Brushless DC motor control using PLC

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Abstract

The aim of this paper is to investigate controlling a Brushless DC Motor (BLDCM) using a Programmable Logic Controller (PLC) instead of micro-controllers chips. As PLCs are now involved in most industrial processes, therefore, developing a program to handle the control of BLDCMs will save electronic components used in the drive circuit. Further, one PLC may control more than one motor via programming extra inputs and outputs already implemented in the PLC or simply by attaching additional input/ output cards. The speed is varied through the PWM technique. The PLC performed well with speeds up to 1550 rpm. The motor did not run faster due to the switching delay (scanning cycle time and hardware) of the PLC.

Key Words

Brushless DC Motor, BLDCM Control, PLC.

1. Introduction

Brushed DC motors have been used in industry due to their linear characteristics and the ease of adjusting their speed through a simple power electronic circuit. The commutator used in brushed DC motors is the main drawback for such systems which has motivated the researchers to direct their studies toward AC systems, induction and synchronous motors. Since the last decade, induction motors have dominated the industry due to the availability of the induction motors variable speed drives. However, these motors operate at low efficiency specially those of low power ratings. The solution for the drawbacks of brushed DC motors and AC motors can be found in BLDCMs, with superior performance. BLDCMs have similar characteristics to the separately excited DC machines but their control is similar to the AC machines control. This paper investigates the possibility of using a PLC (Programmable Logic controllers) to control such motors rather than microcontrollers [1]-[5].

Brushless DC motors can be divided into types, Sinusoidal BEMF and Trapezoidal BEMF. The present study deals with a BLDC motor with a trapezoidal BEMF [6],[7].

BLDCMs' BEMF has a trapezoidal wave form and the stator winding is fed by a rectangular current to produce constant torque. The three phase windings are placed on the stator and the rotor (with magnets) is free to move. There are always two phases on at any one time to provide continuous torque, as illustrated in Fig.1.

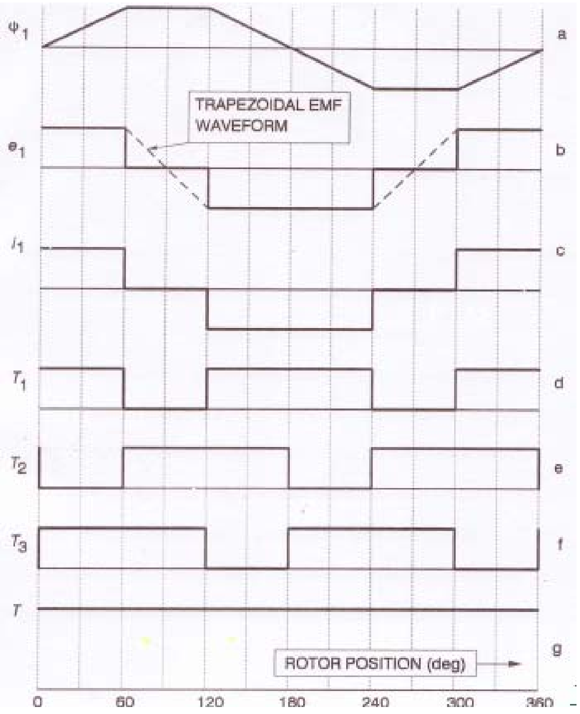

Figure 1-a) flux linkage wave form, b) back-EMF, c) current wave form, d) torque from coil-1, e) torque from coil-2, f) torque from coil-3, g) Total developed torque [7]

The complete scheme for a BLDCM is shown in Fig. 2 which illustrates the sequence followed to drive such systems. As it is seen, the controller waits the signals supplied by the position sensors.

Then, the controller takes an action biasing the power transistors to switch them on or off so that the windings in the motor are powered according to the rotor position. The motor will run continuously as the system constructs a loop action.

