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Development of Induction Motor Monitoring System with Protection against Abnormal Voltage, Current and Temperature

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Abstract – Monitoring and protection system is needed in every industry to avoid unwanted faults in the process components that may leads to excessive downtime and huge losses in terms of maintenance cost and loss of revenue. Monitoring of induction motor parameters under various operating conditions plays a vital role in its performance, reliability, efficiency and life cycle. This research focuses on the design of a system for measuring and monitoring of voltage, stator current and winding temperature of an induction motor under operation. The system also isolates the motor from the supply if threshold values are exceeded by using sensor technology with PIC18f4550 microcontroller. The hardware system was tested with a single phase induction motor. The results obtained show that the measured values conform to analog meters readings. The system adequately monitors and isolates the induction motor to prevent it from breaking down.

Keywords: Induction motor, Microcontroller, Monitoring, Protection, Sensor

1.0 Introduction

Induction motors are the most widely used electro-mechanical devices in a variety of applications and since the squirrel cage induction motor is low-priced, simple, robust, and rugged, it is considered worldwide as the workhorse in industrial applications (Chaturvedi, Akash, Mayank, and Sharif, 2014). Many researchers focused on condition monitoring of three induction motor components: the stator, rotor and bearings. Little attention has been paid to voltage unbalance in the motor supply and the development of induction motor parameters monitoring system (Mirabbasi, Ghodratollah, and Mehrdad, 2009).

Operation of induction motors at voltage and frequencies other than the nominal values, sudden increase in load or load thrown off can cause significant changes in the motor speed. Increase in speed leads to increase in operating temperature and decreases the functional horse power, which leads to reduced life of motor (Pari, Kavipriya, Naveenadevi, Preethi and Suryadharsini, 2017). Induction motor speed and temperature is more affected by high amplitudes of voltage fluctuations, whilst the torque and efficiency are more affected for middle and high amplitudes (Zhao, Ciufo and Perera, 2012).

A temperature protection system is needed to protect induction motor stator winding against thermal overloads in an application where induction motors are frequently started, overloaded and used in high inertia applications with long starting times (Aleksejs, 2015). Thermal overheating degrades the chemical stability of the materials used for stator winding insulation and accelerates the aging process. Unbalance voltage can occur due to Intermittent load or strong fluctuations in power demand, presence of larger single-phase consumers, (Zhao, Ciufo and Perera, 2012), presence of higher harmonics in the supply voltage (Miloje, 2012).

The present day requirement for ever increasing reliability of electrical machines is parameters monitoring and protection against variations. Though, it does not remedy the fault in most cases but early detection of variations in voltage, current and temperature and appropriate action would eliminate subsequent damage to motor, then reducing the cost of repair and downtime. The traditional measuring apparatus like meters cannot give a continuous measuring, monitoring and storing results of induction motor parameters (Shubhang and Rajesh, 2011).

Hence, a cost effective, reliable and accurate hardware system is designed to have a continuous monitoring of these parameters and protect against variation in voltage, current and temperature and isolate the induction motor from supply if the threshold value is exceeded.

2.0 Proposed System

Faults results in loses in the motor and also leads to increased electricity charges due to poor power factor, reduced efficiency, and power consumed. This paper is limited to motors operating directly on sinusoidal power and not through adjustable speed drives. The proposed system consists of different units such as voltage sensor, current sensor, temperature sensor, PIC18F4550 based processor, and induction motor under test.

2.1 Voltage measurement and monitoring

Voltage is an important parameter to measure in the monitoring of the induction motor as the variations in induction motor input voltage causes variation in stator current, temperature and also the speed. A potential transformer voltage sensor is used to measure and monitor line voltage of the induction motor. The sensor decreases the voltage at the ratio of 220:12. Electronic circuitry shown in Figure 1 is used to scale and shift the voltage to required level. A voltage divider is used to scale the input voltage, V_p by the ratio of the resistances shown in equation 1.

