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Two Quadrant Speed Control of Permanent Magnet DC Motor Using PLC

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Abstract: In this paper, a Two Quadrant speed control of a permanent magnet D.C motor (PMDCM) is performed using programmable logic controller (PLC). Besides that motor breaking is also achieved. The PLC is used as a controller to provide controlling PWM pulses to the MOSFETs of the DC to DC converter to have variable armature voltage. Variable armature voltage leads to variable motor speed. The motor speed is very well controlled between zero and its rated value.

Keywords: Programmable Logic Controller (PLC), Permanent magnet D.C. Motor (PMDCM), D.C motor controller, DC to DC converter.

Introduction

In cost sensitive and low power applications such as auxiliary drivers in automotive vehicles, general purpose drives in production lines, home appliance and toys, permanent magnet (PM) excited brushed D.C motors are still dominant, due to their simplicity of structure, high efficiency and low initial cost. The use of PM in place of field winding offers the advantages of lower manufacturing cost, simple construction, lower starting torque, less air noise and higher efficiency [1,2]. As a result of the developments in semiconductor technology, the speed of D.C motors are precisely controlled using different controlling techniques such as FPGA, DSP, PIC, and PLC [3]. In this paper, a speed control of permanent magnet D.C motor (PMDCM) in both directions is presented. Furthermore breaking operation is also applied. The PLC is implemented as a PWM controller to control the operation of the switches to give the suitable operating armature voltage depending on the error signal feedback from the motor.

System Description

The D.C control system based on the PLC is shown in Fig.(1). The system contains three components, PLC, D.C/D.C buck converter and the motor system.

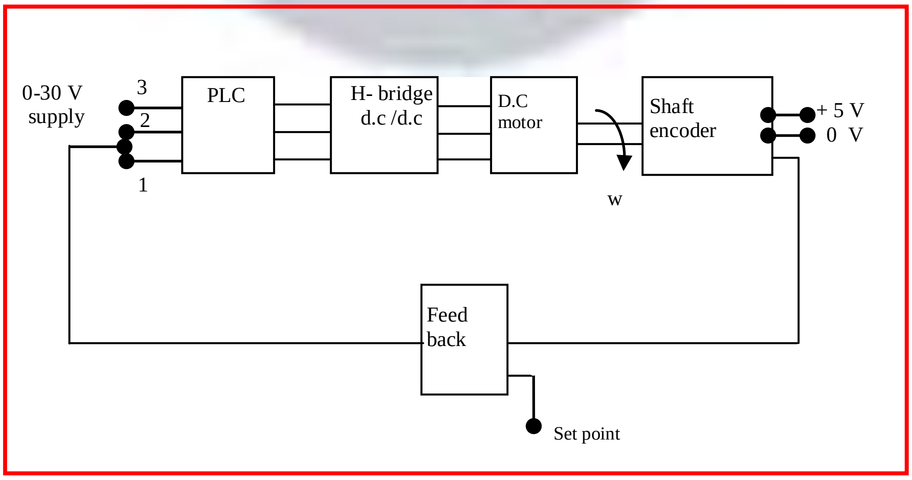


Fig. (1). Block diagram of the control system.

A- D.C motor

The D.C motor is constructed of two main parts, armature (rotor) and stator. The stator consists of permanent magnets which creates constant magnetic field [4]. The armature contains an electromagnet created by the coil wound around the iron core. The armature rotates due to the phenomenon of attracting and opposing forces of two magnetic fields created by the stator and rotor. The electrical and mechanical equations describing the motor characteristics are derived based on the PMDCM equivalent circuit given in Fig. (2).