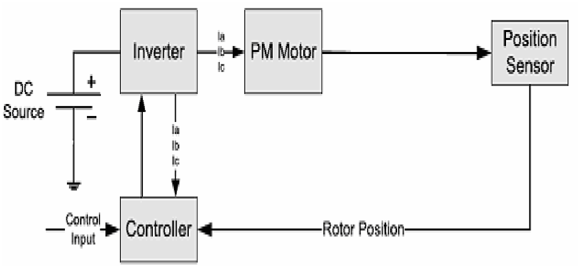

Figure 2-BLDCM drive system

2. PLC Controller

Toshiba T1-16s PLC was used. The PLC has 8 inputs, phototransistors, and 8 outputs, 6 relay outputs and two transistors which are mainly used to provide clock signal or PWM. Most of the outputs are relay outputs which are not fast enough to provide fast switching and have short life span. To overcome this, a transistor output card, sink type, is attached to the PLC, so that all the output signals are taken from these transistors. The driving circuit is implemented to drive six power MOSFETs controlling the BLDCM. Only two MOSFETs are switched on at a time receiving the driving signal from the transistor outputs of the PLC. The circuit is built with six dual input NAND gates, where two CD4011BCN chip are used. The upper half utilizes three NAND gates, where one pin of each NAND gate is common to the PWM and the second pin receives 1 or 0 based on the rotor position. Fig. 3 shows the output of the NAND gate of the upper half when it receives a signal from the PLC in the ON and OFF state.

The circuit works as follows: The PLC takes an action to switch only two NAND gates at any moment driving the output transistors to be switched off which makes the signal to the NAND gate to be high (15V). The effect on the upper half is that the PWM signal will appear on the output on the NAND gate which is applied to the optocoupler.
When the optocoupler is on the MOSFET is driven to the off state and vice versa. In the lower half, the MOSFET will be on at all times (no PWM) during the off period of the PLC transistor output. Once the rotor moves and the PLC receives the new position from the feed back sensors, the current off transistor output is activated (switched on) and new one is switched off to drive a different MOSFET (from the upper or lower half based on the BLDCM sequence of operation). All resistors are selected based on the maximum current consumption of each component.

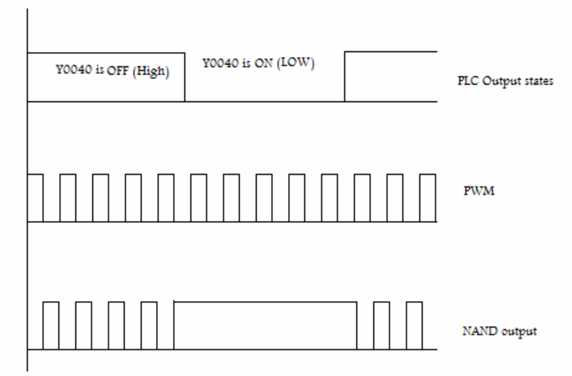

Figure 3-Upper Half Driving Signal

The lower half is not assigned to a PWM, soft switching method; however, one pin is always on and the other waits the signal from the PLC. This is illustrated in Fig. 4. The output of the NAND gate is applied to the optocoupler, HCPL-4503, to operate in the pull down mode. The complete drive circuit including the controller is shown in Fig. 5.