Set $R_1 = 5k\Omega$ and $V_i = 2.5V$

$$V_p = 12\sqrt{2} \sim 17V$$

$$V_i = \left[\frac{R_2}{R_1+R_2}\right] V_p \qquad (1)$$

$$R_2 = 29k\Omega$$

LM358 is used to perform the level shifting and achieving 5volt using equation 2.

$$V_{out} = 2.5\left[1+\frac{R_4}{R_3}\right] \qquad (2)$$

V_{out}, 5V positive polarity analog voltage was connected to a summing amplifier to have an output voltage of 2.5V. 2.5V, analog output of summing amplifier is converted to digital by 10 bit inbuilt ADC of PIC18f4550 before processing. Equation 3 is used for the conversion of voltage sensor output to digital.

$$ADC\ count = \frac{analog\ value * 1023}{2.5} \qquad (3)$$

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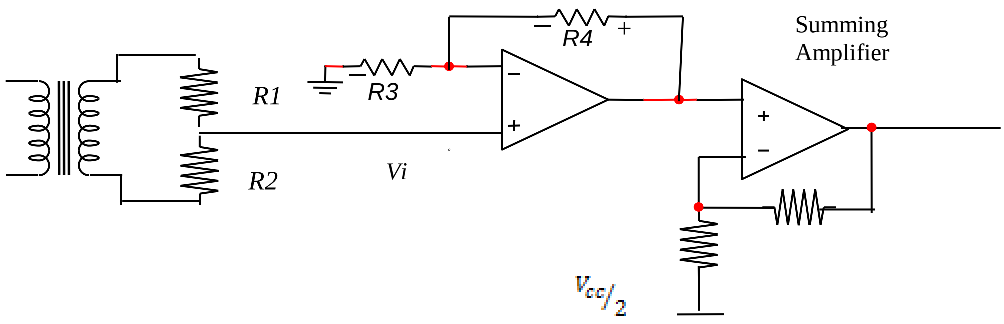

Figure 1: Voltage Sensing Circuit

2.2 Current measurement and monitoring

ACS712 is a current sensing integrated circuit that works on the principle of Hall Effect sensing of current is used to measure and monitor induction motor stator current. ACS712 current sensor senses current up to 30Amp. This module gives dc voltage output proportional to the input ac line current. The output is buffered by an LM358 operational amplifier. When this voltage is converted to digital with inbuilt ADC on the PIC18F4550 microcontroller, equation 7 is used to determine stator current as shown through equations 4 to 6. To protect the microcontroller from over voltage due to accidental or over range, a 5 volt zener diode is used. Figure 2 shows the current sensing circuit.

$$Sensor\ output\ voltage = (0.066 \times i) + 2.5 \quad (4)$$

$$Current, i = \frac{(Sensor\ output\ voltage - 2.5)}{0.066} \quad (5)$$

$$ADC\ count = \frac{1023}{v_{cc}}\left(\frac{v_{cc}}{2} + 0.066i\right) \quad (6)$$

$$i = 0.074(ADC\ count - 512) \quad (7)$$

$$v_{cc} = 5V$$

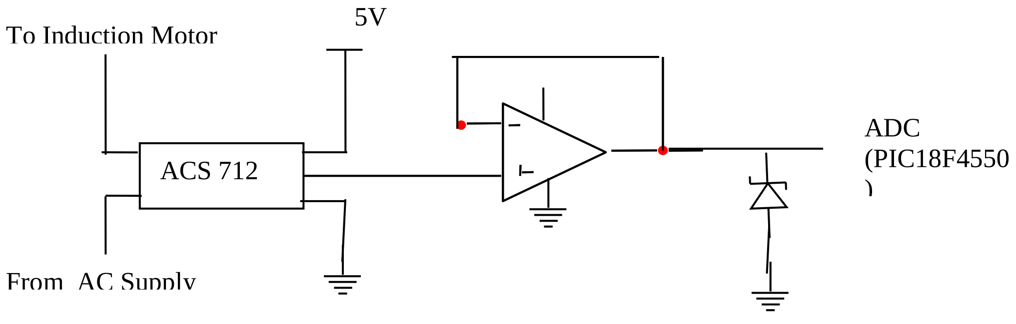

Figure 2: Current Sensing Circuit.

