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Overview and an Approach to Develop a Four Quadrant Control System for DC Motors without using Microcontroller

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Abstract:
In this paper, 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, L293D IC.

I. INTRODUCTION

As per the requirement, a motor is needed to operate in any quadrant. The need of four quadrant operation can be very well demonstrated with the help of the operation of a motor lifting a load as shown in Fig. 1.1. The can be either no load or load conditions. A steel wire is wounded on a drum to raise the cage and a counterweight. The counterweight magnitude is less than the loaded cage, but greater than that of empty cage. For each quadrant of operation, we have shown the direction of rotation ω, load torque, TL, and motor torque TM. Consider the load torque is constant and not dependent on the motor speed.

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 ω 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, TM should act in the same direction of motor speed, ω. 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 TM will be negative and speed ω 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.

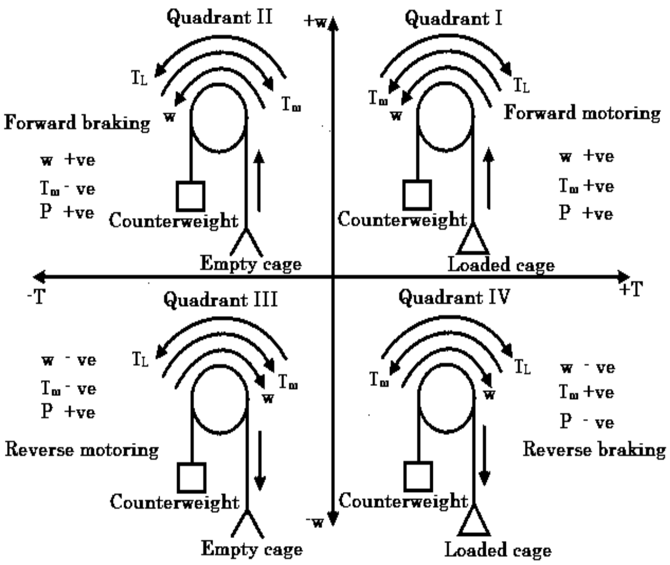

Figure. 1. Four Quadrant operation of DC motor

1.3. No load reverses motoring:

This is the third quadrant operation where no load hoisted down as shown in Fig. 1.1. The downward motion of empty cage is prevented by the counterweight. So the direction of TM should be in the same direction of ω. The direction of rotation is reversed due to the downward movement of the cage, i.e., ω is negative and hence TM 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 ω is negative and TM 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.

II. FOUR QUADRANT OPERATION OF A SEPARATELY EXCITED DC MOTOR

In a separately excited DC motor, the steady state speed is controlled by applying the appropriate magnitude and polarity of the voltage. The torque of the motor is directly proportional to the armature current. It is possible to develop positive or negative torque by controlling voltage. The Fig 2.1. Shows four quadrant operation of a separately excited DC motor in which the torque is indicated by a dot symbol on one of motor terminals.

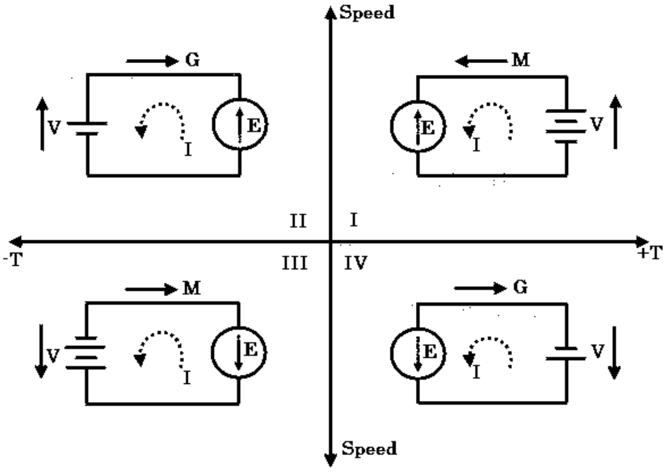

Figure.2. Four quadrant operation of a separately excited DC motor

2.2.1. Forward Motoring:

In this mode of operation, the applied voltage, power, speed and torque are all positive. Therefore, the motor rotates in forward direction.