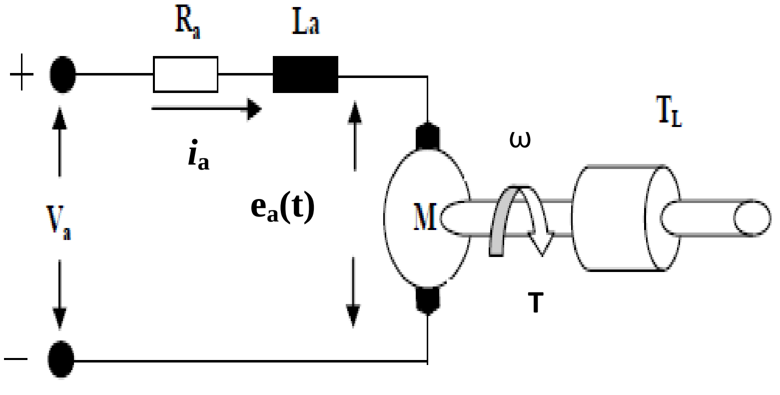


Fig. (2). PMDCM equivalent circuit

$$V_a = R_a i_a + L_a \frac{di_a}{dt} + e_a(t) \quad \text{.....1}$$

$$e_a(t) = K_v \omega(t) \quad \text{.....2}$$

$$T_e(t) = J\frac{d\omega(t)}{dt} + B\omega(t) + T_l(t) \quad \text{.....3}$$

$$T_e(t) = K_t i_a(t) \quad \text{.....4}$$

Where V_a is the applied armature voltage, i_a is the armature current, R_a and L_a are the armature winding resistance and reactance respectively, ω is the rotational speed of the motor, T_e is the motor torque, T_l is the mechanical load torque , J and B are moment of inertia and viscous coefficients of the motor, K_v and K_t are voltage and torque constants respectively. At the steady-state operation of the motor the derivative terms in equations (1) and (3) are goes to zero, then from equations 1-4, the rotational speed can be written as:

$$\omega = \frac{V_a K_t - T_l R_a}{BR_a + K_v K_t} \quad \text{.....5}$$

If the term BR_a is much smaller than $K_v K_t$, then :

$$\omega = \frac{V_a}{K_v} - \frac{T_l R_a}{K_v K_t} \quad \text{.....6}$$

B- D.C to D.C Converter

The D.C To D.C converter(chopper) is used to supply the PMDCM with variable D.C voltage from a fixed supply voltage. The arrangement of the D.C chopper fed permanent magnet D.C motor is shown in Fig.(3).

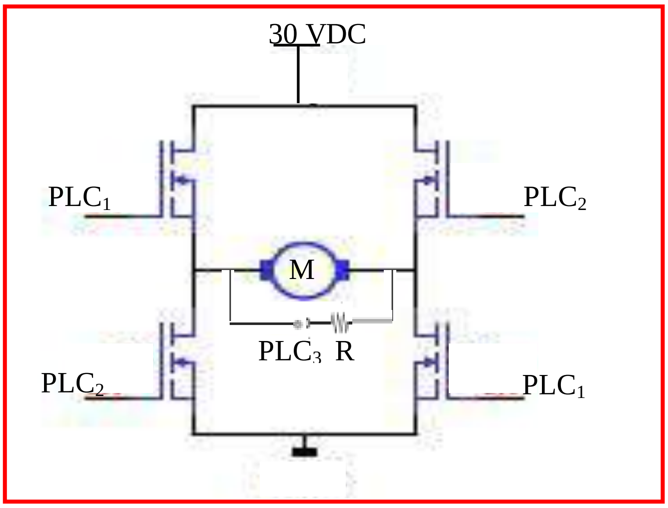


Fig. (3). D.C to D.C converter fed PMDCM.

The armature is driven by a voltage V_a between 0V and 30V D.C. The IRFP450 MOSFET switches in Fig.(3) are arranged to permit motor operation in both directions. The resistor R is selected to hold motor current during breaking before any change in the direction of rotation. The pulses PLC_1, PLC_2, and PLC_3 are controlling pulses supplied by the PLC for speed control. The possible modes of operation of the switches and the governing equations are shown in reference [5].

C- The PLC

Programmable logic controllers (PLC) are widely used in industrial control because they are inexpensive, easy to install, stable operation, and very flexible in applications. A PLC interacts with the external world through its inputs and outputs. Since technology for motion control of electric drives became available, the use of PLC with power electronics in electric machines applications has been introduced in manufacturing automation[6]. This use offers advantages such as lower voltage drop when turned on and the ability to control motors and other equipments with a virtually unity power factor. Every moment, signal from shaft encoder is received in the form of pulses, these pulses are fed to comparator type LM324 together with the set value of speed as shown in Fig.(4).

