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# Four Quadrant DC Motor Control without Microcontroller

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**ABSTRACT:** we proposed an approach to designed a four quadrant control system for a DC motor without using Microcontroller. The four quadrants of operation of DC motor are clockwise, counter clock-wise, forward brake and reverse brake. After a brief review about the operating principle of DC motors, we have described the need of a four quadrant control system and its speed control techniques in those quadrants. It is found that the four quadrant operation of the dc motor is highly recommended for industries where motors are required to rotate in clockwise as well as counter-clockwise and apply brakes instantly in both the directions. In case of an emergency, the motor needs to be stopped immediately. In such cases, the proposed system is very appropriate as both forward braking and reverse braking are possible. Application of a reverse voltage across the motor for a brief period causes instantaneous braking in both the directions. For this purpose, 555 timer is used which develops required pulses. For the operation of the motor push buttons are provided. These buttons are interfaced to the circuit providing an input signal to it; which in turn controls the DC motor through a driver IC.

**KEYWORDS:** Four Quadrant Operation, DC Motor, 555 Timer, H-bridge motor drive.etc.

## I. INTRODUCTION

The main goal of the four quadrant DC motor without microcontroller 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 high power electronic devices to operation 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.

**The four operating modes of the motor are:**

**1.1. Full load condition:** This is the first quadrant operation in which the motor is lifting the loaded cage upwards. The direction of rotation of motor  $\omega$  will be in anticlockwise direction, i.e., positive speed during this condition. The load torque acts in opposite direction to that of motor rotation. Therefore, to raise the load upwards, the motor torque,  $T_M$  should act in the same direction of motor speed,  $\omega$ . Hence, the motor speed and motor torque both will be positive. Also the power taken from the supply is positive. This is called forward motoring.

**1.2. No load condition:** This is the second quadrant operation in which the motor is lifting the unloaded cage upwards. As mentioned above, the counterweight is heavier than the unloaded cage and this can lead the hoist to move upwards

at a dangerous speed. To prevent this, motor must produce a braking torque in the opposite direction of motor speed. Therefore, the torque  $T_M$  will be negative and speed  $\omega$  will be positive. Since the speed of the cage is positive, it receives the power from the supply and so the power is positive. This second quadrant operation is called forward braking. Figure. 1. Four Quadrant operation of DC motor

**1.3. No load reverses motoring:** This is the third quadrant operation where no load hoisted down as shown in Fig. 1. The downward motion of empty cage is prevented by the counterweight. So the direction of  $T_M$  should be in the same direction of  $\omega$ . The direction of rotation is reversed due to the downward movement of the cage, i.e.,  $\omega$  is negative and hence  $T_M$  also becomes negative. The power supplied to the motor is positive. This third quadrant operation is called reverse motoring.

**1.4. Full load reverse motoring:** In the fourth quadrant, the loaded cage moves downwards and the motion takes place without use of any motor. But there is a chance that it will move downwards at a dangerous speed. Hence braking is required to limit the speed of the cage within a safe range. Hence, the direction of  $\omega$  is negative and  $T_M$  is positive. Also the power is negative. This fourth quadrant operation is called reverse braking. Hence it can be derived that an electrical machine can act as a motor in first and second quadrants and it can act as a generator in third and fourth quadrants. Only a separately excited DC motor or three-phase AC induction motor can operate in these four different modes.

