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Protection of DC Motor from Field Failure

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Abstract—DC motors find a wide range of use in various fields because of their small size and high energy output. Field failure of DC motor is very common phenomenon. This paper presents a low cost system for the protection of DC motor from field failure. The purpose of this field failure relay is to protect the motor from the damage of field failure and also provide a simple speed control technique. Operational amplifier and microcontroller together works as field failure relay. The class-E chopper is used to rotate the motor in either directions and for breaking. The pulse width modulation technique is used for smooth speed control. The concept of op-amp in field failure protection can be extended for application to different DC motor drives such as: series, separately excited and permanent magnet DC motor.

Keywords— DC motor; field failure protection; smooth speed control; operational amplifier; microcontroller; class-E chopper; pulse width modulation.

INTRODUCTION

Direct current (DC) motor has already become an important drive configuration for many applications across a wide range of powers and speeds. The ease of control and excellent performance of the dc motor will ensure that the number of applications using them will continue to grow for the foreseeable future. These motors are main building blocks in different industries. Their malfunction will not only lead to repair or substitution of the motor, but also effect major financial losses due to unpredicted process downtime. Reliable protection of dc motors is essential for reducing the motors malfunction rate and prolonging motors life. If the main field of a shunt motor or a compound motor is extremely weakened or if there is complete loss of main field excitation, a serious damage to motor can occur under certain condition of operation. Since the speed of a dc motor is inversely proportional to flux, its speed tends to rise rapidly when the flux is decreased. If the field failure occurs, the armature will draw heavy current (as good as short circuit condition), the motor speed will raise dangerously high level. Therefore to protect these motors use of power electronic control offers not only better performance caused by precise control and fast response, but also maintenance, and ease of implementation. In parallel with the advance in power electronic there have been great advance in microcontroller-based control systems due to the microcontroller flexibility and versatility.

METHODOLOGY

Principle of operation of DC motors: The DC motor utilizes this concept by changing the direction of the current flowing through the brushes into the coiled wire in the armature. A permanent magnet creates a constant magnetic field, and when current runs through the coils, a force is created that turns the armature. The direction of the rotating force is given by the Fleming's Left Hand rule When the armature has turned far enough, the brushes are now in contact with the opposite ends of the coiled wire, effectively reversing the polarity of the voltage across the coil and reversing the current flow, which create a force that spins the armature further in the same direction. [9]

DC shunt motor: In case of a shunt wound dc motor or more specifically shunt wound self excited dc motor, the field windings are exposed to the entire terminal voltage as they are connected in parallel to the armature winding as shown in the figure below.

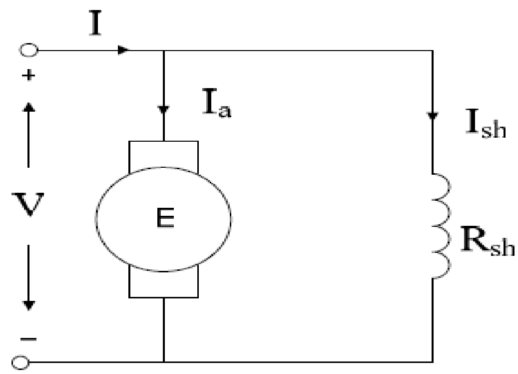

Fig.1. DC Shunt Motor

To understand the characteristic of these types of DC motor, let us consider the basic voltage equation given by

$$E = E_b + I_a R_a \ldots\ldots\ldots (1)$$

Where, E, E_b, I_a, R_a are the supply voltage, back emf, armature current and armature resistance respectively

$$E_b = k_a \phi \omega \ldots\ldots\ldots (2)$$

since back emf increases with flux φ and angular speed ω, Now substituting E_b from equation (2) to equation (1) we get,

$$E = k_a \phi \omega + I_a R_a$$

$$\omega = \frac{E - IaRa}{k\phi} \ldots\ldots\ldots (3)$$

The torque equation of a dc motor resembles,

$$T_g = K_a \phi\, I_a \ldots\ldots\ldots (4)$$

This is similar to the equation of a straight line, and we can graphically representing the torque speed characteristic of a shunt wound self excited dc motor as

