Protection System for Industrial Motors using Vibration sensor and Arduino Microcontroller

Jagadiswaran Chelvarajah¹, Ravi Lakshmanan², Sathish Kumar Selvaperumal³

¹,²,³ Faculty of Computing, Engineering and Technology, Asia Pacific University

Corresponding Author Email: jagadis_93@yahoo.com

Abstract. The core aim of this research is to develop a protection system for the industrial motors by analyzing vibration and temperature parameters and to automatically reduce the operating speed of the motor with an alarm indication when the threshold of both the parameters are exceeded. All the algorithms for the functionality along with the GUI of the system is built using LabVIEW. The automated speed control of the system is done by integrating a servo motor with algorithms built which acts based on the output of both the sensing parameters. The maximum speed of the motor is 1300 rpm and based on the testing carried out, it is observed that the speed is successfully reduced upto 500 rpm when with five speed range in between the maximum and minimum speed. The type of motor used in this project is a single phase induction motor. Placement of the vibration is set to be on top of the housing of the motor which provided the highest sensitivity based on testing carried out and the vibration rate generated by the motor operating at maximum rpm on no load was 0.47g where ‘g’ is the unit represented by the vibration sensor for amount of acceleration acted upon the sensor. In a nut shell, the functionality of the system was successfully achieved based on the objectives and overcoming the drawbacks from past research works.

Index Terms: Motors, Protection, Sensor.

1. Introduction

Induction motors operating on AC are the most widely recognized electric motors in industries today. Most common commercial application of induction motors are implemented in fans, washing machines, water pump and industrial applications such as production lines, wind tunnels and winders. [1], [2] Commercial appliances and industrial applications mostly run on single-phase and three-phase induction motors. A three-phase AC motor contains three principle stator windings and works on three-phase AC power. They normally produce large initial torque and which has various range of horsepower depending on the application. Induction motors are preferred today due to their cost effective and sustainability [3]. However, every machinery has their wear and tear components. Various fault detection systems available in the market are mostly very expensive. Thus, various studies [4] have been carried out to invent a cost effective condition monitoring system which is able to alert the user at an early stage fault occurrence. One of the cost effective method is by monitoring the vibration frequency produced by the motor. When the frequency exceeds the normal vibration rate, the alarm alerts the maintenance engineers to troubleshoot the cause of it. In an induction motor, vibrations can be classified into two groups which are magnetic and mechanical respectively. [5] An example of a mechanical fault, oscillatory amplitude of vibration is present which has a beat. This is due to frequency generated by closely positioned components alternately strengthening then cancelling each other, as their comparative phase differs. As for the magnetic fault, when either side of the rotor experiences
balanced forces, motor torque is produced [6]. When the attraction forces are imbalanced, this results to vibration due to the variation of air-gap in magnetic field in the induction motor. If attention is not given to these vibrations at an early stage, this might result to severe damage in the induction motor. [7] The fundamental explanation behind the faults occurred in induction motor are electrical and mechanical strains. Mechanical strains are due to overloads and sudden change in load, which causes fault in bearing and rotor bar. Moreover, the electrical strains produce stator winding short circuits causing complete motor failure. All these faults [8] lead to unusual vibration and heat being produced. Moreover, failure of such components and elements in induction motor can lead to plant shutdown, injuries to people and raw material wastage. Condition monitoring has prevented premature failure. Past researches had implied several methods for rotor bar damage detection such as measuring the temperature, axial flux, speed of rotation, infrared recognition, monitoring Radio Frequency (RF) emission, and acoustic measurement. These methods [9] were found to be invasive, time consuming, costly and less reliable. In some production lines, motors are required to perform on certain speed requirements, both with respect to efficiency of speed control and accordance to economical operation. Unlike AC motors, speed of a DC motor is much simpler to control because the speed of a DC shunt motor can be adjusted with higher efficiency and stable speed regulation, but in an induction motor, the stability of speed regulation and efficiency had to be sacrificed. [10], [11] The purpose of this research is to design a vibration detector which indicates warning and acts a protection system which lowers the speed of the induction motor when there is a presence of vibration which is higher than the ideal frequency till the maintenance engineers arrive to diagnose the fault. The system proposed would consists of vibration sensor, temperature sensor, microcontroller, real time monitoring using GUI, a speed control circuit and a wireless alarming circuit.