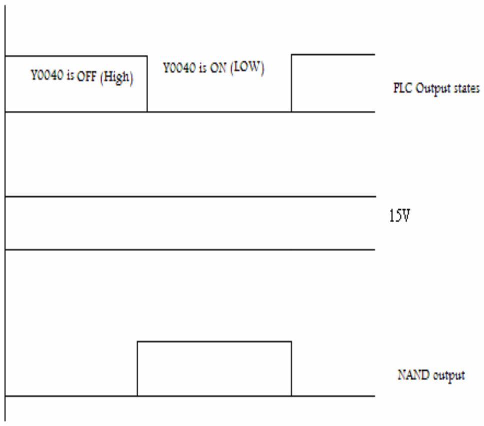

Figure 4-Lower Half Driving Signal

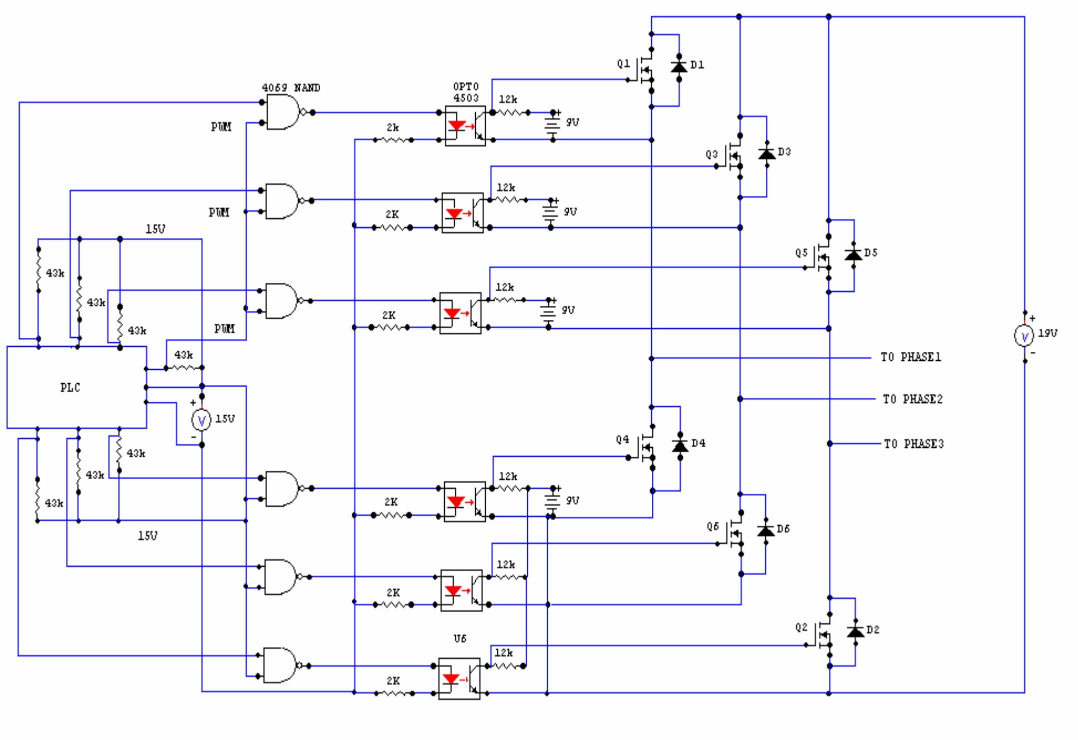

Figure 5-MOSFET DRIVE Circuit

3. PLC Program

The PLC position is programmed so that only two output transistors are switched on based on the feedback sensors with the addition of programming the dedicated transistors to provide the PWM signal for the speed control. The program written to the PLC is as in Fig 6. Line 1 sets the PWM function to be used for the dedicated transistor and sets the switching frequency to 1000 Hz. Lines 2 to 4 are used to set the duty cycle of the PWM. Line 5 and 6 are used for fault detection. The rest of the program is to switch the output transistors on and off according to the three input statuses.

4. Results

The motor operated as a normal BLDCM as expected when the PLC is used as a controller. Variable speeds were also achieved through the duty cycle of the PWM signal at no-load. The motor is operated at different switching frequencies as well. The maximum recorded speed of the motor was around 1550 rpm at average voltage of 15.5V with switching frequency of 1 KHz. The results are shown

TABLE and

TABLE . Table 1 provides the speed verses the duty cycle, which is varied from 40% to 80%, and table 2 shows the recorded current at each duty cycle in the same range as in the speed curve. Both figures are plotted at different switching frequencies as indicated.

The graphical representation of the tables is plotted as in **¡Error! No se encuentra el origen de la referencia.**7 and **¡Error! No se encuentra el origen de la referencia.**. It is noticed that the motor runs at a higher speed when low switching frequency is applied, however higher current is also also. Linearity of the speed curve is observed with all switching frequencies; however the speed tends to be constant when the duty cycle is close to 100%.

