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Development of an Induction Motor Parameters Measurement and Monitoring System using Sensor Technology and dsPIC30F4011

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Abstract- Induction motors are popular electro-mechanical devices used in various applications, often regarded as the backbone of the industry. Although their straightforward design and advanced manufacturing technology make them quite sturdy and dependable, they are prone to several faults. The performance, dependability, efficiency, and life cycle of a motor are all greatly impacted by monitoring of its parameters under varied operating conditions. To schedule motor servicing, troubleshooting, automation and for future reference, such parameters should be continuously measured, tracked, and saved. This research entails creating a system that utilizes sensor technologies and the dsPIC30F4011 microcontroller to measure, monitor, and record the temperature, speed, and current of an induction motor during its operation. A three-phase induction motor was used to test the developed hardware system. It was noted that the findings obtained matched the readings from analog meters.

Key words: dsPIC30F4011, Fault, Induction Motor, Measurement, Monitoring, Sensors

1 Introduction

Measuring and tracking an electrical machine's internal parameters under different working settings is frequently highly helpful for determining its performance, efficiency, dependability, and lifespan. Conventional measuring devices, such as meters, are unable to provide continuous measurement, monitoring, and data storage for these parameters (Shubhang and Rajesh, 2011). Therefore, a cost-effective, dependable, and precise hardware system need to be developed that will continuously measure and record the current, speed, and temperature of an induction motor using sensor technology in conjunction with the dsPIC30F4011. This will enable continuous monitoring of the induction motor condition by the operator.

1.1 Causes and effects of Variation in Motor Current, Temperature and Speed

Rotor faults result in changes to rotor resistance and inductance, which alter the stator current (Khalaf et al., 2011). Mechanical problems such as bearing faults in the load attached to an induction motor, results in various rotational frequencies in the stator current, caused by fluctuations in load torque (Erik et al., 2012). A short circuit in the stator winding causes a negative magnetomotive force (MMF), which diminishes the overall MMF in the motor phase. Consequently, the distortion of the net MMF affects the air-gap flux waveform (Neelam and Ratna, 2009), inducing harmonic frequencies within the stator-winding current. Consistent monitoring of stator current is essential for real-time condition assessment and fault detection using a method called "Motor Current Signature Analysis" (MCSA) (Chaitali and Vitthal, 2014).

Electrical stresses include the adverse effects of transient voltage events, as well as failures like turn-to-turn or turn-to-ground issues, and faults such as line-to-line, line-to-ground, or multiphase line-to-ground (Ahmet and Mehmet, 2015). These faults can cause a significant rise in temperature. To protect induction motor stator windings from thermal overload—particularly in cases where motors are frequently started, overloaded, and operated under high inertia with extended starting times—a temperature protection system is crucial (Aleksejs, 2015). Excessive heat can jeopardize the chemical stability of the insulation materials used for stator windings and hasten the aging process. Operating induction motors at voltage and frequency levels different from their nominal values, or experiencing sudden load changes, can result in substantial fluctuations in motor speed. An increase in speed raises the operating temperature and reduces functional horsepower, which ultimately shortens the motor's lifespan (Pari et al., 2017). To analyze the spectrum around the induction motor's fundamental frequency or to detect its envelope, it is essential to measure the speed in order to calculate the slip.

Many industries already utilize measurements for control and protection purposes (Peter et al., 2008). Condition monitoring systems have mainly concentrated on identifying particular failure modes in one of the three key components of induction motors: the stator, rotor, or bearings. Recent studies have increasingly focused on the electrical monitoring of motors, especially the analysis of stator current (Mohamed, 2000). A range of sensors for current, speed, and temperature can be employed to gather data from an induction motor for failure detection purposes.

2 Proposed System

The proposed system includes various components, such as a current sensor, temperature sensors, speed sensors, a dsPIC30F4011-based processor, a PC, an LCD, and the induction motor being tested.

2.1 Current Measurement and Monitoring

Measuring current is crucial for observing the condition of a three-phase induction motor is crucial, as major faults often result in variations in stator current. An ACS712 current sensor was connected in series with one of the motor's phases for testing. The ACS712 is an integrated circuit for current sensing developed by Allegro Microsystems which utilizes Hall Effect technology to measure current. At zero current, the ACS712 outputs a 2.5V analog signal, resulting in an output range of 2.5V to 5V. According to the datasheet, the ACS712 (30A version) delivers a typical sensitivity of 66 mV per ampere, meaning that a voltage of 0.066V corresponds to 1 ampere of current through the load. The relationships between sensor output voltage and current are defined by equations (1) and (2). The circuit configuration is illustrated in Figure 1.