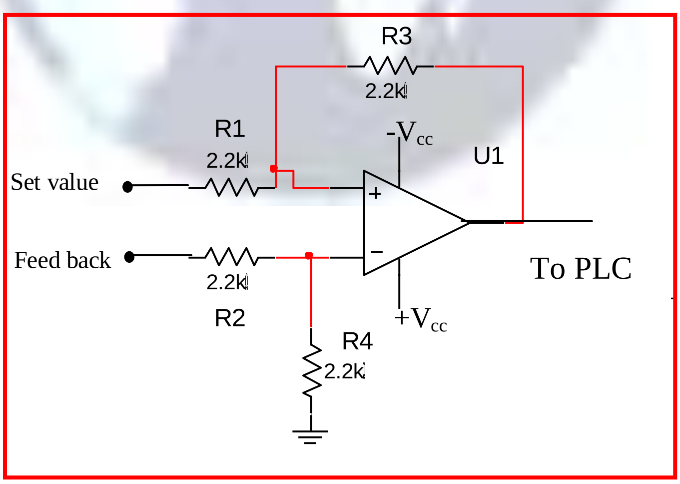


Fig.(4). LM324 Comparator

The output pulses from the comparator are fed to the PLC, these pulses together with the PLC program shown in Fig.(5) controls the operation of the D.C to D.C converter which controls the motor speed in both directions of operation besides the breaking signal through the relay Q3.

