Design & Development of Four Quadrant Dc Motor Control without Microcontroller

Saurav Jadhav¹, Jayesh Bansode², Swapnali Dange³, Salim Nadaf⁴

U.G. Student, Department of Electrical Engineering, NMCOE, Peth, Maharashtra, India¹
U.G. Student, Department of Electrical Engineering, NMCOE, Peth, Maharashtra, India²
U.G. Student, Department of Electrical Engineering, NMCOE, Peth, Maharashtra, India³
Assistant Professor, Department of Electrical Engineering, NMCOE, Peth, Maharashtra, India⁴

Abstract

This paper aims to designed to develop a four quadrant control system for a DC motor. The motor is operated in four quadrants i.e. clockwise; counter clockwise, forward brake and reverse brake. The four quadrant operation of the dc motor is best suited for industries where motors are used and as per requirement as they can rotate in clockwise, counter-clockwise and also apply brakes immediately in both the directions. In case of a specific operation in industrial environment, the motor needs to be stopped immediately. In such scenario, this proposed system is very apt as forward brake and reverse brake are its integral features. Instantaneous brake in both the directions happens as a result of applying a reverse voltage across the running motor for a brief period. 555 timer used in the project develops required pulses. Switches are provided for the operation of the motor which are interfaced to the circuit that provides an input signal to it and in turn controls the motor through H-bridge. Optionally speed control feature can be achieved (but not provided in this project) by push button operation. This project can be enhanced by using higher power electronic devices to operate high capacity DC motors. Regenerative braking for optimizing the power consumption can also be incorporated.

KEYWORDS: Four Quadrant, Dc Motor, microcontroller, design, etc.

1. Introduction

The main goal of the project is to develop a speed control system for a dc motor for all quadrants with the help of a four quadrant unity to control clockwise, counter clockwise, forward broke and reverse brake modes of a dc motor. The system is very useful for industries operation since industries usually require dc motor to operate in all four quadrants for various operational cases. The four quadrant operation of the dc motor is best for industries where motors are used and as per requirement as they can rotate in clockwise, counter-clockwise and also apply brakes immediately in both directions. In case of a specific operation in industrial environment, the motor needs to be stopped immediately. In such scenario, this proposed system is very important as forward brake and reverse brake is its integral feature. Instantaneous brake in both the directions happens as a result of applying a reverse voltage across the running motor for a short period. 555 timer used in the project develops required pulse. Push buttons are provided for the operation of the motor which are interfaced to the circuit that provides an input signal to it and in turn controls the motor through a driver IC. Optionally speed control feature can be achieved (but not provided in this project) by push button operation. This project in future can be improved by using higher power electronic devices to operate high capacity dc motors. Regenerative braking for optimizing the power consumption can also be incorporated. The system is very useful for industrial operation since industries usually require dc motor to operate in all four quadrants for various operational cases. This system enables to operate motors in all four quadrants.

2. Literature Review

The main function of the proposed system is to develop a Digital notice board that display message sent from the user
through mobile phone (SMS) and to design a simple, user friendly system, which can receive and display message/information in a particular manner with respect to date and time which will help the user to easily keep the track of notice board every day and each time he uses the system. System consist of two section called as sender and receiver. Sender is responsible for sending valuable information through the GSM protocol. In order to access Digital notice board the sender must enter into the corresponding mobile number [3]. When the user enter correct mobile number, the message can be typed and get space for the information transmission. To make the proposed system more user friendly we make an android application. By using this application sender can directly enter the message. In receiver section, PIC microcontroller is connected on GSM module for accessing the sim card. It is a capable little device that enables people of all ages to explore radio waves transmission and reception. We use here embedded C language and GSM protocol as the basic working principle.

3. SPECIFICATION

This propose project puts forward a dc motor four quadrant based controlling system. This allows user to operate the dc motor in four different quadrants:
- Clockwise
- Anti-clockwise
- Forward brake
- Reverse brake

The propose system use an H-bridge motor drive IC for controlling the dc motor from a corresponding switch used by the user for pressing. The four switches are connected to the circuit for controlling movement of the motor. The 555timer used in the project to develop the required pulses. The relays are used for charging the polarities of the motor as well as to brake the motor. In the regenerative mode, the current is applied to the circuit in such a way that a reverse torque is produce.