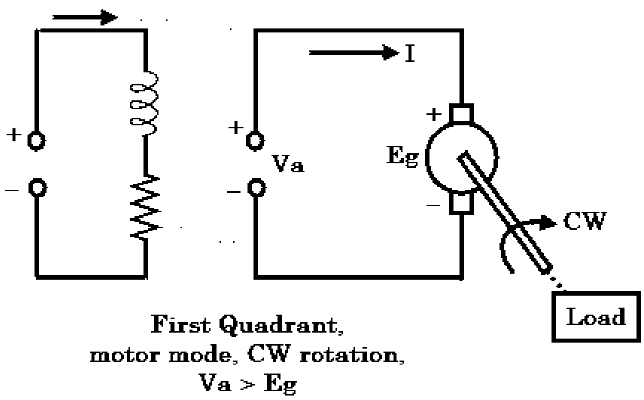

Figure.4.2a) Forward Motoring

2.2.2 Forward braking:

In this mode of operation, the motor runs in forward direction but current flows in negative direction. This negative torque reverses the direction of energy flow. Since the load torque and motor torque are in opposite direction, the combined effect will cause to reduce the speed of the motor. The process by which the mechanical energy of the motor is returned to the supply is called as regenerative braking.

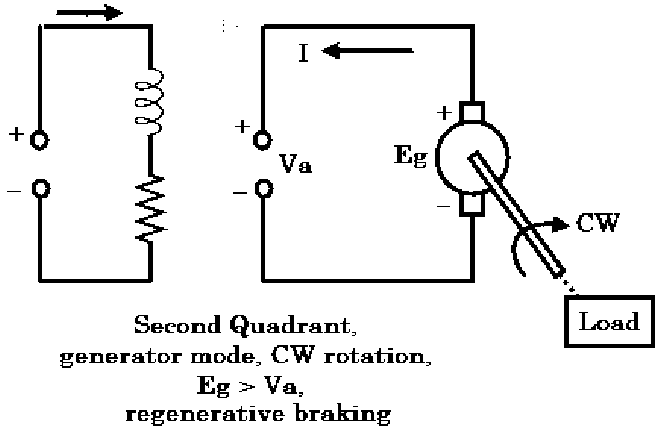

Figure.5.2b) Regenerative Braking

2.2.3. Reverse Motoring:

This is the third quadrant operation of the motor in which the motor voltage and current are negative. Thus, the power is positive. Due to the reverse polarity of the supply, the motor starts rotating in a anticlockwise direction.

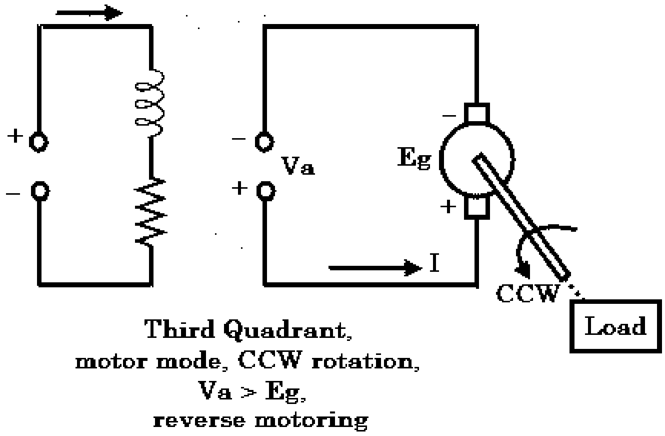

Figure.6.2 C) Reverse Motoring

2.2.4. Reverse Regenerative Braking:

This is the fourth quadrant mode of operation in which the voltage is negative and its armature current is positive. This mode of operation is alike to the second quadrant operation and the regeneration occurs whenever the back emf is more than the negative supply voltage. Hence the torque will be positive which opposes the load torque, thus the speed of the motor will be reduced during reverse operation of the motor.