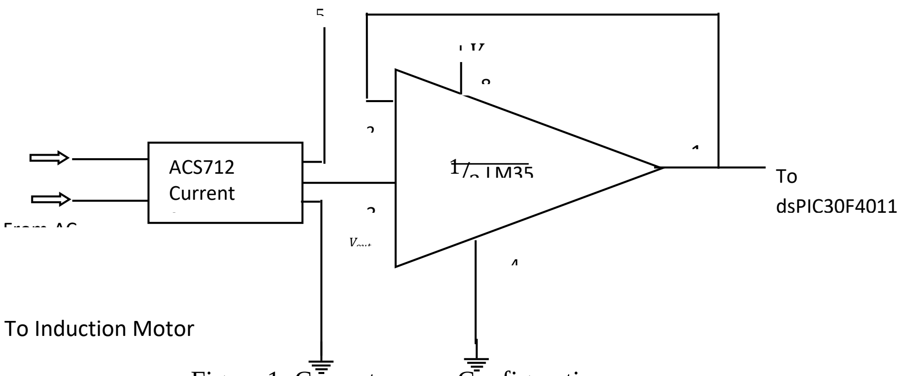


Figure 1: Current sensor Configuration

$$Sensor\ output\ voltage = (0.066 \times current) + 2.5 \qquad (1)$$

$$Current = \frac{(Sensor\ output\ voltage - 2.5)}{0.066} \qquad (2)$$

10 bit analog to digital converter that has value in range of 0-1023 was used; therefore, equation (3) and (4) give the ADC count and current respectively.

$$ADC\ Count = \frac{1023}{v_{cc}}\left(\frac{v_{cc}}{2} + 0.066i\right) \qquad (3)$$

$$i = 0.074(ADC\ Count - 512) \qquad (4)$$

2.2 Temperature Measurement and Monitoring

Stator winding temperature measurement is very important because winding melting is due to the over temperature. When the motor operates for extended periods while under load, it tends to heat up, which decreases its efficiency. To monitor and measure the temperature, a 10 kΩ NTC thermistor was mounted in direct contact with the stator windings of the tested three-phase induction motor. In addition, a 10 kΩ resistor was connected in parallel with the thermistor to create a voltage divider circuit, as illustrated in Figure 2, with its output linked to a digital signal processor.

Equations (5) and (6) are the output voltage and thermistor resistance at a measured temperature respectively.

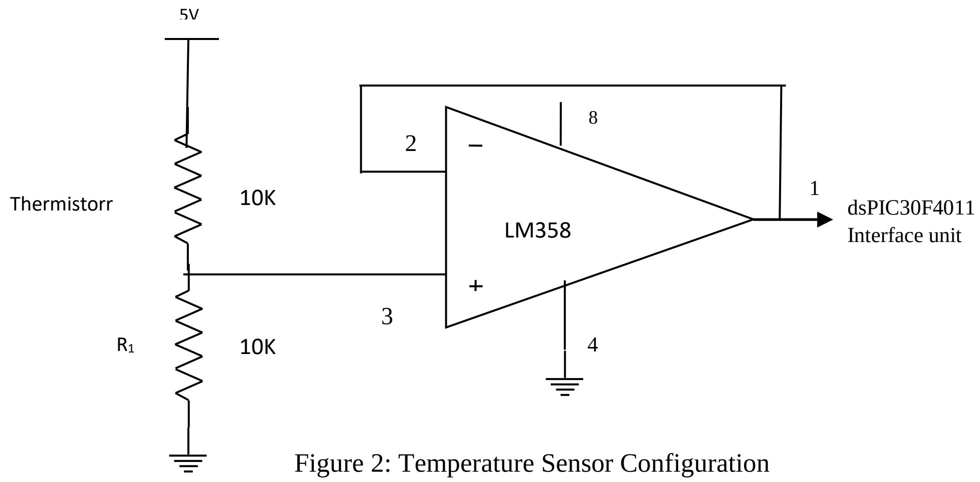


Figure 2: Temperature Sensor Configuration

$$v_{out} = v_{cc}\left(\frac{R_1}{R_T+R_1}\right) \quad (5)$$

$$R_T = R_1\left(\frac{v_{CC}}{v_{out}} - 1\right) \quad (6)$$

Representing voltage as digital within a certain scale, thermistor resistance becomes equation (7).

$$R_T = R_1\left(\frac{D_{max}}{D_{measured}} - 1\right) \quad (7)$$

The Steinhart-Hart Equation shown in equation (8) is used to derive a precise temperature of the thermistor.

$$\frac{1}{T} = A + Bln(R_T) + Cln(R_T)^3 \quad (8)$$

where R_T is the resistance of the thermistor at temperature, T (in kelvins), A, B, and C are Steinhart model coefficients?