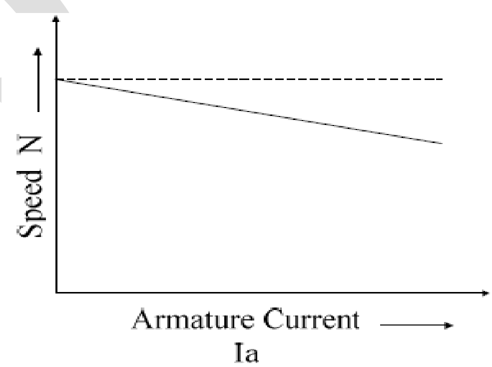

Fig.2. Torque speed characteristics

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The shunt wound dc motor is a constant speed motor, as the speed does not vary here with the variation of mechanical load on the output. Therefore this motor is widely used in many constant speed applications where the speed is to be maintained constant irrespective of load. [11]

Operational Amplifier: An op-amp operates on analog input. It can be used to amplify or attenuate this input, and to carry out mathematical operations such as addition, subtraction, integration, and differentiation. Because of their wide range of uses, op-amps are encountered in most electric circuits.

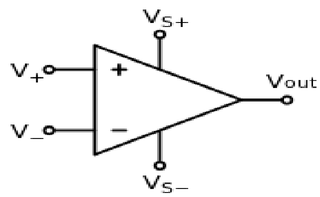


Fig.3. Op-Amp

The fundamental function of an op-amp is to greatly amplify the differential between the two inputs, and output the result. If input at V(+) is greater than at V(−), the op-amp will amplify and output a positive signal; if V(−) is greater, the op-amp will output an amplified negative signal. Two other features of a typical op-amp are: (a) the input impedance is extremely high, and (b) the output impedance is extremely low. Because the op-amp's gain is so high, even small differences in the inputs will rapidly drive the output voltage to its maximum or minimum value. For this reason, op-amps are usually connected to a negative feedback.[8]

Op-Amp as Comparator: A comparator circuit compares two voltages and outputs either a 1 (the voltage at the plus side; VDD in the illustration) or a 0 (the voltage at the negative side) to indicate which is larger. Comparators are often used, for example, to check whether an input has reached some predetermined value. In most cases a comparator is implemented using a dedicated comparator IC, but op-amps may be used as an alternative. Comparator diagrams and op-amp diagrams use the same symbols.

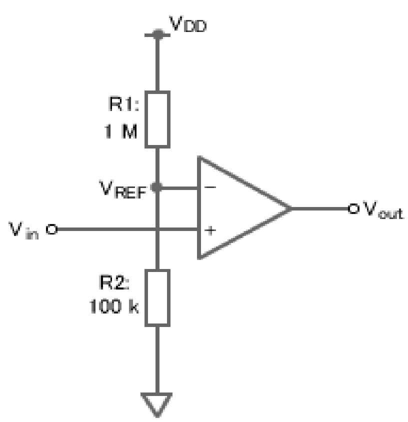


Fig.4. Comparator Circuit

Figure 4 shows a comparator circuit. Note first that the circuit does not use feedback. The circuit amplifies the voltage difference between Vin and VREF, and outputs the result at Vout. If Vin is greater than VREF, then voltage at Vout will rise to its positive saturation level; that is, to the voltage at the positive side. If Vin is lower than VREF, then Vout, will fall to its negative saturation level, equal to the voltage at the negative side. In practice, this circuit can be improved by incorporating a hysteresis voltage range to reduce its sensitivity to noise. [8]

