



e-ISSN: 2319-8753 | p-ISSN: 2320-6710

IJIRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 10, Issue 4, April 2021

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 7.512



9940 572 462



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Star-Delta Starter using IoT with Monitoring and Performance Analysis of Induction Motor

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ABSTRACT: Mostly, induction motors are used in industries. Owing to its popularity in small scale industries, reliability, robustness, and economy as compared to other starting methods, Star-Delta starters are used here. This report proposes real-time monitoring and control of processes deploying star-delta starter for induction motors and smart sensors interfacing internet communication with the user to maximize safety, security and reliability through high precision automation and control. IoT can be used to automate the process controls [1], service information systems and operator tools using digital controllers, all in order to achieve enhanced productivity and a safe distribution system for better health monitoring and incipient failure detection [2]. Existing approaches of condition monitoring are dependent on expensive special sensors and proprietary software. Monitoring of induction motor plays an important role for motor energy management. Electric motor management is important because it saves energy and reduces operating costs, minimizes downtime and increases productivity. Increasing efficiency also reduces costs. Here, hence, we propose a condition monitoring system for the motor parameters like temperature, speed, vibration and current, utilizing a commonly available motor and IoT module (Arduino) with analysis via MATLAB. This system provides continuous real-time tracking of the motor health and alerts the user before any severe damage occurs.

KEYWORDS: Star-Delta Starter, Induction Motor, IoT, Health Monitoring, Sensors, Automation, Energy Management, MATLAB.

I. INTRODUCTION

Induction motor, especially three-phase induction motor, plays a vital role in the industry due to their advantages over other electrical motors. Therefore, there is a strong demand for their reliable and safe operation. If any fault or failures occur in the motor, it can lead to excessive downtimes and generate great losses in terms of revenue and maintenance. Therefore, an early fault detection is needed for the protection of the motor. In the current scenario, the health monitoring systems of the induction motor are increasing due to its potential to reduce operating costs, enhance the reliability of operation and improve service to the customers. But due to the complexity of the systems, they often require high skilled staff/technicians, maintenance and initial capital costs.

For an induction motor, the starting current can reach 5-10 times the full-load current [3]. To overcome this, star-delta starter is usually used in small scale industries. Initially it operates in star then switches to delta. It is an old and reliable technique used in industries. In this automated era, we require some microcontroller which helps to achieve remote starting of the motor and monitor the performance of induction motor which also enables remote access of data. Additionally, alerting system is required along with monitoring.

Condition monitoring is an important factor in assuring well-being of motors. Existing approaches of condition monitoring are dependent on expensive systems like SCADA, SIMATIC SCADA, ALCARO, etc. This paper also reviews various forms of existing condition monitoring methods and highlights the need for an economical intelligent starting, monitoring and fault diagnosis system. Therefore, an economical remote Star-Delta starter with condition monitoring of induction motor using IOT is proposed. This system not only will help to remote start or stop the motor with desired time delay from user but also will give an economical alternative to present monitoring counterparts being used in the industry. It will prove helpful for small scale industries wherein currently available commercial monitoring won't be feasible.

Energy management is important to judiciously utilize energy and maximize profits along with enhancing a competitive position in the market. In industry, motor systems are responsible for 70% of electricity consumption. These include, for example, material conveying, pumping, fan, refrigeration, and compressed air systems. Improvements of older motor driven systems (MDS) have the potential to save between 10% and 30% of energy consumption and running costs, thus offsetting the investment for highly efficient components within three to five years.

[14]. Energy audits are an important instrument for increasing the efficiency of motor driven systems: An energy audit is a systematic analysis of energy consumption within a defined system in order to evaluate opportunities for improved energy performance. It is therefore an effective instrument to detect optimisation potentials for existing in-service motor driven systems.[13]

The Internet of Things (IoT) is a network of physical objects are embedded with devices, sensor, network connectivity and are provided with unique identifiers and the ability to automatically collect and transfer data over a network without requiring human-to-human or human-to-computer interaction[4][5][6][7]. IoT has evolved from the convergence of wireless technologies, micro-electromechanical systems and the Internet. The internet of things also called an Internet of objects. Online monitoring system for continuous casting equipment is established based on IoT sensing technology and communication technology. The parameters such as voltage, current, speed and torque of induction motor were monitored[8].

Parameter monitoring using various sensors with proper integration of Mobile application and the system via Wi-Fi[9] using Internet of Things (IoT) technology can be done along with contingency alert to the user; if exceeds reference value then automatically motor disconnects and outcome is displayed on monitored values in LCD and mobile application. The proposed idea aims to provide flexible and medium distance connectivity between location of the machine and user by the implementation of IoT. The Internet of Things in automation will increase operational efficiency, lower costs, and improve productivity. The real-time information provided by the IoT and sensors are graphically exhibited continuously by using Blynk IoT. The system has a high independence, less maintenance, simple establishment, least support prices. Test results confirm possibility usage of system.