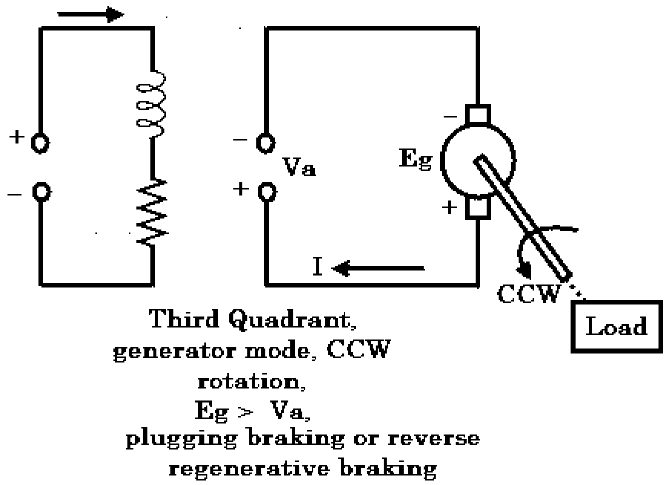

Figure.7.2 d) Reverse Regenerative Braking

III. MOTOR SPEED CONTROL OPERATION

The block diagram of motor speed control operation is shown in Fig. 3.1

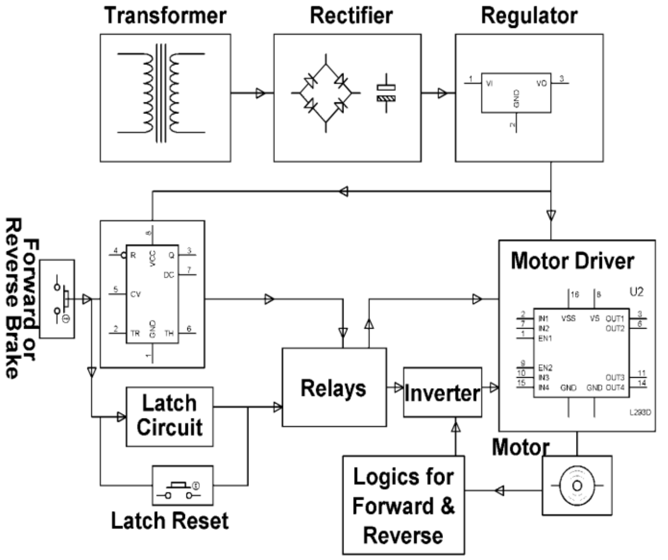

Figure. 8.1. Block diagram of motor speed control

The speed control for DC motor is done by using four-quadrant chopper which makes it potential to exhibit forward & reverse motoring and braking. The speed of DC motor is directly proportional to armature voltage and inversely proportional to flux. If the flux is kept constant, the speed can be varied by varying the armature voltage. By reversing armature voltage, the direction of rotation can be reversed. In this paper, we used a small Fractional Horse Power (FHP) DC motor. The armature of FHP is excited by a variable dc supply which is obtained from four-quadrant chopper. The system can be provided with various control keys. These keys can be START, FORWARD, FORWARD BRAKE, REVERSE, REVERSE BRAKE and STOP. Using these keys, we can set the motor to run in any one of the modes. The speed can be varied by varying the voltage given to the PWM converter.

3.1. 555 TIMER:

The 555 Timer IC is an integrated circuit implementing a diversity of timer and multivibrator applications. The standard 555 package includes over 20 transistors, 2 diodes and 15 resistors on a silicon chip installed in an 8-pin mini dual-in-line package (DIP-8). The 555 timer IC is a simple 8 pin DIL package IC. It can be used as a monostable or astable multivibrator. It can be used to source or sink 100mA or supply voltages of 5v to 15v. It can also disrupt the power supply or can be used as a decoupling capacitor.

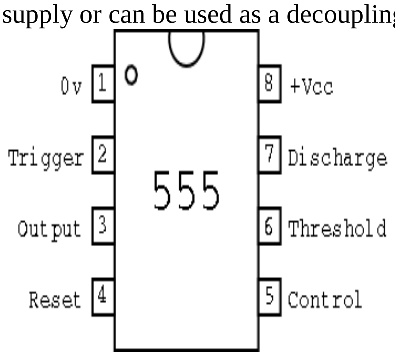

Figure.9.2 555 Timer IC

3.2. Motor Driver L293D

L293D is a dual H-bridge motor driver IC. L293D acts a current amplifier as it takes a low-current control signal and provides a higher-current signal. This high current control signal is used to drive the motors. L293D contains two inbuilt H-bridge driver circuits. In its common mode of operation, two DC motors can be driven simultaneously, both in forward and reverse direction. L293D has 2 set of provisions where one set has input 1, input 2, output 1 and output 2 and other set has input 3, input 4, output 3 and output. If pin no 2 & 7 are high, then pin no 3 & 6 are also high. If enable 1 and pin number 2 are high leaving pin number 7 as low, then the motor rotates in forward direction. If enable 2 and pin number 10 are high leaving pin number 15 as low, then the motor rotates in forward direction If enable 1 and pin number 2 are low leaving pin number 7 as high then the motor rotates in reverse direction. If enable 2 and pin number 15 are high leaving pin number 10 as low, then the motor rotates in forward direction.

3.2.3 DC Motor:

A DC motor runs on direct current (DC) electricity. A simple 2-pole DC electric motor can be used for this approach.

IV. FUTURE SCOPE

This proposed approach 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.

V. CONCLUSIONS

It can be studied that the four quadrants of operation of DC motor are clockwise, counter clock-wise, forward brake and reverse brake. The need of a four quadrant control system and its speed control techniques in those quadrants are explained. Our approach suggests used of 555 timer 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.

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