The speed of the induction motor is automatically reduced when there is a presence of vibration higher than the ideal rate [12]. This system [13] has an advantage compared to existing protection system because the system does not completely shut down the induction motor which enables the production to continue in a production line until the maintenance engineer troubleshoots the fault. The implementation of TRIAC will be responsible for the speed reduction of the motor. The advantage of TRIAC is, it prevents power loss during reduction of the speed compared to the conventional methods because the firing angle of the TRIAC [14] takes control of the AC voltage before supplying it to the load.

2. Proposed Methodology

2.1. Block Diagram

A SSR relay which is basically a TRIAC embedded with several electronic components was proposed for the automated speed control by sending signals in the form of pulses via digital pin of Arduino. A SSR relay is an ideal electronic relay for switching of high voltage AC with the aid of TRIAC, using a 5V DC supply. Despite being ideal for AC switching, for a speed control, there has to be a constant and rapid switching pulses to reduce and increase the speed of the motor which the SSR relay is unable to produce, which results in lacking during the reduction of the motor speed. This is due to the implementation of optocoupler in the SSR relay which transfers the electrical signal from the DC to the AC circuit via light as the medium. The disadvantage of an optocoupler is the low current transfer ratio which is also affected by the operating temperature. During a high speed switching, the optocoupler tends to heat up resulting to slower signal transfer from one circuit to another. In order to compensate the delay, a TRIAC speed control circuit was constructed with the same operating principle of a SSR relay but replacing the optocoupler with a potentiometer instead, which enables a smother and spontaneous speed control. This is due to the operating principle of the potentiometer which applies Ohms Law where the voltage can be varied by increasing or decreasing the resistance. In order to automate the speed control, a servo motor was connected to the potentiometer via a connecting shaft. The algorithm created in LabVIEW sets the rotation angle of the servo motor based on the output from the vibration sensor and temperature sensor. The modification on the proposed GUI was implemented by removing the RPM meter due to the operating speed of the motor which does not match the compatibility.
of the sensor which can be used with the microcontroller board. Figure. 1 shows the block diagram of the speed control method.

![Block Diagram]

**Figure 1**

### 2.2 Constructional details

This section illustrates the constructional details of the hardware developed and integrated for the system which consists of the constructional details of the speed control circuit, configuration of the microcontroller with sensors as input and the servo motor as output. Figure. 2 illustrates the schematic diagram developed using the Fritzing software for the speed control circuit which is integrated to the industrial motor for speed reduction purposes.

![Schematic Diagram](image)

**Figure 2: Schematic diagram using Fritzing**

As illustrated in Figure. 2 the TRIAC which is basically a bidirectional triode thyristor used in this circuit is a BT 138 which has the maximum operating voltage of 600 volts AC based on the datasheet. The implementation of TRIAC has many advantages in the proposed system since the aim is to reduce the speed of the motor which is basically to be able to take control on the AC supply flowing to the industrial motor. During this operation the TRIAC is able to control the current on both halves of the sine wave of the AC supply and hence improving the power utilization whereas a normal thyristor is only able to control half of the waveform of AC supply.