II. RELATED WORK

The existing star-delta starter has many types like manual switch over and automatic switch over using timers, but there are many disadvantages in the existing system. In manual switch over star-delta starter the connection between the star and delta switch is changed by manual operation by the SPDT (Single Pole Double Throw) switch. In this case the switching between the connection should be when the motor reaches the 35% of the rated speed. But to attain the required speed the timing delay is must. So, it is not possible for manual switch over for changing in precision of time. In the automatic star delta switches the timers are used for accurate switch over between the connection. But the main drawback back of this starter is it cannot handle the load control of the motor, i.e., breaking of the motor supply under overloading or during specific load current condition. This drawback is reduced in the proposed system using microcontrollers. Also, the present starters do not have any temperature and speed monitor in the on-board starter[10].

There are existing systems, which uses Bluetooth Low Energy (BTLE) for sharing the data between main control unit and of sub units which can be more than one unit. BTLE is an emerging wireless technology developed by the Bluetooth Special Interest Group (SIG) for short-range communication. In contrast with previous Bluetooth flavours, BTLE has been designed as a low-power solution for control and monitoring applications. The Advantages of BTLE are low power consumption, low cost and BTLE uses a frequency hopping spread spectrum that is inherently more robust to jamming in RF environment. The disadvantages of BTLE are Covers low area and Wide range control is not possible[11]. The embedment of a microcontroller into the system makes it a standalone system that is capable of taking decisions to keep the system functioning properly [12].

Starting of induction motor by providing low voltage application by using simple conventional star-delta starter provides provision for energy saving by using PLC simulation software but the logic which is developed is much complicated. We have developed starting and condition monitoring by using conventional star-delta-star starter but in effective manner. The proposed system consists by using Arduino software/hardware device, WI-FI module and also. we have developed condition monitoring system for motor which send real time data of motor such as current, speed and temperature to user over the internet which helps to monitor the health of the induction motor[12].

III. METHODOLOGY

The system workflow is depicted via the block diagram shown in Figure 1. The hardware components include- Arduino microcontroller, Relay, SMPS, Contactor, Current sensor, Tilt sensor, Speed sensor and Temperature sensor. In the block diagram, the temperature sensor is connected directly to the Arduino. Temperature sensor will collect data from motor and send it to microcontroller. The microcontroller is interfaced with Wi-Fi module, then temperature can be monitored through the mobile phone application. The speed of the motor is identified using the IR sensor; An IR tag is attached to the motor with the IR sensor perpendicular to it. By the number of times the tag gets counted and the timing of the rotation the speed can be calculated. The speed of the motor thus identified is logged via microcontroller, and it sends data to the mobile phone using Wi-Fi module. Current sensor is used here to monitor the current flow in

each phase, this data is sent to the microcontroller for monitoring purposes. In case the current flow exceeds the rated value or reference value, the motor automatically gets disconnected from the supply. By this way, it is possible for this starter to control circuit at incipient fault stage and monitor accordingly using mobile phone application. Figure 2 shows Hardware Implementation consisting of hardware components that was described above. Three contactors are used to activate the motor. Each contactor is connected to the relay module which gets input from the microcontroller. These contactors are used for main, star and delta connection.

During operation, the Main Contactor (KM3) and the Star Contactor (KM1) are closed initially, and then after a period of time, the star contactor is opened, and then the delta contactor (KM2) is closed. The contactors are actuated with the help of relays which are energized when they receive signal from the microcontroller. The microcontroller receives input from user through mobile application via Wi-Fi module. So, by using the internal timer of the microcontroller, the relay is actuated accordingly. The microcontroller turns either Red or Green LEDs ON/OFF and turns the three relays ON or OFF.

The Star and Delta contactors are electrically interlocked through relay, which is triggered by controller through code. Time delay in seconds is produced through code which is fed into the microcontroller.

In effect, there are four states:

- 1) OFF State: All Contactors are open.
- 2) Star State: The Main and the Star contactors are closed and the delta contactor is open.
- 3) Open State: The Main contactor is closed and the Delta and Star contactors are open. There is voltage on one end of the motor windings, but the other end is open so no current can flow. The motor has a spinning rotor and behaves like a generator.
- 4) Delta State: The Main and the Delta contactors are closed and the Star contactor is open. The motor is connected to full line voltage and full power and torque are available.

