International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-8 Issue-3, February 2019

Implementation of Microcontroller based Fault Detection and Protection System for DC Motor

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Abstract*: The acute aim of this paper is to identify the nascent faults that may cause due to various reasons like over current/voltage, under voltage, high temperature, overload, and single phasing and to protect the motor from such faults. These type of faults mainly occur due to variation of parameters i.e. voltage, current, and temperature. Due to this fault, the motor winding gets heated which causes insulation failure, thus the life of the motor reduces. This project uses AT89S51 microcontroller for detection of electrical faults. The same microcontroller was developed by Intel and based on 8-bit microcontroller family. The circuit was designed successfully in Proteus simulation software as well as in real time environment and various testing conditions was applied to check the system robustness. The improved performance of the microcontroller and associate system network is established against system constraints through its efficient mechanism.

***Index Terms*: Microcontroller AT89S51, LM35 temperature sensor, ACS712 current sensor, LM339 quad voltage comparator**

I. INTRODUCTION

With rise of population, the size and complexity of electrical equipment is growing day by day. There are two types of appliances available in the market. The first type is associated with motoring mode and designated as inductive load and others are resistive load. Appliances like heaters (room heaters, water heaters) and luminaires (bulbs, CFLs, tube lights) do not need voltage stabilizer. When the voltage is lower, less current flows through it and vice versa. If the voltage is less, the output of the appliance will be less. Hence power consumption of the appliances will be less. But if the voltage is higher than the normal voltage, more current will pass through the appliances. If the high voltage is persistent, the high current will also be persistent which may cause burning of the appliances and consumption of electricity will be more. All inductive appliances have an operating voltage range. Operating voltage range of a ceiling fan is much higher than an air conditioner. Thus, ceiling fan works at low voltages also but air conditioner does not. If the voltage given to the air conditioner is lower than the operating voltage range, then it will not start at all. But if it is in running condition, it will produce a humming sound. Since it will not produce enough Counter Electromotive Force (CEMF) which is a phenomenon in which flow of current reduces in the motor windings. Hence the motor draws more current to operate the system. If this is consistent, it can overheat and burn the motor. When a high voltage occurs, it will fetch more current at the time of starting which causes insulation damage and short circuit. But after reaching the steady state the current becomes less. So, we have to distinguish the operating voltage range and voltage fluctuations as shown in Fig.1, and put a voltage stabilizer to protect the appliances.

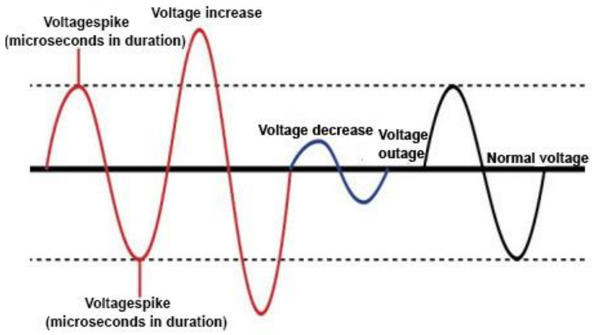

Fig.1. Waveform of Over Voltage and Under Voltage

According to the National Electrical Code, any current greater than the rated current of the equipment or the ampacity (rated continuous current carrying capacity) of a conductor is defined as over current. It causes short circuit, overload, and ground fault. When current flows through a conductor, it produces heat which is shown in Fig.2.

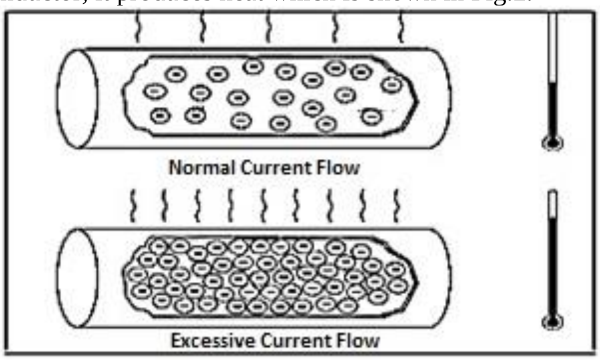

Fig.2. Effect on temperature when current flows through a conductor

An excessive amount of heat can damage electrical components. Over current protection devices control the flow of current and restrain the conductors of the circuit from overheating. In this project allegro ACS712 current sensor is used as a current protective device.