The first leg of DB3 Diac was connected to the gate terminal which triggers the TRIAC with a minimum current of 0.1 A based on the datasheet. Diac are mostly used in conjunction with TRIAC in order to ensure symmetrical firing. While triggering the TRIAC there will be a slight difference in the two half waves of AC which results to high harmonics being produce which is detrimental in power system. Thus, when the AC flows through the Diac, it stabilizes both halves of the AC waveform before flowing to the gate terminal of TRIAC. The Diac is also responsible for charging time of the capacitor based on its breakdown voltage. When the breakdown voltage is achieved, the Diac triggers the capacitor whereby the second leg of the Diac is connected to the first leg of the capacitor and followed by the anode pin of TRIAC connected to second leg of the capacitor which finally connected to the neutral line of the load. Since the trigger current of a TRIAC is 0.1 A, thus implementation of a capacitor is to ensure the voltage and current harmonics is restricted by the internal impedance of the capacitor while discharging. (Rabisankar et al. 2015) Since the required output current is 0.1 A, thus the value of suitable capacitor to be used can be first found by finding the capacitive reactance using the formula,
VRMS
I_{RMS} = \frac{1}{\sqrt{2}}(2.1) \text{ VRMS}
X_c = \frac{1}{I_{RMS}^2} \text{ (2.2)}
X_c = \frac{2200}{0.4A}
X_c = 2200\Omega
Upon finding the capacitive reactance, the value of the capacitor can be found using the formula,
\begin{align*}
X_c &= \frac{1}{n_f c} \text{ (2.3)}
\end{align*}
\begin{align*}
2200 &= \frac{1}{2\pi \times 50Hz \times c}
\end{align*}
\begin{align*}
2200 &= \frac{2200}{100\pi c}
691428.5714 c = 1
1 = 691428.5714
1 = 1.446 \times 10^{-6}
C = 1.45 \mu F
The cathode terminal off the TRIAC is connected in series with the first leg of the 10K resistor and the live line of the load. This configuration makes a close circuit. Finally a potentiometer with a value of 250K is integrated in the circuit in order to vary the speed of the motor by varying the amount of supply fed to the motor with the aid of TRIAC. The first and second leg of the potentiometer which is known as the slider are connected together and linked to the live line of the supply. This enables the variation of voltage based on the Ohm’s law. The third leg of the potentiometer is then connected in series to the Diac. The configuration of the 10K resistor and the film capacitor also acts a snubber circuit which suppresses the sudden voltage spike in the circuit caused by the inductance in the circuit. This prevents damage to the electronic components while producing an adequate amount of current to the TRIAC. Furthermore, since the circuit is operating on AC, thus, a heat sink was attached on the TRIAC while helps to disperse the heat produced. The circuit was first constructed on a breadboard to ensure there was no errors in the connections and to test the functionality of the circuit. Since the circuit is operating on AC, breadboard is not a suitable base to be used for a long run as it will not be able to withstand the AC voltage passing through it. Thus, upon testing the circuit, it was then converted to a printed circuit board which is also known as PCB. The schematic diagram of the circuit was first converted to a PCB diagram using the PCB wizard software and the actual pcb was produced. Lastly, the servo motor used which has a rotation angle from 0 to 180° was connected to digital pin 2 which reacts upon the output from the temperature and vibration sensor based on the algorithm generated. Since the servo motor was implemented in order to automate the speed control, thus it was assembled to the potentiometer using a connecting shaft. The potentiometer is initially set at maximum which enables the industrial motor to run at the maximum speed. The servo motor on the other hand is set to 180 degrees and finally attached together. The Arduino was powered by a Lithium Polymer battery rated at 11.1V, 2200 mAh which was stepped down to 5 volts using the DC-DC buck converter. This is to ensure the efficient performance of the Arduino microcontroller while
obtaining the values from the sensors and controlling the servo motor. The microcontroller was integrated with the software via serial communication provided in the laptop. Placement of the vibration and temperatures was one of the important element in during construction of the hardware. Based upon several testing and resources from the journals, the vibration sensor was placed on the top surface of the motor in the center part. This is due to the placement of the rotational element such as bearing, shaft and placement of winding located in the middle of the motor. Thus, a better sensitivity can be gained during occurrence of vibration.

The piezo film was insulated with electrical tape at the part where the signal and ground wires are attached. Since the motor is powered by AC, the insulation was essential to prevent any sort of shortcircuiting or interruption to the vibration sensor. The piezo is then placed in the position where the vibration is detected in the ‘thickness’ direction as illustrated in Figure. 3.