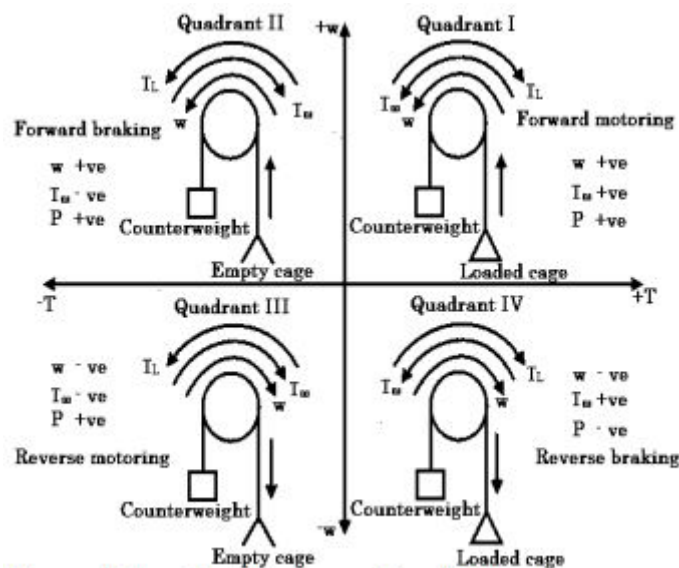


Figure. 1. Four Quadrant operation of DC motor

## II. CIRCUIT OF DC MOTOR

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  $\Phi$ . If the magnetic saturation in the flux path can be neglected, then  $\Phi_f = k_f \times i_f$  : where  $k$  is a field constant of proportionality. The motor carries in its slots is called armature winding, which handles the electrical power. This 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 in fact 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  $i_a$  Where  $k_t$  is the torque constant of the motor. In SI unit,  $k_t$  and  $k_e$  are numerically equal, this can be shown by equating the electrical power,  $i_a$  and the mechanical power,  $W_m T_{em}$ .

$$T_{em} = k_t \phi_f i_a \dots\dots\dots (1)$$

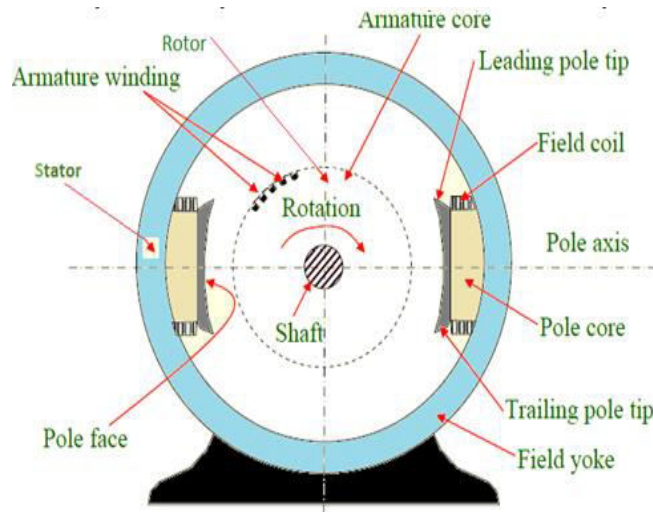


Figure 2-Construction of DC motor

The electrical power is calculated as:  $P_e = e_a i_a$   
 $= k_e \phi_f W_m i_e \dots\dots\dots (2)$

And the mechanical power as:  $P_w = W_m T_{em}$   
 $= k_f \phi_f W_m i_a \dots\dots\dots (3)$

In steady state:  $P_e = P_m$

Therefore from the foregoing equation:  $k_e \left( \frac{Nm}{A.W_b} \right) = k_e \left( \frac{V}{W_b \cdot rad/s} \right) \dots\dots\dots (6)$

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  $V_t$  the induced back-emf  $i_a$ , the armature winding resistance  $R_a$  and armature winding inductance  $L_a$ :  $V_t = E_a + R_a I_a + L_a \frac{di_a}{dt} \dots\dots (7)$

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:

$$T_{em} = \frac{V_t}{a} (J_m + J_s + a^2 (M_T + M_w)) + a F_{wl} \dots\dots\dots (8)$$

Determines how the motor speed builds up.

$$T_{em} = J \frac{d\omega_m}{dt} + B W_m + T_{wl(t)} \dots\dots\dots (9)$$

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 mode of operation. 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 (3) 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 ac motor and converts the electrical energy into mechanical energy supporting its motion. In braking mode, the machine works as a generator and convert 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.

### III.APPLICATION OF FOUR-QUADRANT OPERATION

- ✓ Compressor, pump and fan type load require operation in the first quadrant only. As their operation is unidirectional, they are called one quadrant drive system.
- ✓ Transportation drives requires operation in both directions
- ✓ If regeneration is necessary, applications in all four quadrants may be required. If not, the operation is restricted to quadrant 1 and 3 thus; dynamic braking or mechanical may be required.
- ✓ In hoist drive, a four quadrant operation is needed.

function	quadrant	speed
Forward motoring	1	+
Forward braking	2	+
Reverse motoring	3	-
Reverse braking	4	-

### IV.COMPONENT USED

#### 1. 555Timer

- ✓ 555 timer IC is an integrated circuit (chip) implementing a variety of timer and multivibrator applications.
- ✓ The original name was SE555 (metal con) NE555 (plastic DIP) and the past was described as “the IC time machine”
- ✓ Depending on the manufacture standard 555 package include over 20 transistors, 2 diodes and 15 resistors on a silicon chip installed in an 8pins mini dual-in-line package (DIP-8)