2.3 Temperature measurement and monitoring

Thermal overheating degrades the chemical stability of the materials used for stator winding insulation. Gradual deterioration of its mechanical and electric integrity leads to insulation failure; therefore, thermal monitoring is critical to induction motors protection. NTC thermistors made from a pressed disc or cast chip of semiconductors are used as temperature sensor. A resistor divider of Figure 3 is used to perform a ratiometric measurement such that the V_{cc} source voltage to the divider is the same as the reference to the buffer. The equations for V_T and its ADC conversion are as shown in equations 8 to 10. The output is buffered by an LM 358.

$$v_T = v_{cc}\left(\frac{R_1}{R_T + R_1}\right) \quad (8)$$

$$R_T = R_1\left(\frac{v_{CC}}{v_T} - 1\right) \quad (9)$$

$$R_T = R_1\left(\frac{1023}{ADC\ Count} - 1\right) \quad (10)$$

The Steinhart-Hart Equation shown in equation 11 is used to derive a precise temperature of the thermistor.

$$\frac{1}{T} = A + B\ln(R_T) + C\ln(R_T)^3 \quad (11)$$

Where; R_T is the resistance of the thermistor at temperature, T (in Kelvin), A, B, and C are Steinhart model coefficients

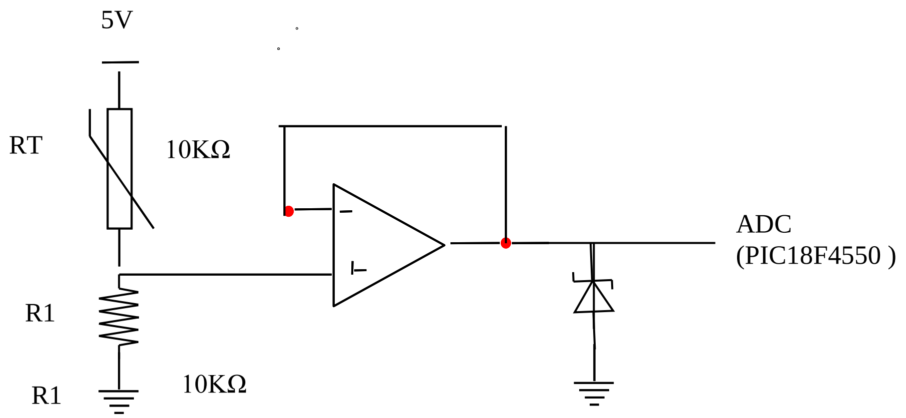

Figure 3: Temperature Sensing Circuit

2.4 Measurement and control system development

A Measurement and Control System device based on PIC18F4550 microcontroller was developed and it is the core of motor monitoring and protection system. The circuit diagram of the developed system is shown in Figure 4, the microcontroller acquires and processes data from sensors, and sends results to Liquid Crystal Display (LCD. The motor is disconnected from the supply and alarm also activated if the set threshold values for temperature, voltage and current are exceeded. The design of Printed Circuit Boards (PCB) and schematic diagram was done using DipTrace software as shown in Figures 5 and 6 respectively