Torque of a three-phase induction motor is proportional to flux per stator pole, rotor current and the power factor of the rotor. $T \propto \phi I_2 \cos \phi_2$ OR $T = k \phi I_2 \cos \phi_2$. Measuring parameters like Load torques for different values {Full load, Half Load, quarterly (1/4th) loaded and NO Load} Electromagnetic Torque, Frequency, Voltage, Currents, Real Power and Reactive Power along with Speed can be found out and are used to carry out auditing. The nine main steps of the energy audit methodology for motor driven systems (MDS) are listed below and are described

- Step 1: Acquisition and energy audit planning
- Step 2: Opening meeting
- Step 3: Data collection
- Step 4: Measurement plan
- Step 5: Conducting the site visit
- Step 6: Data analysis
- Step 7: Energy audit reporting
- Step 8: Closing meeting
- Step 9: Connection to energy management and motor policy

The aim is to achieve the most cost-efficient motor systems justified under the respective economic conditions. Induction motors have a high efficiency at rated speed and torque. However, at light loads, motor efficiency decreases dramatically due to an imbalance between the copper and the core losses. Hence, energy saving can be achieved by proper selection of the flux level in the motor [3,4]. The main induction motor losses are usually split into: stator copper losses, rotor copper losses, core (iron) losses, mechanical and stray losses. To improve the motor efficiency, the flux must be reduced, obtaining a balance between copper and core losses. Many traditionally available and new methods for adjusting flux may be used for the same.

Using the star-delta starter system thus proposed for starting, various parameters can be monitored continuously with a facility to alert the user.

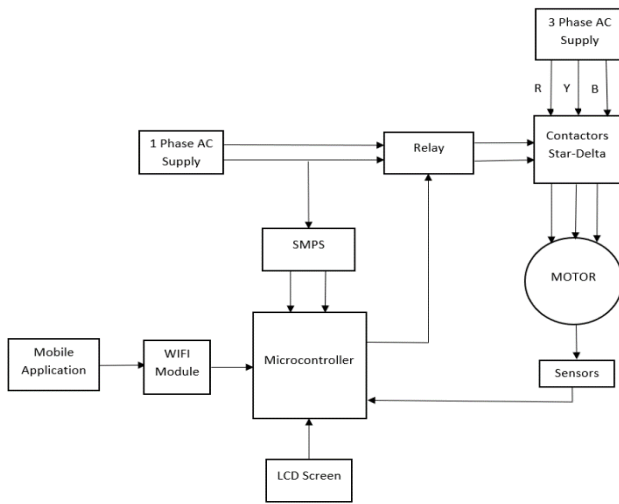


Figure 1. Block Diagram of Star Delta Starter using IoT

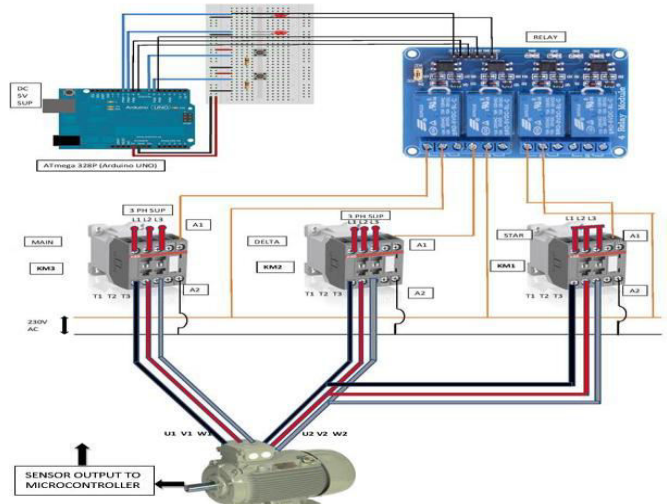


Figure 2. Circuit Diagram of Star Delta Starter using IoT

IV. EXPERIMENTAL RESULTS

The proposed system was analysed in MATLAB Simulink to test and validate. Figure 3 shows various parameters measured in a wye or star connected induction motor. Following figures, namely Figure 3.1 to Figure 3.7, show the measured parameters from the scope output of the MATLAB model of Figure 3.