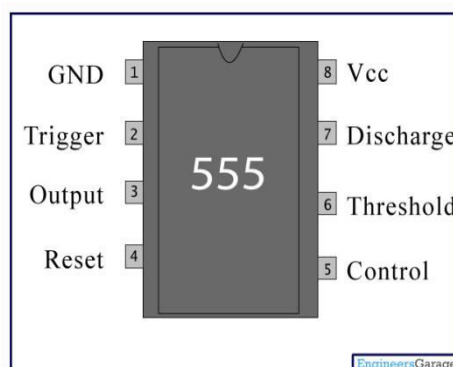


Figure 3-555Timer

The 555 timer IC is a simple 8pin DIL package IC it can:

- ✓ Be used as a monostable
- ✓ Be used as an astable
- ✓ Source or sink 100A
- ✓ Use supply voltage of 5V to 15V
- ✓ Disrupt the power supply, use a decoupling capacitor

## 2. H-bridge motor drive

- ✓ H-bridge motor drive act as current amplifier since they take a low current control signal and provides a higher-current signal.
- ✓ This higher current signal is used to drive the motor
- ✓ H-bridge driver circuit, In its common made of operation, two dc motors can be driven simultaneously, both in forward and reverse direction

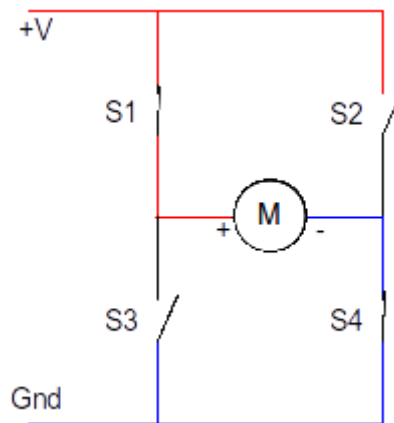


Figure 4- H-bridge motor drive

## 3. DC MOTOR

A dc motor is an electric motor that runs on direct current (dc) electricity. In any electric motor, operation is based on simple electromagnetism

A simple 2poles dc electric motor (here red represents a magnet or winding with a “north” polarization, while green represents a magnet or winding with a “south” polarization).

Every dc motor has six basic parts-axle, rotor (a-k-a, armature), stator, commutator, field magnet(s) and brushes

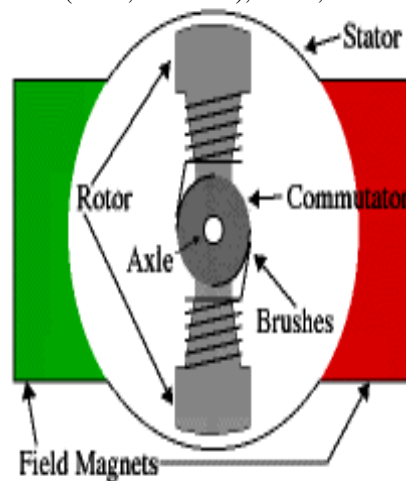


Figure 5-Dc Motor

#### 4. TRANSISTOR

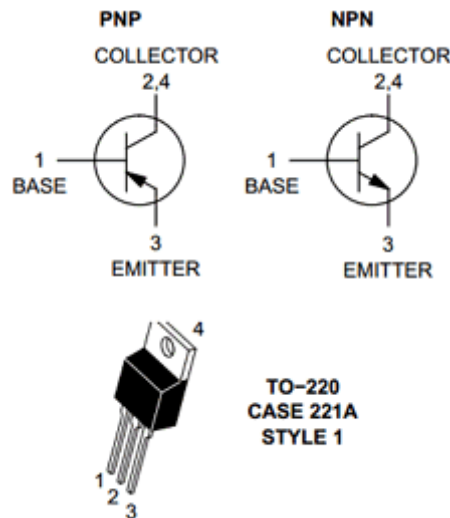


Figure 6- Transistor

- ✓ The transistor is a three-layer semiconductor device consisting of either two n- and one p-type layer of material or two p-types and one n-type layer of material.
- ✓ The former is called an npn transistor, and the latter is called a pnp transistor.
- ✓ The emitter layer is heavily doped with the base and collector only lightly doped.
- ✓ The outer layer has widths much greater than the sandwiched p- or n- type material.
- ✓ The operation of the npn transistor is exactly the same if the role played by the electron and hole are interchanged.

#### V. SPECIFICATIONS

This proposed 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 proposed system uses 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 changing 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 produced.

#### VIII. DATA ANALYSIS

This proposed 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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- Anti-clockwise
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The proposed system uses 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 changing 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 produced.



The four-quadrant of the dc motor is achieved 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.

function	quadrant	speed
Forward motoring	1	+
Forward braking	2	+
Reverse motoring	3	-
Reverse braking	4	-

### IX. 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.

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