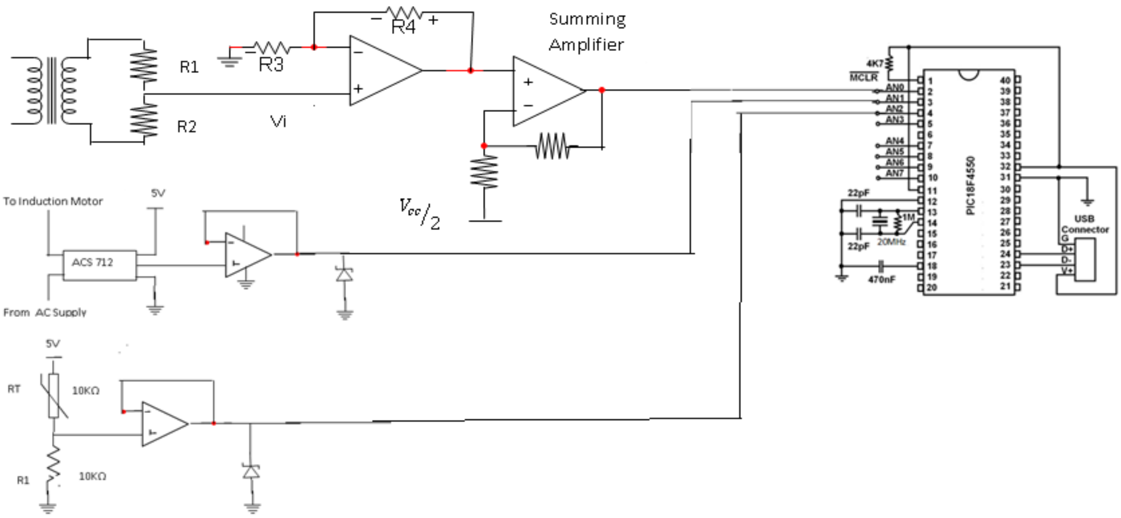

Figure 4: Circuit diagram of the Developed System

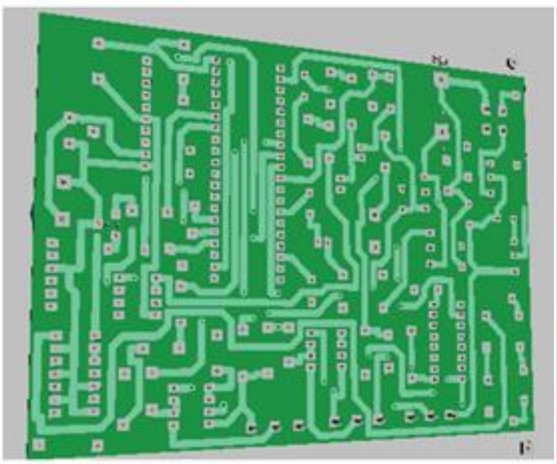

Figure 5: Bottom view of Printed Circuit Board

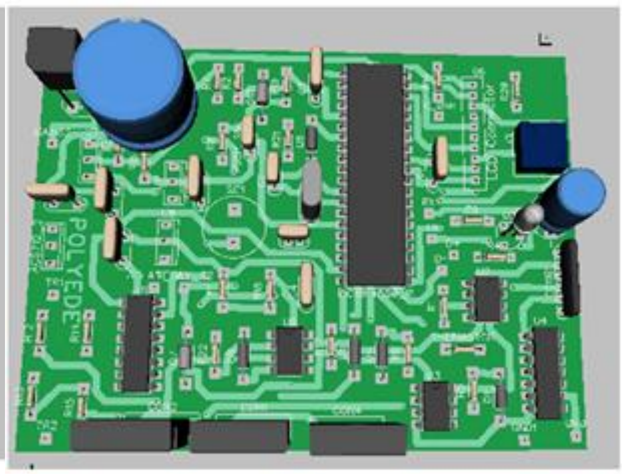

Figure 6: Top view of Printed Circuit Board

3.0 Measurement and Control System Implementation

A powerful voltage, current and temperature monitoring and control system has been achieved for an induction motor using PIC18F4550 microcontroller. The designed system implementation has been carried out using two stages, namely hardware and software implementation. Figure 7 shows the block diagram of system hardware implementation. It consists of several sensor devices and coordinator device. The coordinator device reads sensor measured data which located in induction motor and transmits them to the LCD, mikroC source code for PIC libraries is the software used for data acquisition, conversion, communication and display.