Manuscript published on 28 February 2019.
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II. SYSTEM ARCHITECTURE

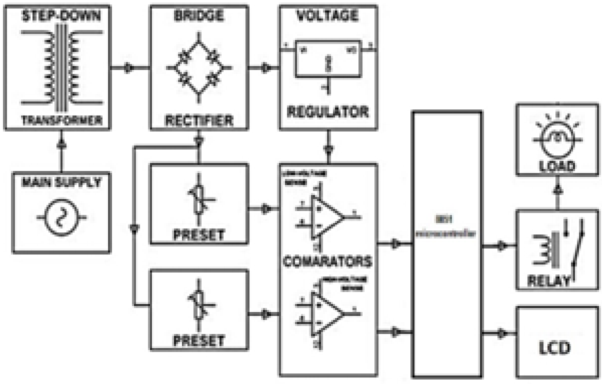

Fig.3 An overview of the Model architecture

As shown in Fig.3, the AC power supply is converted into DC by using a rectifier. Under normal conditions, the microcontroller handles the data from different sensors. If the supply current/voltage is higher or lower than the rated current/voltage, then the microcontroller senses faulty condition using window comparator and sends a signal to the relay to break the circuit and cut off the load for safety reasons. In this case, a motor is used as a load. To sense the over temperature condition when the windings of the motor get overheated, a temperature sensor is used. Thus, the faulty situations such as, over current, under/over voltage and over temperature can be avoided. When the abnormal values measured by the sensors become normal values, microcontroller sends a signal back to the relay to run the motor again. It is further extended by interfacing a 16×2 LCD display, to display the events taking place with the motor. It can also be improved by integrating with a GSM modem for sending warning message to the user via SMS [3].

There are two types of electrical motor faults:

A. Faults inside motor: -

- Phase to phase fault
- Phase to ground fault
- Internal winding short circuit
- Windings overheating
- Complications in windings

B. Faults due to external sources: -

The origins of faults are situated outside but their impacts can damage the motor.Diverse electrical faults, its probable causes and consequences are depicted in Table 1[2].

III. DESIGN OF MODEL

A. Power Supply Module

Various kinds of power supply modules are available. In this project microcontroller based 5V DC regulated power supply circuit is used as shown in Fig. 4. It converts 230V AC to 5V DC in four steps; which are described briefly in below:

1) Stepping Down the Voltage Level: The transform of high voltage to low voltage is done by step-down transformer. Its output voltage is less compared to the input voltage. Its primary winding is 230V and secondary winding is 12V. So, 230V AC is stepped down to 12V AC. 12V which is the secondary winding voltage is the RMS value, then the peak value is calculated as, $12\times\sqrt{2}\approx17V$.