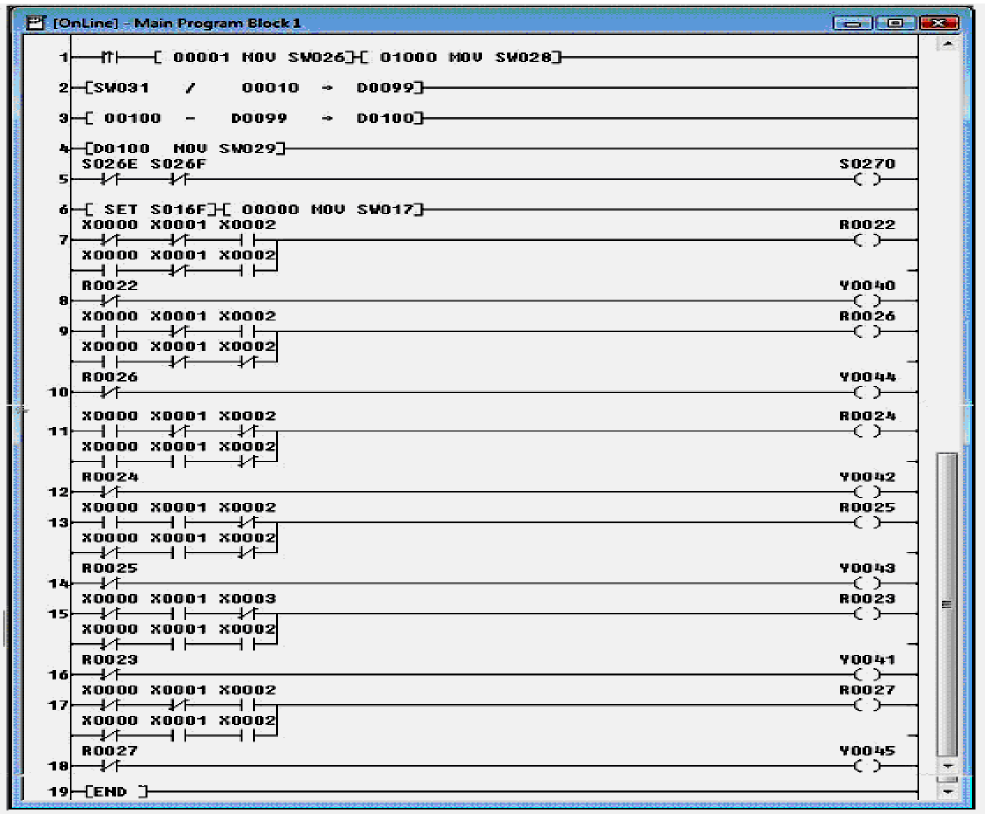

Figure 6-PLC Program

TABLE I-Results of Speed verses duty cycle at different switching frequencies

Switching Frequency, Hz	500	1000	2000	3000	4000
Duty Cycle%	**Speed, rpm**				
40%	1273	1160	945	655	425
50%	1377	1285	1112	915	730
60%	1437	1411	1300	1170	1031
70%	1500	1463	1430	1320	1200
80%	1500	1543	1475	1430	1400

TABLE II-Results of Current verses duty cycle at different switching frequencies

Switching Frequency, Hz	500	1000	2000	3000	4000
Duty Cycle%	**Current, A**				
40%	0.55	0.27	0.11	0.05	0.02
50%	0.85	0.5	0.23	0.1	0.06
60%	1.5	0.9	0.5	0.3	0.1
70%	2.3	1.8	1.15	0.7	0.4
80%	3	2.9	2	1.3	0.88