HARDWARE DESIGN

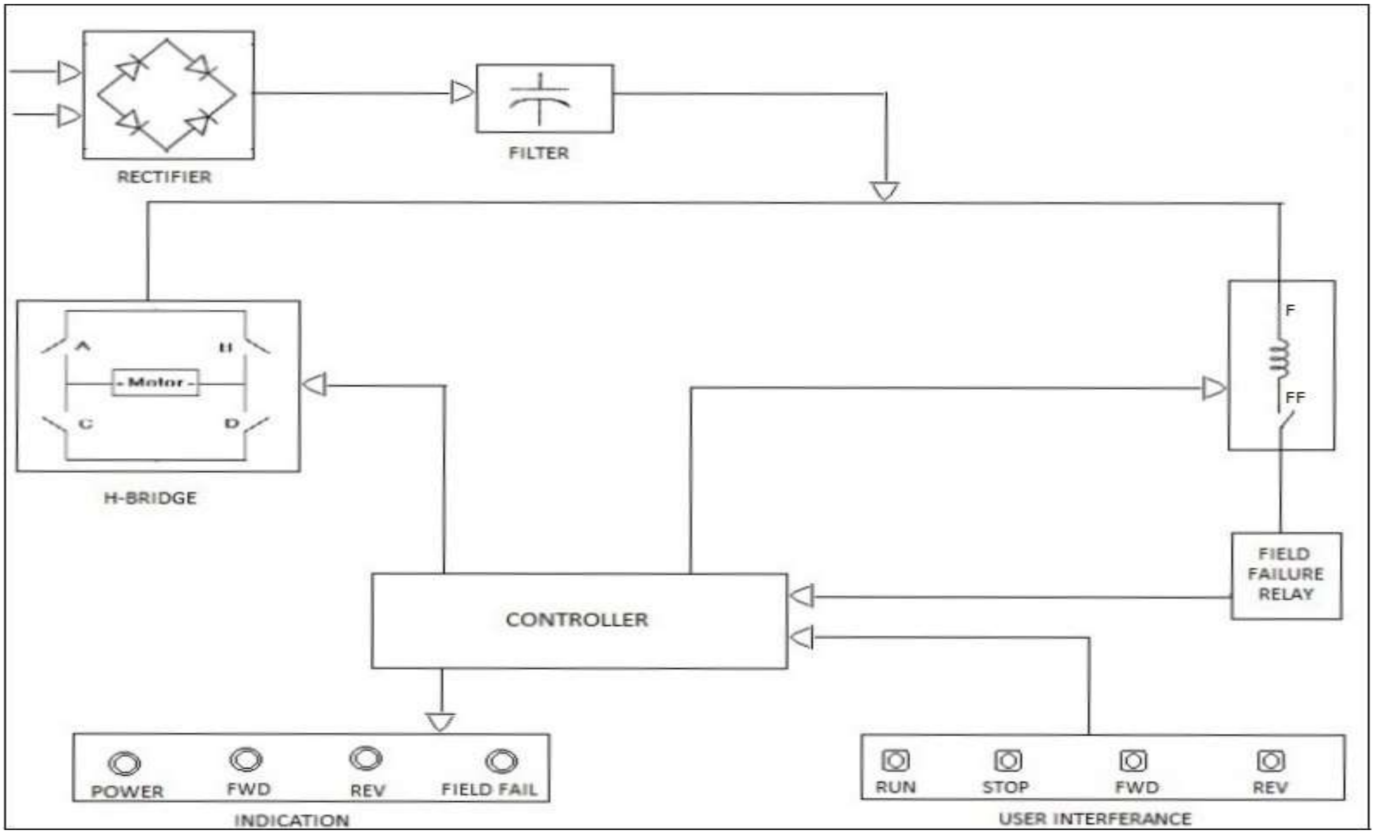


Fig.1. Block diagram of field failure relay system

The ATmega8 is a low-power CMOS 8-bit microcontroller based on the AVR RISC architecture. By executing powerful instructions in a single clock cycle, the ATmega8 achieves throughputs approaching 1 MIPS per MHz, allowing the system designed to optimize power consumption versus processing speed. It has 8K bytes of In-System Programmable Flash with Read-While-Write capabilities. 23 general purpose I/O lines and 32 general purpose working registers & Three flexible Timer/Counters with compare modes allows user to connect with ant digital equipment. [12]