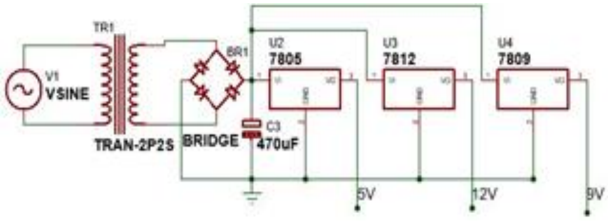

Fig.4. Circuit diagram of Power supply module

TABLE 1: - Possible causes, consequences and effects of different faults

Faults	Causes	Consequences	Effects on the motor
Unbalanced voltage	Phase opening, Single phase load, Upstream of motor	Decreases the available torque, Increase in losses	Overheating
Voltage drop and dip	Instability in mains voltage, Connection of high loads	Decreases the available torque, Increase in losses	Overheating
Harmonics	Main supply pollution by nonlinear load	Decreases the available torque, Increase in losses	Overheating
Starting too long	Increase in resistance torque, Voltage drop	Decreases the available torque, Increase in losses	Overheating
Locking	Mechanical problem	Increase in starting time	Overheating
Overload	Increase in resistance torque, Voltage drop	Over current	Overheating
Voltage surge	Electrostatic discharge, Lightning, Disconnection of load	Dielectric breakdown in winding	Destruction of winding by loss of insulation
Short circuit	Phase to phase fault, Phase to ground fault, Winding to winding fault	Current surge, Electrodynamics stress	Windings get destroyed

2) Converting AC to DC: In this case, AC power is transformed into DC using a power electronic converter called full-wave rectifier. The bridge rectifier is made up of 4 diodes attached in the form of a bridge. The diode carries only the forward bias and will not carry during the reverse bias. In forward biased condition the anode voltage of the diode is greater than the cathode voltage. Diodes D2 and D4 conducts during the positive half cycle and diodes D1 and D3 conducts during the negative half cycle. Therefore, AC becomes DC[3]. Here the resulting waveform is not pure DC because it contains pulses. Thus, it is called pulsating DC. Since the voltage drop across the diodes is, $2\times0.7V=1.4V$; the peak voltage will be, $17-1.4\approx15V$ approximately.

3) Smoothing the Ripples with Filter: In this step pure DC power is obtained from pulsating DC power using a capacitor filter.

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The pulsating DC power contains a minimum amount of AC ripples. Ripples can be removed by using inductor-filter, capacitor-filter, and resistor-capacitor coupled filter. It is designed by connecting a shunt electrolytic capacitor in parallel of rating 470 µf. During the positive half cycle, input voltage increases from zero to peak value, capacitor accumulates the energy as an electrostatic field. In the negative half cycle input voltage decreases from the peak value to zero and capacitor liberates the stored energy. This property of capacitor converts pulsating DC into pure DC.

4) Converting 12V DC into required DC level: 15V DC is converted into 5V (under voltage level), 9V (normal voltage level), 12V (over voltage level) by IC7805, IC7809, IC7812 voltage regulator respectively. It has three terminals pin-1 is an input pin, pin-2 is a common pin, and pin-3 gives constant DC output.

In voltage regulator, it has an operating amplifier which acts as an error amplifier. Zener diode is used for providing voltage reference. Its operating voltage range is 7.2V to 35V. If voltage increases beyond this limit then heat loss occurs.

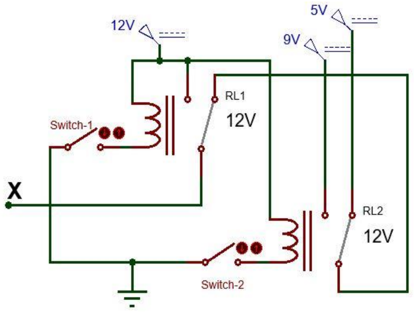
B. LM339 Voltage Comparator

When voltage increases beyond the rated voltage, it can damage motor insulation. To solve this problem, LM339 voltage comparator is used. In an LM339 quad voltage comparator, it has four independent op amps. So, it can analyse four different inputs. If the voltage at the inverting input terminal is greater than the noninverting input terminal, then the output goes to ground (gives zero output voltage). If the voltage at the noninverting input terminal is greater than the inverting input terminal, then the output increases high to VCC.

Over/Under Voltage Sensing Circuit

In this study, 5V, 9V, 12V are taken as under voltage, normal voltage, over voltage respectively. In Fig.5 (a), two relays are connected in such a way that a common wire labeled as ‘x’ goes to the noninverting input of the comparator-1 and inverting input of the comparator-2 as shown in Fig.5 (b).

1) *Normal Voltage*



When the current

Fig.5 (a) Simulation of over voltage and (b) under voltage using two relays and comparators

This sensor gives a ratio metric output. When the input current is zero, its output voltage is VCC/2. It is available in three types, (i) ACS712-05B operates within 5A range, (ii)ACS712-20B operates within 20A range, (iii) ACS712-30A operates within 30A range.