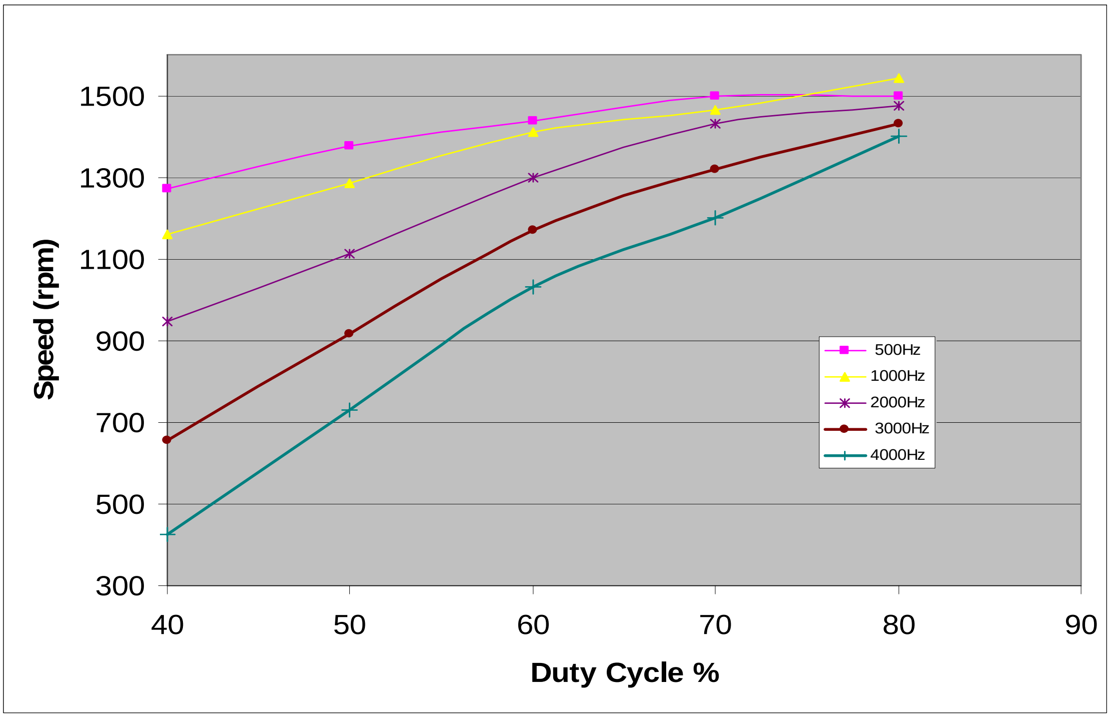

Figure 7-Graphical representation of speed verses duty cycle at different switching frequencies

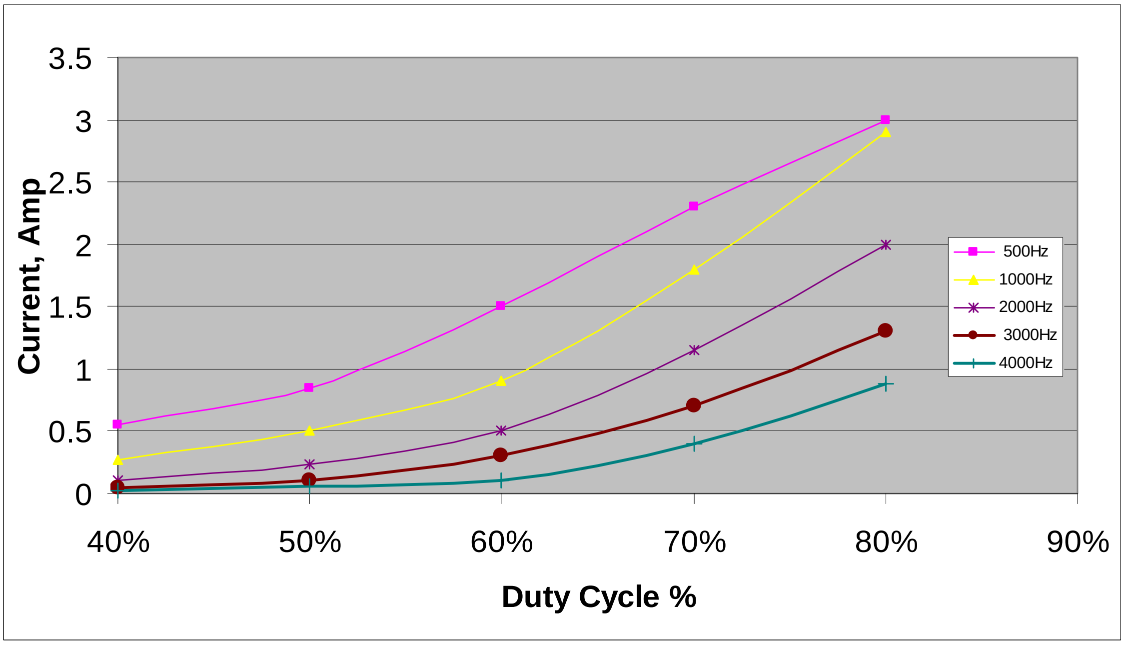

Figure 8-Graphical representation of current verses duty cycle at different switching frequencies

5. Conclusion

It is clear that PLCs are fully equipped control systems. When Toshiba PLC, T116-S, is used the maximum speed was 1550 rpm at average voltage of 15V. The on and off delays from the driving transistor of the PLC made the operation to consume more current and reduces the speed because of the on/off delay. Faster PLCs are recommended for better performance when a BLDCM needs to be controlled such as DVP-

ES/EX Series from Delta Corporation. Nevertheless the T116-S can be fairly used also for speed operations up to 1500 rpm with switching frequency of 2 KHz for insensitive applications.

6. References

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