The silicon bridge rectifier (kbpc1000w-g) is a bridge rectifier module in which four diodes are arranged in bridge foam to convert ac signal into dc signal. The module has four terminals two of them for ac input and remaining two for dc output. During the positive half cycle of the input signal two of the four forward biased diodes conducts and during negative half cycle the remaining two conducts in this way load is supplied during both the half cycles. An electrolytic capacitor is used which filters the ripples from the output of bridge rectifier. [10]

The driver IC-IR2110 is high voltage, high speed power MOSFET and IGBT drivers with independent high and low side referenced output channels. Proprietary HVIC and latch immune CMOS technologies enable ruggedized monolithic construction. Logic inputs are compatible with standard CMOS or LSTTL output, down to 3.3V logic. The output drivers feature a high pulse current buffer stage designed for minimum driver cross-conduction. Propagation delays are matched to simplify use in high frequency applications. The floating channel can be used to drive an N-channel power MOSFET or IGBT in the high side configuration which operates up to 500 or 600 volts. [12]

The operational amplifier(lm358) Ic consist of two independent, high- gain, internally frequency-compensated op-amps, specifically designed to operate from a single power supply over a wide range of voltages. The low-power supply drain is independent of the magnitude of the power supply voltage. Application areas include transducer amplifiers, DC gain blocks and all the conventional op-amp circuits, which can now be more easily implemented in single power supply systems. For example, these circuits can be directly supplied with the standard + 5 V, which is used in logic systems and will easily provide the required interface electronics with no additional power supply. In linear mode, the input common-mode voltage range includes ground and the output voltage can also swing to ground, even though operated from only a single power supply voltage. [12]

The IGBT (FGA25N) is a three-terminal power semiconductor device primarily used as an electronic switch as it was developed, came to combine high efficiency and fast switching. It switches electric power in many modern appliances variable-frequency drives (VFDs), electric cars, trains, variable speed refrigerators, lamp ballasts, air-conditioners and even stereo systems with switching amplifiers. Since it is designed to turn on and off rapidly, amplifiers that use it often synthesize complex waveforms with pulse width modulation and low-pass filters. In switching applications modern devices boast pulse repetition rates well into the ultrasonic range—frequencies which are at least ten times the highest audio frequency handled by the device when used as an analog audio amplifier. Using Fairchild's proprietary trench design and advanced NPT technology, the 1200V NPT IGBT offers superior conduction and switching performances, high avalanche ruggedness and easy parallel operation. This device is well suited for the resonant or soft switching application such as induction heating, microwave oven. [10]

The voltage regulator (LM7805) IC is three-terminal positive regulator which is available in the TO-220 package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut-down, and safe operating area protection. If adequate heat sinking is provided, they can deliver over 1 A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components for adjustable voltages and currents. [12]