F. AT89S51 Microcontroller

The 8051 microcontroller is invented by Intel. It is an 8-bit family of microcontroller, made with 40 pins DIP, 4 kb

Condition: When the switch-1 is OFF and switch-2 is ON, 9 volt goes from ‘x’ wire to both the comparators. Both the comparators give output 1. The motor works properly in this condition.

2) Over Voltage Condition: When the switch-1 is ON and switch-2 is OFF, 12 volt goes from ‘x’ wire to both the comparators. Comparator-1 gives output 1 whereas comparator-2 gives output 0. The output of comparator-2 is given to the P1.4 pin of microcontroller. Hence it commands the motor to stop.

3) Under Voltage Condition: When both the switches are OFF, 5 volt goes from ‘x’ wire to both the comparators. Comparator-1 gives output 0 whereas comparator-2 gives output 1. The output of comparator-1 is given to the P1.3 pin of microcontroller. Hence it commands the motor to stop.

C. Over Temperature Sensing Circuit

There are two kinds of thermal protection method[6]

1) *Indirect Method: Protection by using a thermal relay.*
2) Direct Method: Protection by using sensors.

Thermal relays fail to operate with large powerful motors as they operate at heavy conditions. For this purpose, the heat is measured using a sensor. Different types of temperature sensors are available such as Thermistors, Thermocouples, Thermometers, Resistor temperature detectors, Infrared sensors, and Semiconductors. Here semiconductor IC LM35 is used because it can calibrate temperature more correctly than a thermistor and it produces a high output voltage than thermocouples which may not need to amplify. This sensor gives electrical output comparative to the temperature in degree celsius. The range of operation is, -55°C to 150°C. When the temperature rises or falls by 1**°C** the output voltage differs by 10mV. Its scale factor is 0.01V/°C.

Over Temperature Condition: In temperature comparator circuit when the voltage of LM35 increases beyond the other input terminal voltage, then it gives output 0 to the P1.5 pin of microcontroller. Hence it commands the motor to stop.**Over Current Sensing Circuit** increases above the rated current, it can cause malfunctioning of the motor. To solve this problem the overload sensing circuit is used. It monitors the load current using ACS712 Hall sensor module [3]. This device works on the principle of Hall-effect. Its output DC voltage depends upon the DC/AC input current (it can deal with both DC and AC input current). Then this DC voltage is given to the LM339 voltage comparator which compares and sends output to the P1.6 pin of microcontroller.

ROM, 128 bytes RAM, two 16-bit timers.
It has 4 numbers of parallel 8-bit ports. A crystal oscillator is integrated on it having crystal frequency of 12 MHZ. It is a high-performance device and operates on low power. The 8-bit non-volatile flash memory allows us to reprogram the program. This microcontroller is mainly used in embedded systems as it gives highly flexible and economic solutions.

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G. LCD Display

16×2 liquid crystal display is used which displays 32 characters at a time in two rows. Each character has a size 5×7 pixel matrix. There are 16 pins available in the module out of 8 pins are data pins and remaining are ground pin, power supply pin, contrast adjusting pin, register select pin, read-write pin, enable pin, 2 pins are for backlight of LCD.

H. Relay

The relay is an electromechanical switch. It is automatically operated without human interaction. Current circulating in the inductor coil generates a magnetic field which attracts the lever and changes its position from normally closed contact (NC) to the normally opened contact (NO). When coil de-energizes swing terminal goes back to normally closed contact. Relays are double throw/changeover switches.

C. Algorithm for Microcontroller Programming

A program has been implemented in assembly language to check the values at microcontroller pins i.e. P1.3, P1.4, P1.5, P1.6 and enable or disable the pin P1.7 accordingly which is connected with the motor[1]. The steps of operation of this process are discussed briefly in the following steps and the flowchart is presented in Fig.6.