2.3 Speed Measurement and Monitoring

Speed measurement is needed in order to determine the slip of the induction machine under test. The rotor speed is measured by mounting the disk of optical encoder on the rotating shaft of the induction motor. Optical encoder used is having 120 slots and resolution of 3 deg per mechanical turn. The output is digital (0-5V) and it is connected to the dsPIC30F4011 system. The induction motor rotor speed is given by equation (9).

$$\omega = \frac{2\pi n}{NT} \quad (9)$$

where T is the sampling period, N is the number of windows on the disk and n is the number of pulses.

3 Hardware Implementation

The implementation of the design was executed in two phases: hardware and software. For the hardware phase, three sensors were utilized, and their corresponding circuit outputs were connected to the dsPIC30F4011, as depicted in Figure 3. The dsPIC30F4011 features a high-speed 10-bit analog-to-digital converter (ADC), enabling the conversion of analog input signals into 10-bit digital values. The ADC transformed the continuous analog output signals from the ACS712 and thermistor into discrete digital values.

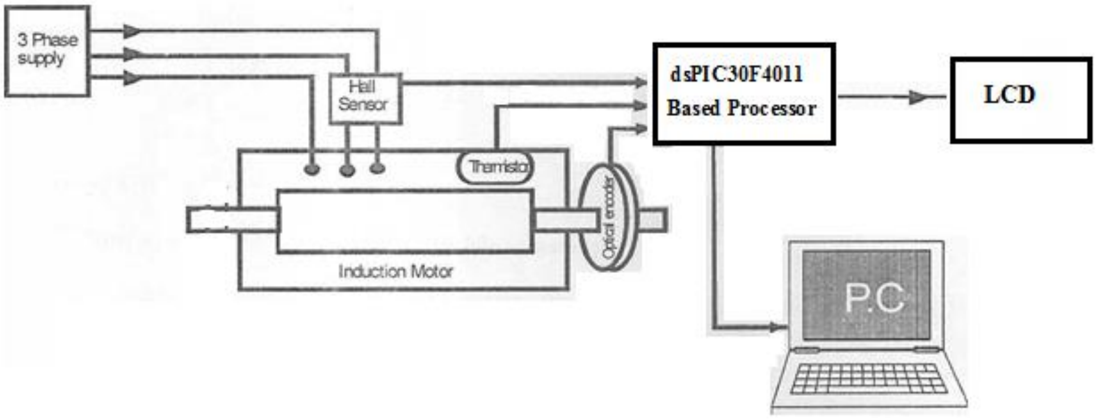
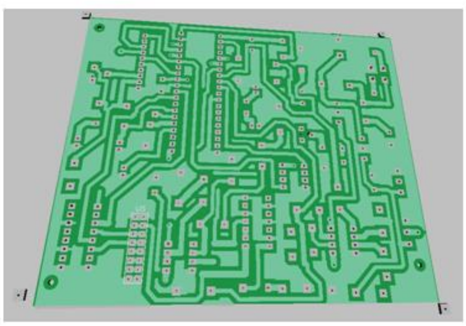


Figure 3: Block diagram of Hardware Implementation

The dsPIC30F4011 was equipped with one megabytes of Random Access Memory (RAM) which allows processing of large data files at acceptable speeds. It also supports unlimited reads and writes to the memory array. An SD memory card is used to store measured data. The RAM used is 24LC1023, manufactured by Microchip. 74HC14 and HC4050 that provides six inverting buffers with Schmitt trigger action are connected between the DSP and output in order to make output signals sharp and jitter free. The resistance of the thermistor varies so greatly and takes on very high resistance at low temperature; therefore, signal is inappropriate for feeding into an ADC without buffering. The LM358, a dual-channel operational amplifier, is employed to buffer the thermistor output and to rectify any output voltage errors. The ACS712 Hall Sensor module measures current levels up to 30 amps, generating a DC output that corresponds to the input AC line current. This DC voltage is subsequently amplified by the LM358 before being sent to the ADC. The dsPIC30F4011 shows the values of the monitored and measured signals on an LCD screen. To facilitate data streaming from the dsPIC30F4011 to a personal computer (PC), a BF-810 USB-to-serial converter was employed, enabling access to the measured values and current waveform.

The design for the PCB and component assembly for the entire hardware has been created using DipTrace software, as illustrated in Figures 4 and 5.