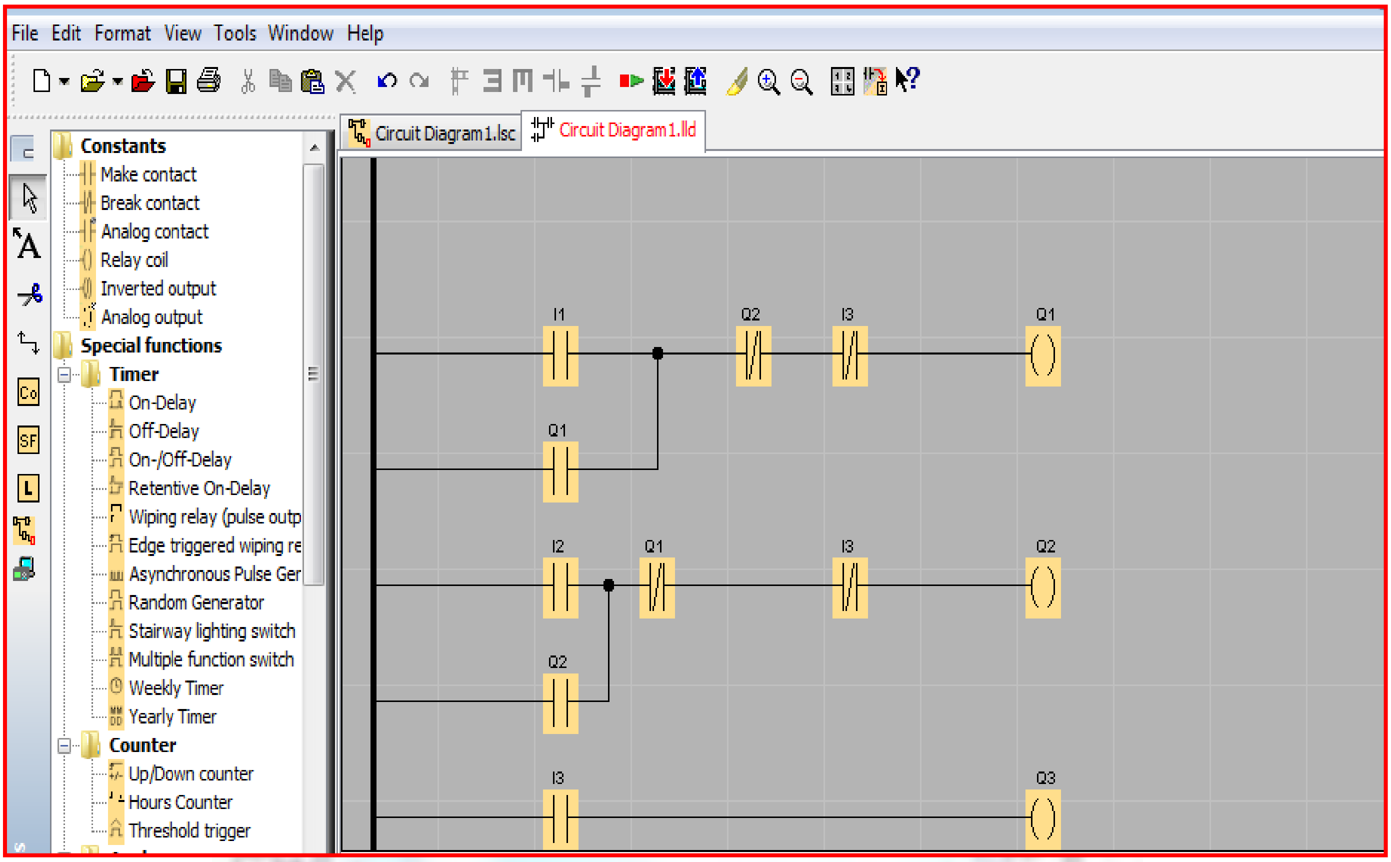


Fig. (5) PLC Program for PMDC speed control.

Results and Discussion

The open loop and the closed loop results for the encoder output shown in Fig$_s$. 6 and 7 are taken for same motor input voltages (3V, 7V, 15V and 20V). From the mentioned figures , it is clear that the encoder output pulses have the same frequency, this means that the closed loop circuit was properly working to retain the speed of the motor to be constant as the motor torque is changed. An important point was checked in this work is the reduction ratio of this type of gear motor which can be shown in the following steps.

From Fig.6 b

V_{in} = 3V

Motor shaft speed (N_{sn}) = 289 r.p.m

Encoder output pulses cycle time = 680µs

$$\omega_{enc} = 2\pi f = 2\pi \frac{1}{t} = \frac{2\pi}{680 \times 10^{-6}} = \frac{2\pi \times 10^{6}}{680} = 9.244 \times 10^{3}$$

$$N_{enc} = \frac{60}{2\pi}.\omega_{enc} = \frac{60}{2\pi} \times 9.244 \times 10^{3} = 88.318 \times 10^{3}\, rpm$$

The reduction ratio

$$= \frac{N_{enc}(\text{encoder pulses speed})}{N_{sh}(\text{ motor shaft speed})} = \frac{88318}{289} = 305.6$$

Motor shaft speed (N_{sh}) = 625 r.p.m.

Encoder output pulses cycle time = 320μs

$$\omega_{enc} = 2\pi f = 2\pi \times \frac{1}{t} = \frac{2\pi}{320 \times 10^{-6}} = \frac{2\pi}{320} \times 10^{6} \quad \text{rad/sec}$$

$$N_{enc} = \frac{60}{2\pi} \times \omega_{enc} = \frac{60}{2\pi} \cdot \frac{2\pi}{320} \times 10^{6} = 187.5 \times 10^{3}$$

$$\text{The reduction ratio} = \frac{N_{enc}}{N_{sh}} = \frac{187.5 \times 10^{3}}{625} = 300 \quad \text{r.p.m}$$

Also, from Fig.6 g

V_{in}= 15V

Motor shaft speed (N_{sh}) = 2520 r.p.m.

Encoder output pulses cycle time=80μs

$$\omega_{enc} = 2\pi f = \frac{2\pi}{t} = \frac{2\pi}{80 \times 10^{-6}} \quad \text{rad/sec}$$

$$N_{enc} = \frac{60}{\pi} \omega_{enc} = \frac{60}{\pi} \times \frac{2\pi}{80 \times 10^{-6}} = \frac{6}{8} \times 10 = 750 \times 10^{3} \quad \text{r.p.m}$$

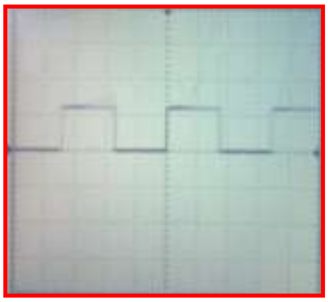
$$\text{The reduction ratio} = \frac{N_{enc}}{N_{sh}} = \frac{750 \times 10^{3}}{2520} = 298$$

From the above results the reduction ratio is about 1:300 which is near to the theoretical one of the encoder sensor module (KL-68009).

