speed, voltage, and current).

Authors: Laith A. Khalaf, Omar T. Mahmood, and Ahmed M. T. Ibraheem, "Dep. of Electrical Power Technology Engineering, NTU, Iraq". Emails: laith.abd@ntu.edu.iq, omar.talal@ntu.edu.iq, ahmed_alnaib2018@ntu.edu.iq respectively, Omar T. Mahmood is currently a "Ph.D. student" at the "Dep. of Electrical and Electronic Eng., Faculty of Eng., UPM, Serdang 43400, Selangor, Malaysia" Email: gs60480@student.upm.edu.my

REFERENCES

- [1] Basava Ram Durga, P.Subhash kumar, M.Punya Teja, and et al., " Speed Control of PMLDLC Motor Using PLC," AJAST, Vol. 1, Issue 6, pp. 114-119, July 2017.
- [2] Anju Roy and Dominic Mathew, " Speed control of sensorless BLDC motor with two side chopping PWM," IOSR-JEEE, Vol. 6, Issue 3 (May. - Jun. 2013), pp.16-20.
- [3] R.Manikandan, R.Arulmozhiyal, M.Sangeetha, "Sensorless Speed Control of FSTPI Fed Brushless DC Motor Drive Using Terminal Voltage Sensing Method," IJSCE, Vol. 4, Issue-1, March 2014
- [4] Kiran Kumar G R, Shivakumar L. N, " Application of PLC for the Speed Control of D.C. Motor- A Novel Approach," International Journal of Advances in Electrical Machine and Power Electronics Vol. 1 Issue 1, pp. 14-17, 2017.
- [5] S.Rambau, "Modeling and Control Of A BLDCM," master thesis Dep. of Electrical Engineering National Institute of Tech. Rourkela 2007.
- [6] Alex Van den Bossche, Dimitar Vaskov Bozalakov, Thomas Vyncke, Vencislav Chekov Valchev, " Programmable Logic Device Based Brushless DC Motor Control" EPE Journal, 2011.
- [7] Akshay Ingole et al., " Speed Control of BLDC Motor Using PLC," International Journal of Advance Research in Science and Engineering, Vol. No.4, Issue 03, PP 288-293 March 2015.
- [8] Middle Mahesh, K. Leleedhar Rao, "Speed Control of BLDC Motor Using Six Pulse Converter" International Journal of Latest Trends in Eng., Vol. 8, Issue 3, pp. 040-044, 2016.
- [9] M Shaba Anjum, and Vishal Srivastava, "Speed Control of Brushless DC Motor using PLC," International Journal for Scientific Research & Development| Vol. 3, Issue 09, pp. 583-586,2015.
- [10] Ahmed J. Ali, Laith A. Khalaf, Ahmed H. Ahmed, "Modeling and simulation of a 3- ϕ induction motor based on two types of WFA", IJECE, Vol. 11, No. 2, April 2021, pp. 1105-1113.
- [11] Ahmed M. T. Ibraheem Alnaib, Omar Talal Mahmood, Noha Abed-Al-Bary, "PLC Controlled Multiple Stepper Motors Using Various Excitation Methods", IEEE International Conference on Engineering Technologies and their Applications, Islamic University, pp. 54-59, 2018.
- [12] Al-Naib, A. "Design an Industrial Robot Arm Controller Based on PLC", Przeglad Elektrotechniczny, 2022, 98(7), pp. 105–109.
- [13] Ahmed J. Ali, Mohammed Y. Suliman, Laith A. Khalaf, Nashwan S. Sultan, "Performance investigation of stand-alone induction generator based on STATCOM for wind power application", IJECE, Vol.10, No.6, Dec. 2020, pp. 5570-5578.