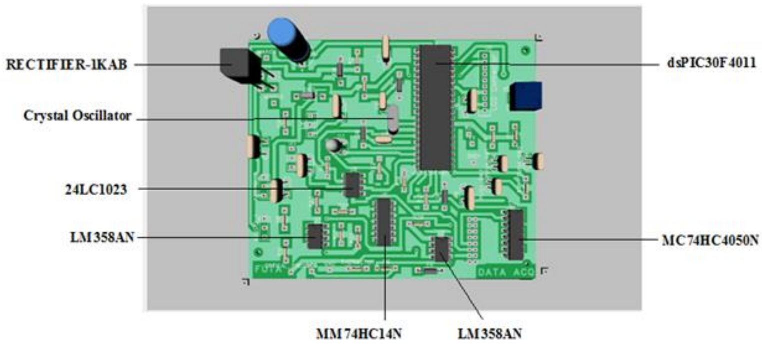


Figure 4: Printed Circuit Board.

Figure 5: Components Assembly.

The algorithm of Cooley-Turkey was used work to perform Fast Fourier Transform (FFT) of stator input current using MATLAB software. This allowed monitoring of stator current spectrum. dsPIC30F4011 monitors, measures, stores and displays the results on LCD and PC. The algorithm for software implementation of the system is given as;

Algorithm

Step 1; Induction motor Start running

Step 2; Initializing the ADC by giving three parameters input.

Step 3; The ADC outputs are given to the dsPIC30F4011 (microcontroller).

Step 4; The dsPIC30F4011 runs the corresponding program using the source code and MATLAB software, storing the results on an SD card while also displaying them on an LCD or transmitting them to a PC.

Step 5; LCD display current, temperature and speed magnitude.

Step 6; PC display current, temperature and speed magnitude and current waveform.

Step 7; End.

4 Results and Discussion

In the proposed system, a graphical user interface (UI) called the motor analyzer has been developed, as depicted in Figure 6. The motor analyzer allows for ongoing tracking and visualization of the induction motor's current, temperature, and speed, highlighting the input current level, rotor speed, and stator temperature. Additionally, the current waveform and its frequency spectrum are monitored online through the motor analyzer.

The dsPIC304011-based system is linked to a 2 hp, 3.1A, 2840 rpm, 415V, three-phase star-connected squirrel cage induction motor. Table 1 presents the results obtained after ten minutes of operation.

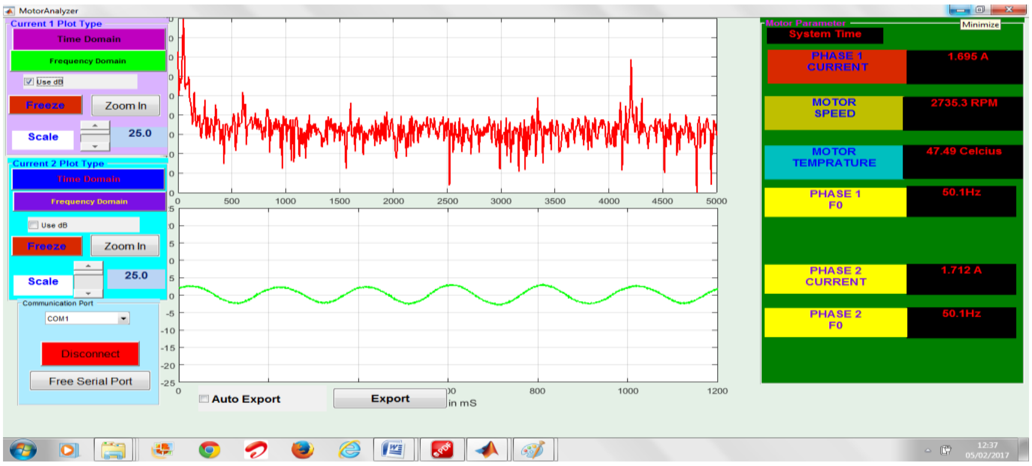


Figure 6: Motor Analyzer Graphic user interface

Table 1: Measured Value Displayed by LCD and Motor Analyzer

Nominal Current (A) $\left(\frac{3.1}{\sqrt{3}}\right)$	Load Current (A)	Rotor Speed (rpm)	Stator Temperature (deg Celsius)
1.790	1.590	2793.5	47.49
1.751	1.581	2758.1	48.52
1.782	1.573	2700.2	46.97
1.776	1.554	2734.3	45.34
1.774	1.582	2744.8	44.97

5 Conclusion

The prototype model based on the dsPIC30F4011 for measurement and monitoring is straightforward in design, dependable, highly adaptable, and economical. It offers a rapid response to changes in monitored parameters. Continuous monitoring, measurement, and data storage can be used to create a database for scheduling motor maintenance, troubleshooting, and future reference, thereby enhancing the motor's lifespan. Moreover, the system enables real-time condition monitoring and fault diagnosis of induction motors via current signature analysis, especially when paired with a relay and alarm system for enhanced protection.

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