Step-1: Run the motor.
Step-2: Display the running status of motor.
Step-3: Check for over/under voltage, over temperature and over current condition.
Step-4: If yes Stop the motor else jump to step-2.
Step-5: Display the type of faults when motor stops.

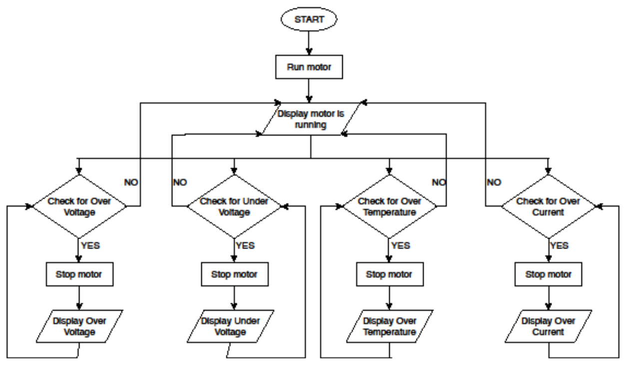

Fig.6 Flowchart of proposed program steps

IV. RESULT ANALYSIS

In this project a model has been constructed using proteus software as well as in real time environment which is shown in Fig.7 and 8, to protect the motor against all types of faults. Sensors monitor the temperature, current and gives data to the microcontroller. The point when an unclear fault occurs the microcontroller senses it and stops the motor. To realize the whole system configuration in the real time environment different components are used and are described below. 230/12 V transformer which steps down 230V ac current to 12V ac. IC7805, IC7809 and IC7812 voltage regulator circuits give a constant voltage of 5V, 9V and 12V respectively. LM339 comparator is used for comparing voltage with respect to the reference voltage. In over current circuit 741-opamp which is current to voltage converter produces voltage with proportional to the input current. AT89S51 microcontroller is used which sends trip signal to the relay which stops the motor. The DC motor used in this practical method is rated of 12V, 300 rpm, 0.35kgcm torque, no load current = 60 mA (Max), load current = 300 mA (Max). The result of different conditions like over voltage, under voltage, over temperature and over current were shown through 16×2 LCD display and the results were verified with that of circuit implementation in proteus simulation environment for under voltage condition as shown in Fig. 7. And the same is also implemented in real time environment as represented in Fig.8. Normally, these types of faults occur when the supply system rating is violated. In this model when the supply voltage is low (i.e. 5V) or high (i.e. 12V) than the rated voltage (i.e. 9V), it halts the motor. In this project low voltage and high voltage level is considered as 5V and 12V respectively, but in real time situations it can be dealt with any voltage that is below or above the rated voltage. Hence, it maintains smooth running of the motor thereby increasing the lifetime and productivity.

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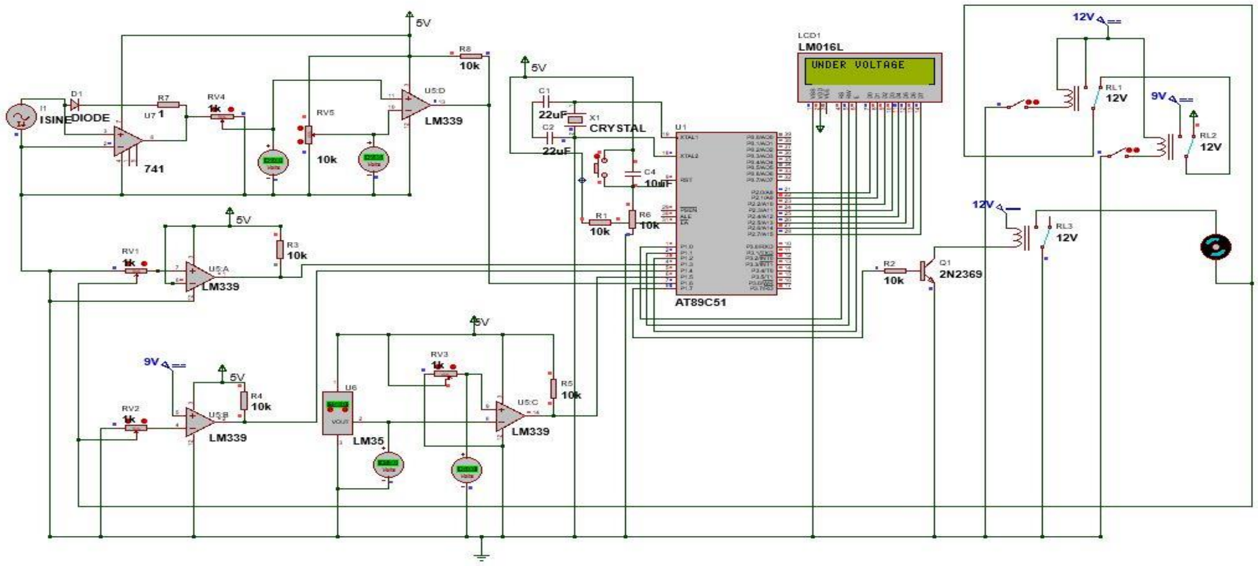