CIRCUIT DIAGRAM

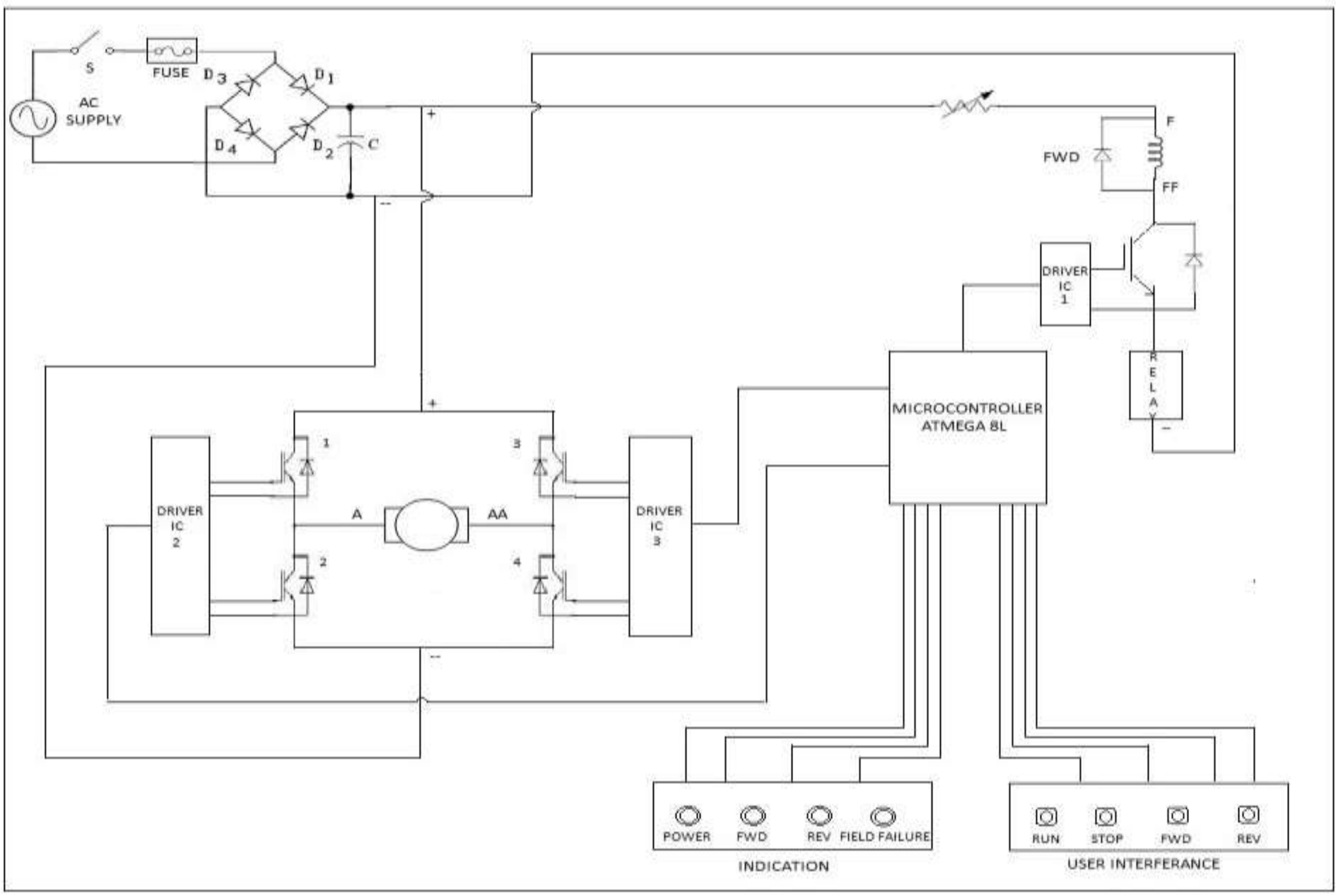


Fig.2.Circuit Diagram

WORKING

In the circuit diagram shown above the rectifier circuit is used to convert AC supply into DC signal. The electrolytic capacitor is used to remove ripples from the DC signal. The field failure relay (contains operational amplifier and microcontroller) the operational amplifier sense the current flowing in the field winding. During the abnormal condition operational amplifier sends the signal to the microcontroller and supply to the armature is tripped using H-bridge. During the normal condition the function of H-bridge is to rotate the motor in forward or reverse direction and break the supply to the armature in fault condition. It consists of IGBT which is used as a switch. The H-bridge is controlled by driver IC depending on microcontroller input. Microcontroller provides timing and control signal to various components of the circuit.

Auxiliary supply of 12V is provided to driver IC's and linear voltage regulator is used to provide constant 5V supply to microcontroller and field failure relay. Using user interface microcontroller can be commended for desired function such as run, stop, forward and reverse operation of dc motor. Using these keys the user can set the motor to run in any one of the following modes namely forward motoring, reverse motoring, forward braking and reverse braking. The Hardware of this system including bridge rectifier and filter circuit, chopper using IGBT, control keys, microcontroller, field failure sensor is shown below.