2.3 Principle
The working principle of the proposed system is based on the flowchart generated as illustrated in Figure. 4. The flowchart generated includes the conditions set in the programming algorithm for decision making. Before setting the threshold values for the vibration and temperature sensor, the motor is run at maximum speed and the values obtained during normal condition is recorded. Upon obtaining the values, a threshold is set which is described in the programming section. As the system initializes, the sensors acquire the vibration rate and operating temperature of the motor. These readings are real-time monitored on a graphical user interface generated on LabVIEW.

As seen in Figure. 4 three conditions are generated whereby the first condition which is, if the vibration rate exceeds the threshold, the Arduino triggers the servo motor to rotate 90 degrees which is half of the initial position which is 180 degrees. The system continues to the second condition which is, if the temperature is more than the threshold, the servo is triggered to 90 degrees, if the first condition is not met. When both conditions are not met, the system analyzes for the third condition where, if both the temperature and vibration rate exceeds the threshold, the servo is triggered to rotate to 0 degrees. When the servo rotates to 90 degrees, it reduces the speed of the motor by 50 percent since both the potentiometer and servo are attached at its maximum rotation limit whereas when the servo is triggered to rotate to 0 degrees, it completely stops the motor from motion.

If all these three conditions are not met, then the system returns the loop to initializing stage and continues to monitor and analyze the motor based on the condition set. This continuous loop and conditions are briefly described in the programming section. Besides triggering the servo motor, the sensors which communicates with the GUI indicates alarm for each of the conditions met. This creates alert to the user to troubleshoot the motor.
3. Simulation and Hardware Results

Figure 5 illustrates the simulation results displayed on the GUI created in LabVIEW. As soon as the system initializes, the data acquisition process begins and waveforms are generated on the graph plotter based on the vibration acted upon the piezo film. Simultaneously, the reading acquired by the LM35 is displayed in the temperature indicator as well as in numeric form. Two types of data are displayed in the form of numeric...
for the vibration where one represents the vibration rate in unit ‘g’ and the other represented in unit ‘Hz’.

Figure. 6 illustrates the final integration of components for speed control circuit on a PCB board. The final integration of the whole system connected to a single phase induction motor used is illustrated in Figure. 7.

4. Testing Results

4.1 Capacitor rating test for speed control

This test was performed to identify the suitable capacitor value to be attached in the speed control circuit which varies the response sensitivity of speed control. Besides, since the capacitor plays a huge role as a snubber circuit in order to absorb the sudden voltage spikes, it is essential to identify the suitable rating of the capacitor. The type of capacitor tested are all film capacitors which are suitable for AC applications.

Experimental setup

Theoretically, since the capacitor is attached to the gate pin of the TRIAC which functions to trigger the TRIAC with current rating at 0.1A. Based on the calculations performed, the most suitable capacitor rating to be used was 1.5μF. Unfortunately the speed control of the motor was not as smooth as required. Thus, a test was carried out to identify the suitable rating of capacitor to be implemented practically which can produce a stable and smooth speed control.

The circuit was tested on a breadboard by placing 3 capacitors with different ratings one after another and the motor was run with speed varied using the potentiometer. The angle of rotation of the potentiometer was identified by drilling a hole on a protractor and fitting it in between the shaft of the potentiometer as illustrated in Figure. 8. A total of five sample of the angle of rotation of the potentiometer was set as reference. The device used to measure the speed of the motor was a contact type tachometer obtained from the lab.

Figure. 8: Assembly of protractor on the TRIAC circuit
As seen from the Figure. 9, the 0.22μF capacitor enables a wider range of speed control at five different angles. The motor clocks at maximum speed of 1300 RPM when the potentiometer is rotated to 140 degrees which is the highest sampling rate for angle of rotation. The speed of the motor reduced by range of 50 to 150 RPM for each sampling angles which has been set. At the angle of 30 degrees of the potentiometer, the speed of the motor was stably reduced to 550 RPM. The second capacitor tested was the 1.0μF capacitor. Based on the results obtained, the speed of the motor was only varied at 3 different angles and stopped at the forth sampling angle at 70 degrees. The speed reduction ranged from 300 to 500 RPM. The final capacitor tested was the 1.5μF capacitor which produced the same effect as the 1.0μF capacitor. Thus, the most suitable capacitor to be implemented in the circuit was the 0.22μF due to its wide range of speed control which is essential in the proposed system.