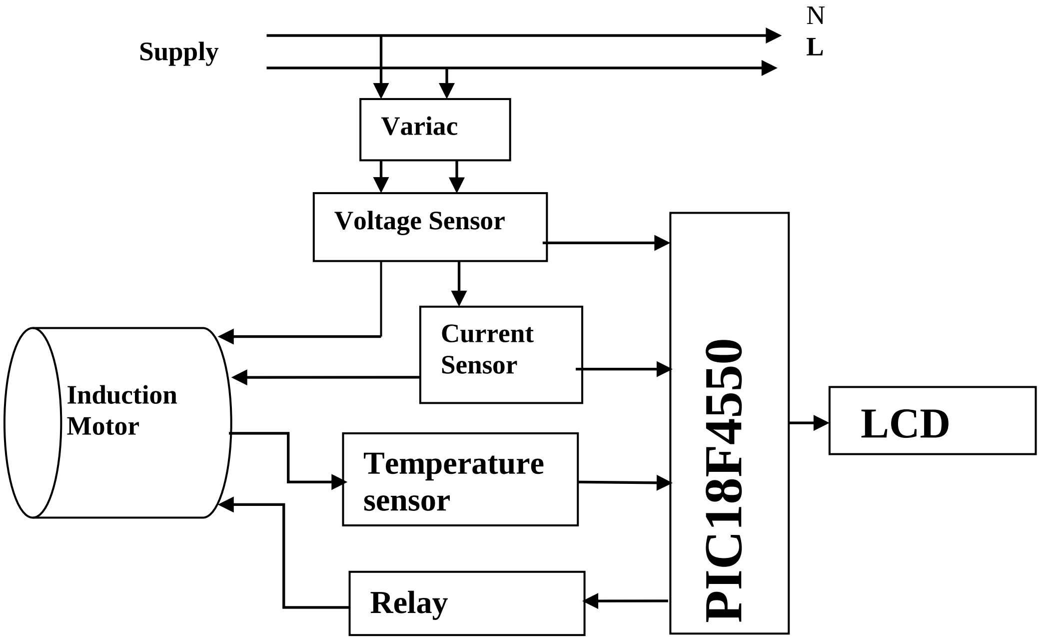

Figure 7: Block diagram of System Implementation

4.0 Testing and Results

Measurement and control system developed permits continuous monitoring and reading of current, temperature and voltage of induction motor by displaying the motor input voltage current, and winding temperature magnitude on LCD. The performance of the developed system was measured by testing it with a 1.5 Hp, 220 V 6.5 A, single phase squirrel cage induction motor, a Variac was used to simulate different voltage level. Table 1 shows the current and temperature measured at 180V after one minute of operation. Table 2 shows the test results at various voltage levels. Table 3 shows the results when the threshold temperature was set at 50^{o}C.

Table 1: Current and temperature measurement results

Time	Motor_Current	Motor Temp/ o C
11:26:15	0.00 A	24.6
11:26:25	5.46 A	25.7
11:26:35	5.46 A	26.4
11:26:45	5.46 A	26.9
11:26:55	5.46 A	27.2
11:27:05	5.53 A	27.6
11:27:15	5.46 A	28.6

Table 2: Voltage Variation measurement results

Maximum Threshold Voltage (V)	Minimum. Threshold Voltage (V)	Supply Voltage (V)	Winding Current (A)	Relay Activation	Alarm Activation	Motor Running
230.00	180.00	175.00	5.40	Yes	Yes	No
230.00	180.00	180.00	5.48	No	No	Yes
230.00	180.00	200.00	6.58	No	No	Yes
230.00	180.00	230.00	8.48	No	No	Yes
230.00	180.00	240.00	9.05	Yes	Yes	No
230.00	180.00	260.00	9.27	Yes	Yes	No

Table 3: Temperature measurement results

Temperature (^{0}C)	Motor running	Alarm Activation
30	Yes	No
50	Yes	No
51	No	Yes

5.0 Conclusion

The developed measuring and monitoring system is simple and robust in design, it is reliable and cost effective. The system gave quick response to changes in monitored parameters. Relay activation when the threshold values are exceeded will improve the performance of the motor. The constant monitoring and measuring can produce data-base for scheduling of the motor servicing, troubleshooting and future reference; this results to an improved motor's lifespan. The system can also be used for on-line condition monitoring and fault diagnosis of induction motor with the incorporated relay and alarm system.

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