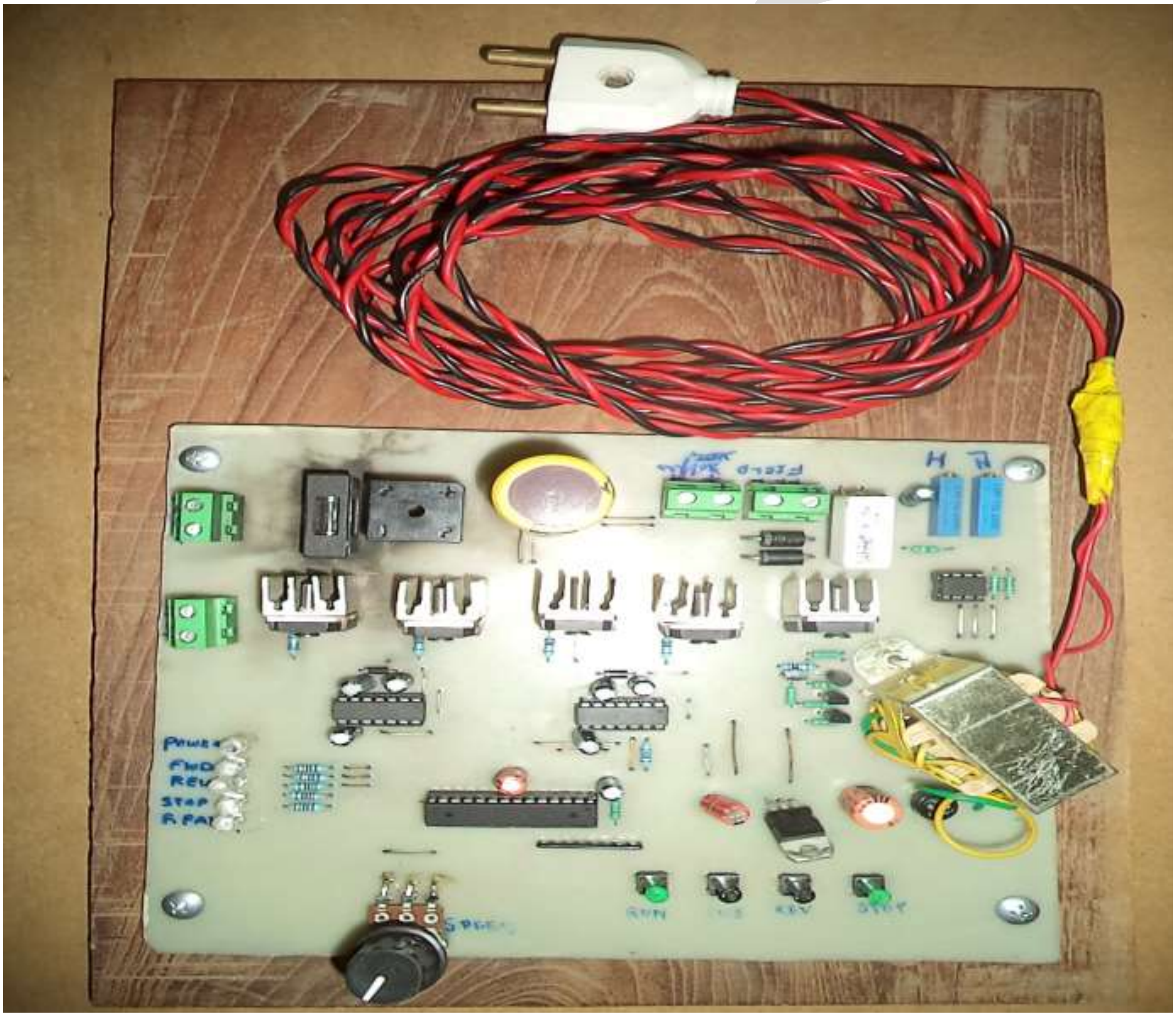


Fig.3.View of Hardware Module

RESULT

Protection system for field failure protection of DC motor is successfully implemented and relay is tested for different values of current through field winding, various operations such as forward motoring, reverse motoring, forward braking and reverse braking successfully performed. We have tested our project on 3HP motor and 5HP motor. The following observation table shows the results. For given motor rating, the speed and the operating time of field failure relay is observed.