4.2 Test for sensitivity based on placement of vibration sensor
Since detection of the vibration was the core element of this project, identifying a proper position for the sensor to be placed is essential due to variation of sensitivity which depends on the position itself. The acceleration of gravity acted upon piezoelectric sensor can be categorized in three which is the measurement from the thickness position, length position and width position as shown in Figure. 10.

Three positions were selected for the testing to be carried out to identify the suitable position which provides the highest vibration sensitivity on the motor. Since the rotational elements and windings of the motor is
located in the center part of the motor, the piezo film was first placed in the center top surface of the motor’s housing. It was attached by taping it using electrical tape. The motor was run at full speed rating at 1300 RPM and the vibration rate produced in the GUI in LabVIEW was observed for a minute to ensure the data is taken when the reading displayed is at minimal fluctuation. The motor is then switched OFF before taping the piezo film on the second position which was the side surface of the motor’s housing. The motor was again run at the maximum speed and data was tabulated. Similarly, the piezo film was taped at the basement of the motor which is the third elected placement, at the center where the motor is attached to the wooden basement using a bolt and screw. The readings displayed for each position were observed in the GUI for a minute before tabulating them.

![Graph of sensitivity of vibration sensor based on placement](image)

Figure 11: Graph of sensitivity of vibration sensor based on placement

Based on the tabulated data, a bar graph was generated to compare the sensitivity of the piezo film while acquiring the vibration rate at three different positions with the motor running at the maximum speed clocked at 1300 RPM. As observed from the graph, the top middle position produced the highest sensitivity reading rated at 0.47g, followed by the basement at 0.30g and the side position at 0.17g. Only one position is chosen for the final placement of the sensor since the objective of the system is to create a protection system which reduces the speed of the motor when an unusual vibration is triggered rather than a vibration analysis system which requires vibration rate from three different axis. Thus, the final placement was chosen as the top center surface for the piezo film to be mounted.

4.3 Test for angle of rotation of potentiometer and servo motor

The TRIAC circuit built contains a potentiometer which is used to vary the speed of the motor. In order to automate the speed control, a servo motor is attached to the potentiometer and it varies the speed based on the output of the vibration and temperature sensor. Since the potentiometer is attached to the servo motor opposite to each other, it is essential to identify the difference between the angle represented by the potentiometer while varied manually using hand and servo motor which is automated via the microcontroller. This enables the synchronization of both the devices rotation angle when attached together.

**Experimental Setup**

The test was first carried out to identify if the automated rotation angle controlled by the microcontroller provides the same reading as displayed on the protractor. In order to execute the test, an algorithm was built in LabVIEW using LIFA with a GUI containing a knob which had angle varying from 0 to 180 degrees. The indicator displays the angle which the servo has rotated when the knob is twisted in the GUI. Then, a protractor was connected to the shaft of the servo motor with a marker which gives the indication of angle while rotating.

When the logic was executed, the angle displayed in the GUI turned out to be the same as the angle displayed on the protractor. This concluded that the precision of the servo motor contained zero error. Since LINX is used as the medium to interface the whole algorithm built in LabVIEW with microcontroller, the input for the servo has to be set in pulses where according to the context help in LabVIEW states, 1500uS of pulses is equivalent to 90 degrees of rotation of the servo motor. Thus, one degree of rotation is equivalent to 16.7uS of pulses.
The second test was carried out to identify the angle of both the devices which falls on the same position when they are rotated. This is because, when both the devices are attached opposite to each other as illustrated in Figure 12, the angle of rotation varies. Thus, five sampling of angle represented by the servo motor were listed down and the opposite angle represented by the potentiometer which falls on the same position as the servo motor was tabulated.