4. DESIGN CALCULATION

In a dc motor, the field flux \( \Phi_f \) is established by the stator, either by means of permanent magnets as shown in the figure (1) where \( \Phi_f \) remains constant or by means of a field winding as shown in figure (2) where the field current \( I_f \) controls \( \Phi_f \). If the magnetic saturation in the flux path can be neglected, then \( \Phi_f = k \times I_f \), where \( k \) is a field constant of proportionality. The motor carries in its slots is called armature winding, which handles the electrical power. This is contrasts to most ac motor, where the power handling winding is the stator for ease of handling the large amount of power, however, the armature winding in a dc machine has to be on the rotor to provide a “mechanical” rectification of voltage and currents (which alternate direction as the conductor rotate from the influence).
Of the one stator pole to the next) in the armature winding conductor, thus producing a dc voltage and a dc current at the terminals of the voltage and winding. The armature winding is a continuous winding, without any beginning or end and it is connected to the commutator segment. These commutator segment usually made up of copper are insulated from each other and rotate with the shaft. At least one pair of stationary carbon brushes is used to make contact between the commutator segment (and hence the armature conductor) and the stationary terminals of the armature winding that supply the dc voltage and current.

In a dc motor, the electromagnetic torque is produced by the interaction of the field flux \( \Phi_f \) and the armature current \( i_a \)

\[
T_{em} = k_e \Phi_f i_a \quad \text{(1)}
\]

Where \( k_e \) is the torque constant of the motor. In SI unit, \( k_e \) and \( k_w \) are numerically equal, this can be shown by equating the electrical power, \( P_e \) and the mechanical power, \( W_m T_{em} \).

The electrical power is calculated as:

\[
P_e = \frac{v_a}{i_a} = k_e \Phi_f V_m i_a \quad \text{(2)}
\]

And the mechanical power as:

\[
P_m = W_m T_{em}
\]

\[
P_m = k_e \Phi_f W_m i_a \quad \text{(3)}
\]

In steady state: \( P_e = P_m \)

Therefore from the foregoing equation:

\[
k_e \left( \frac{V_m}{i_a} \right) = k_e \left( \frac{V_v}{i_a} \right) \quad \text{(6)}
\]

In practice, a controllable voltage source \( V_t \) is applied to the armature terminals to establish \( i_a \). Therefore, the \( i_a \) in the armature circuit is determined by \( V_v \) the induced back-emf \( i_a \), the armature winding resistance \( R_a \) and armature winding inductance \( L_a \):

\[
V_v = E_a + R_a i_a + L_a \frac{di_a}{dt} \quad \text{(7)}
\]

Equation (7) is illustrated by an equivalent circuit in figure (a)

The interaction of \( T_{em} \) with the load torque as given by the equation:

\[
T_{em} = \frac{V_i}{i_a} (j_M + j_s + \alpha^2 (M_T + M_w)) + \alpha F_{wl} \quad \text{(8)}
\]

Determines how the motor speed builds up.

\[
T_{em} = j \frac{2\pi}{\omega} + B W_m + T_{wl}(\omega) \quad \text{(9)}
\]

Where \( J \) and \( B \) are the total equivalent inertia and damping respectively of the motor load combination and \( T_{wl} \) is the equivalent working torque of the load. Seldom are dc machines used as generators; however they act as generator while braking, where their speed is being reduced. Therefore it is important to consider dc machine in their generator made of operation.

5. DATA ANALYSIS

This propose project puts forward a dc motor four quadrant based controlling system. This allows user to operate the dc motor in four different quadrants:

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- Reverse brake

The propose system use an H-bridge motor drive IC for controlling the dc motor from a corresponding switch used by the user for pressing. The four switches are connected to the circuit for controlling movement of the motor. The 555 timer used in the project to develop the required pulses. The relays are used for charging the polarities of the motor as well as to brake the motor. In the regenerative mode, the current is applied to the circuit in such a way that a reverse torque is produce.