(a)

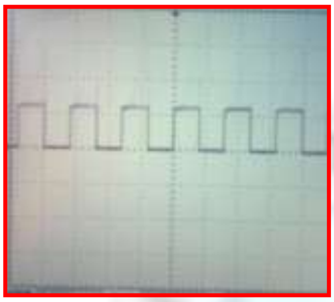
Speed= 114 r.p.m
Vin =2V

(b)



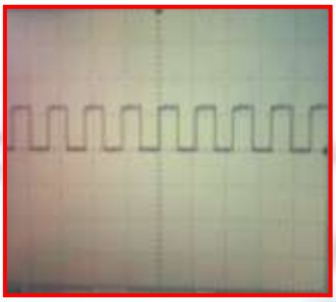
Speed = 289 r.p.m
Vin = 3V

(c)



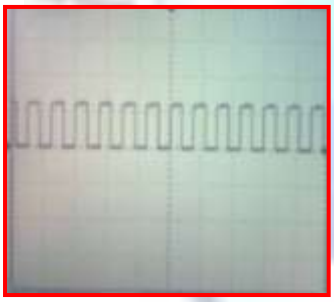
Speed= 625 r.p.m
Vin =5V

(d)



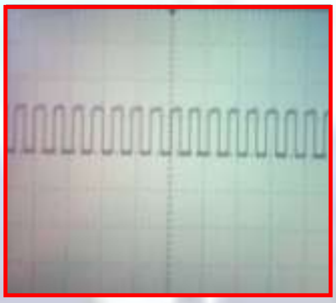
Speed= 920 r.p.m
Vin = 7V

(e)



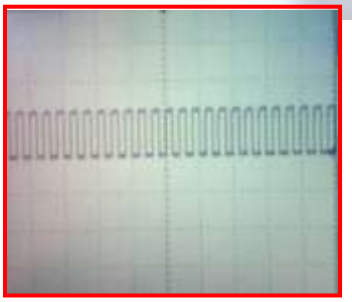
Speed= 1370 r.p.m
Vin =9V

(f)



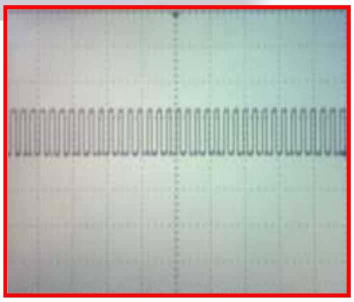
Speed= 1743 r.p.m
Vin = 11V

(g)



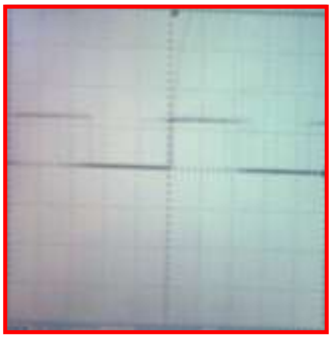
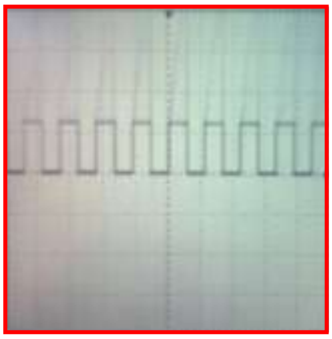
Speed= 2520 r.p.m
Vin =15V

(h)



Speed= 3539 r.p.m
Vin = 20V

Fig 6. Encoder output for open loop speed control

(a) I = 0.3 A (before break)

I = 0.36 (break)

Speed = 289 r.p.m

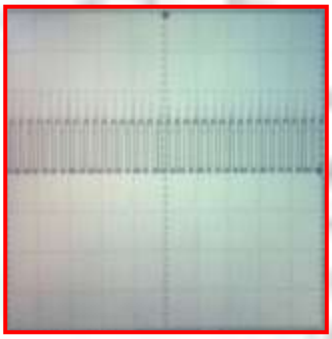
Vin = 3V

(b) I = 0.42 A (before break)

I = 0.47 (break)

Speed = 920 r.p.m

Vin = 7V

(c) I= 0.43 A (before break)

I = 0.5 (break)

Speed = 2520 r.p.m

Vin = 15V

(d) I= 0.45 A (before break)

I = 0.54 (break)

Speed = 3539 r.p.m

Vin = 20V

Fig 7. Encoder output for closed loop speed control

Conclusions

Successful experimental results were obtained from the scheme described in Fig. (1) for d.c motor speed control using d.c converter. The PLC was successfully used to provide a PWM pulses to control the d.c converter output voltages in both magnitude and direction. Due to the ability of opposing motor input voltage, hence the d.c motor speed can be controlled in both directions. The closed loop circuit was effectively operating to give a constant speed as the motor torque is changed.

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