Fig.7. Implementation of overall system configuration in Proteus Software

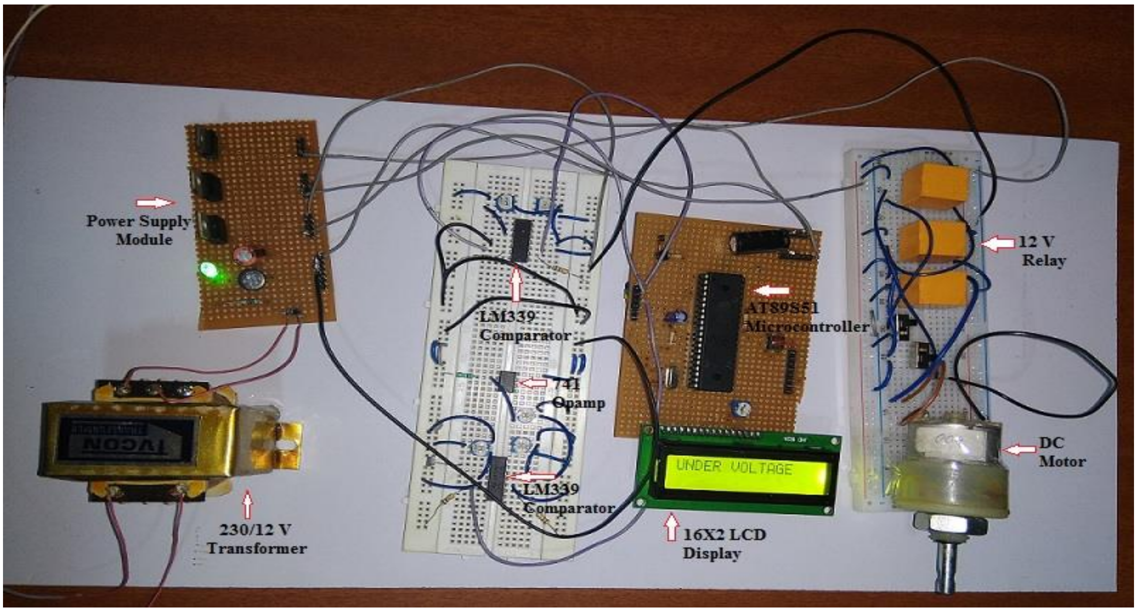

Fig. 8 Implementation in Hardware

V. CONCLUSION

The voltage fluctuations may have antagonistic effects on connected loads. These fluctuations can be initiated by overload, lightning, voltage surges etc. The design and realization of microcontroller-based fault detection system was simulated. The model is successfully implemented in software and also in real time environment. The key points of the observation are summarised as:

A) The AT89S51 microcontroller is designed and operated effectively through Proteus simulation environment.

B) The sensitivity analysis of the system is done and the result infers that the profundity of the project that will be able to trip the motor if any type of fault arises.

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