Figure 12: Potentiometer attached to servo motor

Based on the Figure 13, the angle of rotation of both devices are opposite to each other. Thus, in order to reduce the speed of the motor, the angle of the servo motor has to be increased in order to decrease the angle of the potentiometer. For instance, if the speed required is 1050 RPM which can be obtained by setting the angle of the potentiometer at 70 degrees, the servo has to be set to 110 degrees. Hence, based on the conversion done in the experimental setup, the servo motor has to be set at 1835uS of pulses in the LabVIEW algorithm to achieve 110 degrees of rotation.

13: Graph of angle of servo motor vs potentiometer

4.4 Test to measure temperature difference between two measuring mediums

Temperature is one of the parameter which has been set to trigger the speed reduction of the motor besides vibration. Thus, this test is carried out by measuring the operating temperature of the motor using a thermocouple probes on a multi meter which provides an accurate reading which is used as a reference sample to test the accuracy of the LM35 temperature sensor used in this system.

Experimental Setup

The test was carried out by placing the probes of the thermocouple and LM35 side by side on the surface of the motor. Since the LM35 is integrated to the microcontroller, it was first insulated with flexible rubber insulator to cover the legs of LM35 which were exposed. This prevents any sort of short circuit to occur because the motor is operating under AC whereas the microcontroller operates on DC.

The temperature on the motor was first measured before the motor was turned ON at room temperature. The motor was then turned ON and run for 10 minutes and reading from the thermocouple and LM35 displayed in the GUI was tabulated every 2 minutes.
Based on the results tabulated, a graph was generated to compare the difference between temperature measured by the LM35 and temperature measured by multimeter used as a reference, as shown in Figure. 14. An increase of temperature was noticed for an interval of every two minutes while the motor was run at the maximum speed. Both the LM35 and thermocouple on a multi meter were able to display the variation in temperature but the LM35 displayed a lower reading with a difference of two integer compared to the thermocouple.

Considering the automation of trolley navigation, upon several researches and study the idea of implementing a microcontroller based movement was the most user friendly and affordable yet reliable for the implementation. Different methodologies were available ranging from image processing to accelerometer based following mechanism. With minimal adaptations and modifications, by use of limited economical resources, IR transmitters were made use of to identify the different colored junctions.

4.5 Test to measure vibration rate of motor with and without load

This test was carried out to study the characteristics of the vibration generated by the motor when it runs at various speed with and without load. It is essential to study the characteristics of the vibration produced by the motor to be able to set a threshold in the algorithm created in the LabVIEW which reduces the speed of the motor when unusual vibration is being detected.

The piezo film was attached on the top surface of the motor upon finalizing the suitable position in the previous test, using a metal bracket as illustrated in Figure. 16. This ensures the piezo film is not directly exposed to the heat generated by the motor which can affect the reading of vibration since the resistivity of the piezo can be affected by extreme heat applied directly on its surface based on the datasheet.
Experimental Setup
The motor was first run on no load condition with five different speed range varied using potentiometer and the vibration rate produced at each speed was tabulated. During each interval after speed was varied, the reading was tabulated after several minutes when the GUI displays a constant value of vibration without much of a fluctuation. The second test was carried out by attaching a load of 0.5 kg on the shaft of the motor as displayed on Figure. 17, and the same procedure was repeated for data acquisition.

Based on the results, a graph was generated in order to compare the vibration generated by the motor while operating under two different conditions at various speed range, as shown in Figure. 18. Upon analyzing the graph, it was found that the motor produced lesser vibration while operating at no load condition compared to reading acquired while motor was operating with load of 0.5kg attached to the shaft of the motor. Moreover it was found that, as the speed of the motor reduced, the vibration rate did not vary much between with load and no load condition. This significance can be noticed while the motor was operating at speed of 700 and 500 RPM.
5. Conclusion
The project was successfully accomplished by producing a protection system for industrial motors using Arduino and vibration sensor. The functionality of the system was based on the three. The first objective was achieved by implementing vibration sensor to acquire the vibration data from the industrial motor integrated to the LabVIEW to analyze the vibration rate to trigger the speed control system. The second objective was achieved by constructing a TRIAC circuit which acts as the protection unit responsible for automatic reduction of speed of the motor depending on the reading acquired by the vibration and temperature sensor and based on the threshold set to trigger the unit. The speed control was automated with the aid of servo motor which maneuvers based on the algorithm built in LabVIEW. The final objective was achieved by constructing a graphical user interface on LabVIEW for real time condition monitoring of the motor based on two parameters. Moreover, a warning indicator and audio alarming has been implemented to alert the user when there is an unusual condition is being detected in the motor while operating.