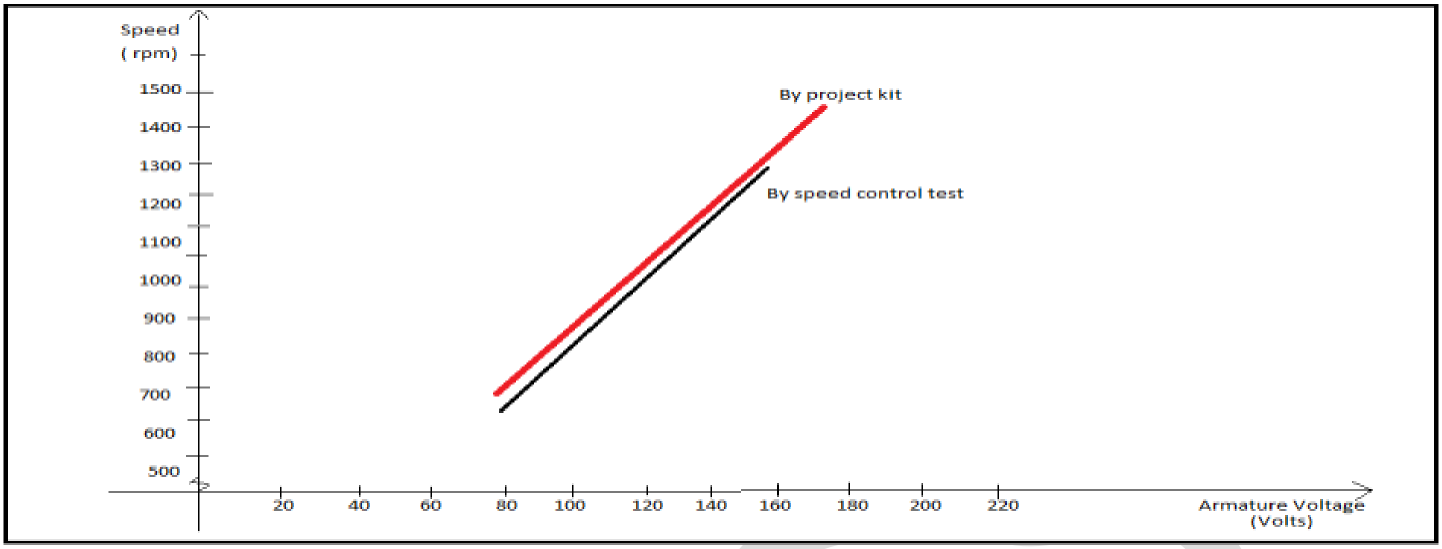
Sr. No.	Motor Rating	Speed in rpm (Min)	Speed in rpm (Max)	Operating time of field failure relay (seconds)
1	3HP,220V,12A,1500rpm	76	1150	0.3
2	5HP,220V,19A,1500rpm	94	1280	0.2

The comparative observation table for speed control test using rheostat control and by the project kit is shown below.

Rating of DC motor: 5HP, 220V, 12A, 1500 rpm. Field current: 0.5A

Serial Number	By speed control test		By the project kit	
	Armature voltage	Speed in rpm	Armature voltage	Speed in rpm
1	80	640	80	651
2	100	820	100	860
3	120	970	120	995
4	140	1130	140	1175
5	160	1280	160	1350
6	180	1300	180	1420

The comparative graph of the two tests:



CONCLUSION

A low cost protection of dc motor from field failure and also simple speed control method can be implemented. Which consists of field failure relay (i.e. the operational amplifier and micro controller) which is used to sense the field failure and cut armature from the main circuit so that the motor is saved from its effects. On the other hand, the class E chopper can not only be used for speed controlling in different direction but also for braking. This system can be extremely suitable for detecting/ sensing absences of field current, directional reversal, speed control, soft starting.

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