The four-quadrant of the dc motor is archived by the varying duty cycle and their charging polarity with the H-bridge IC by appropriate switch pressing. (Alternative speed control feature can be achieved by push-button operation, but is not part of this project, also the motor can be control using L293D IC or using PI) but this project uses H-bridge circuit to control the motor only.
✓ In the first quadrant, power developed is positive and the machine is working as a motor supplying mechanical energy. The first quadrant is called forward motoring.

✓ In the second quadrant operation is known as braking, in this quadrant the direction of rotation is positive and the torque is negative and thus, the machine operates as a generator developing a negative, which opposes the direction.

✓ The kinetic energy of the rotating parts is available as electrical energy which may be supply back to the mains. In dynamic braking dissipated the energy is dissipated in the resistance.

✓ The third quadrant operation is known as the reverse motoring. The motor works, in the reverse direction. Both the speed and the torque have negative value while the power is positive.

✓ In the fourth quadrant, the torque is positive and the speed is negative. This quadrant corresponds to braking in the reverse motoring mode.

<table>
<thead>
<tr>
<th>function</th>
<th>quadrant</th>
<th>speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward motoring</td>
<td>1</td>
<td>+</td>
</tr>
<tr>
<td>Forward braking</td>
<td>2</td>
<td>+</td>
</tr>
<tr>
<td>Reverse motoring</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>Reverse braking</td>
<td>4</td>
<td>-</td>
</tr>
</tbody>
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6. WORKING PRINCIPAL

Figure (a)
In order to consider braking, we will assume that the flux $\Phi_f$ is kept constant and the motor is initially driving a load at a speed of $W_m$. To reduce the motor speed, if $V_t$ is reduced below $E_a$ in figure (a) then the current $I_a$ will reverse in direction. The electromagnetic torque $T_{em}$ given by equation (1) now reverses in direction and the kinetic energy associated with the motor load inertia is converted into electrical energy by the dc machine, which now acts as generator. This energy must be somehow absorbed by the source of $V_t$ or dissipated in a resistor.

In motoring mode, the machine works as an ac motor and converts the electrical energy into mechanical energy supporting its motion. In braking mode, the machine works as a generator and converts mechanical energy into electrical energy and as a result, it opposes the motion. The motor works in both forward and reverse direction i.e. motoring and braking operation.

The product of angular speed and torque is equal to the power development by a motor. For mult-quadrant operation of drives the following conventions about the signs of torque and speed are used. When the motor is rotated in the forward direction, the speed of the motor is considered positive. The drives which operate only in one direction, forward speed will be their normal speed.

In load involving up and down motions, the speed of the motor which causes upward motion is considered to be in forward motion. For reversible drives, forward speed is chosen arbitrarily.

The rotation in the opposite direction gives reverse speed which is denoted by a negative sign. The rate of change of positively in the forward direction or the torque which provides acceleration is known as positive motor torque. In the case of retardation, the motor torque considered negative. Load torque is opposite to the positive torque in the direction.
In the first quadrant, power developed is positive and the machine is working as a motor supplying mechanical energy. The first quadrant is called forward motoring.

In the second quadrant operation is known as braking, in this quadrant the direction of rotation is positive and the torque is negative and thus, the machine operates as a generator developing a negative, which opposes the direction.

The kinetic energy of the rotating parts is available as electrical energy which may be supply back to the mains. In dynamic braking dissipated the energy is dissipated in the resistance.

The third quadrant operation is known as the reverse motoring. The motor works, in the reverse direction. Both the speed and the torque have negative value while the power is positive.

In the fourth quadrant, the torque is positive and the speed is negative. This quadrant corresponds to braking in the reverse motoring mode.

7. CONCLUSION

The system is very useful for industrial operation since industries usually require dc motor to operate in all four quadrants for various operational cases. This project in future can be improved by using high power electronic devices to operation high capacity dc motors. Regenerative braking for optimizing the power consumption can also be incorporated. This system enables to operate motors in all four quadrants. Most industrial scenario dc motors are required to run in clockwise as well as anticlockwise motions as and when required. Some scenarios also need the motor to be stopped in its motion. At such times front braking and reverse braking mechanisms are used.

REFERENCES