References

[1] Chan, B. Ryong, H. Woong, G. Byung, Kim, and J. L. Hyun, “Efficient Wireless Vibration Data Sensing and Signal Processing Technique Based on the Android Platform”, International Journal of Distributed Sensor Networks, p. 1-12, 2016.

[2] J. Chao, P. Agusmian, Ompusunggu, L. Zongchang, D. A. Hossein, Rdakani, P. Fredrik, and L. Jay, “A Vibration-Based Approach for Stator Winding Fault Diagnosis of Induction Motors”, International Journal of Emerging Technology and Advanced Engineering, p. 388-397, 2015.

[3] Himanshu, “Recent Trends of Measurement and Development of Vibration Sensors”, International Journal of Industrial Electronics and Electrical Engineering, p. 47-53, 2016.

[4] S. Madhavendra, O. B. Olvin, Manojguptaa, and R. P. Rajoriaa, “Bearing Fault Monitoring Using CWT Based Vibration Signature”, International Journal of Industrial Electronics and Electrical Engineering, p.234-241, 2016.

[5] Y. U. Manish, and K. S. Ashok, “Real-Time Wireless Vibration Monitoring System Using LabVIEW”, International Journal of Industrial Instrumentation and Control, p. 925-929, 2015. [6] C. Manisha, Nishant, and D. Noor, “Vibration Monitoring of Induction Motor by Using Accelerometer”, International Journal of Scientific Research Engineering & Technology, p. 850-854, 2015. [7] G. S. Maruthi, and H. Vishwanath, “An Experimental Investigation on Broken Rotor Bar in Three Phase Induction Motor by Vibration Signature Analysis using MEMS Accelerometer”, International Journal of Emerging Technology and Advanced Engineering, p. 357-363, 2013.
[8] S. C. Neha, B. S. Ashwini, P. P. Harsha, and S. C. Yugandhara, “Speed Control of Induction Motor using PWM Technique”, International Journal of Engineering Research & Technology, p. 174-179, 2015.

[9] K. Niranjan, P. B. Hima, A. S. Divya, and A. Sravani, “A Novel Implementation of Phase Control Technique for Speed Control of Induction Motor Using Arduino”, International Journal of Emerging Technology and Advanced Engineering, p. 469-473, 2013.

[10] Palpankar, Shraddha, Waghmare, and Shikhewal, “Speed Control of an Induction Motor using Raspberry PI”, International Journal of Innovative Research in Science, Engineering and Technology, p. 7807-7813, 2015.

[11] M. P. Prachi, H. Sanraj, K. Tushar, and Suraj Lekurwale, “Speed Control of Induction Motor Using Triac”, International Journal of Industrial Electronics and Electrical Engineering, p. 36-38, 2015.

[12] Rabisankar, Jayantha, Sushmitha, and Shreyashi, “Automatic Speed Control of Single Phase Induction Motor with the Variation of Ambient Temperature”, International Journal of Scientific and Research Publications, p. 1-4, 2015.

[13] N. Sumit, K. Prasad, and C. Y. Patil, “Fault Detection of Induction Motor Using Current and Vibration Monitoring”, International Journal of Advanced Computer Research, Vol. 3, No. 4, p. 272279, 2013.

S. B. Trupti, S. S. Anushri, S. G. Anushri, U. W. Kaware, and R. K. Dehankar, “Induction Motor Speed Control Using Android Application”, International Journal of Engineering Research and General Science, Vol. 3, p. 140-144, 2012.