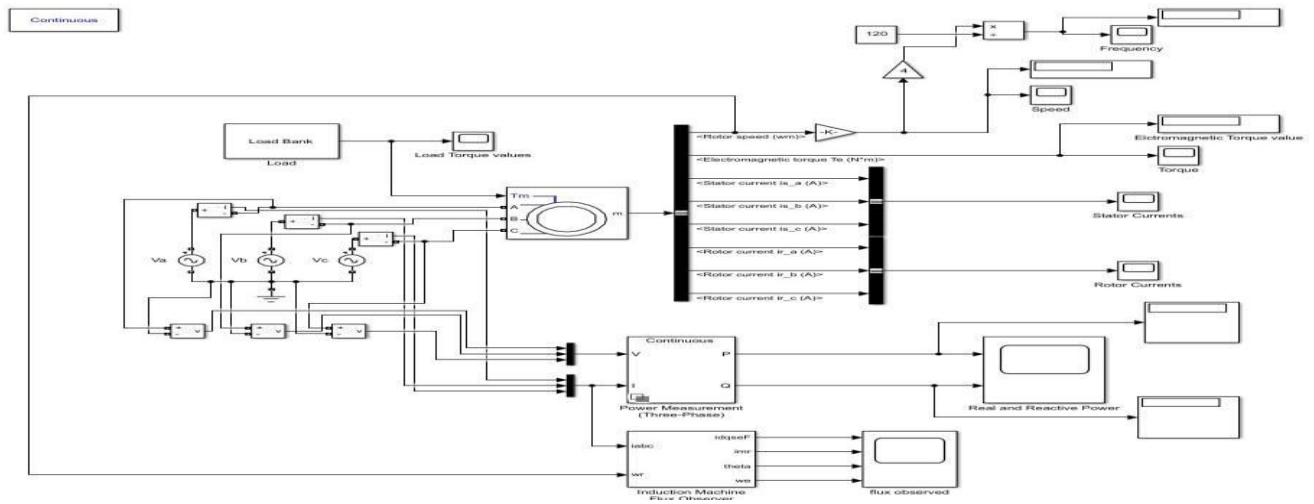


Figure 3. MATLAB Model of Induction Motor for various parameter measurements



Figure 3.1. MATLAB Model Simulink Result – Electromagnetic Torque of Induction Motor

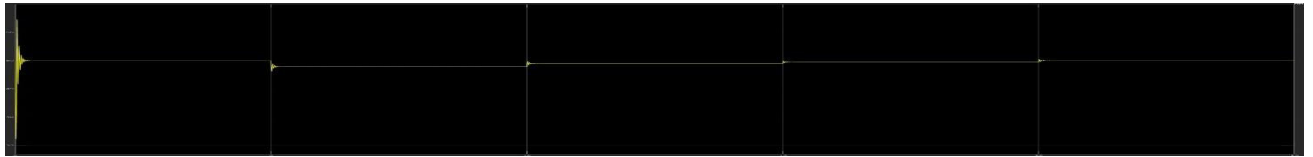


Figure 3.2. MATLAB Model Simulink Result – Rotor Frequency of Induction Motor

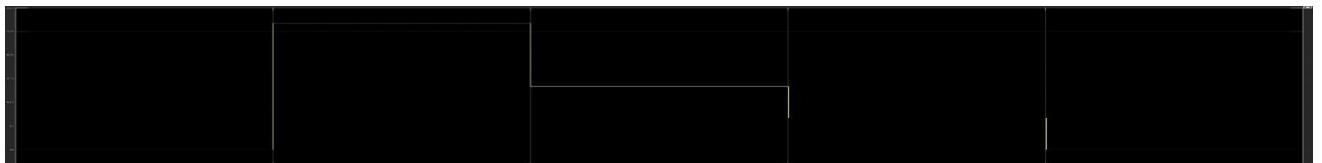


Figure 3.3. MATLAB Model Simulink Result – Load Torque of Induction Motor for different conditions



Figure 3.4. MATLAB Model Simulink Result – Rotor Currents of Induction Motor

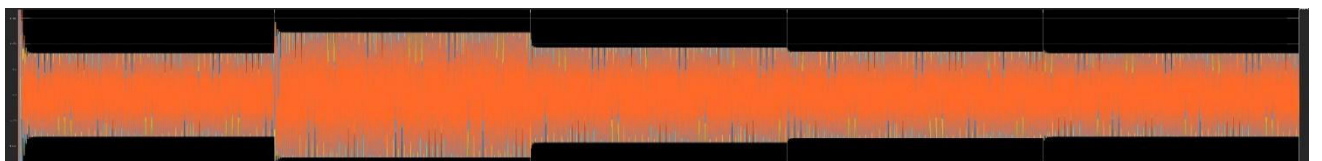


Figure 3.5. MATLAB Model Simulink Result – Stator Currents of Induction Motor

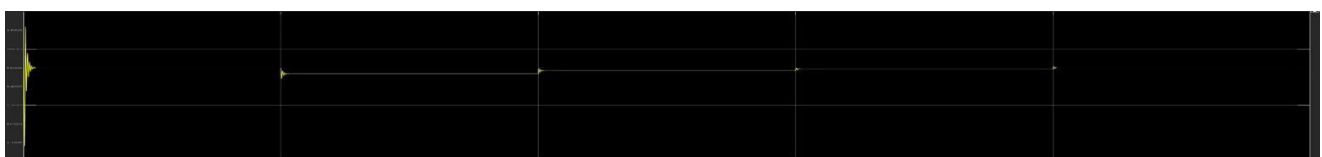


Figure 3.6. MATLAB Model Simulink Result – Rotor Speed of Induction Motor

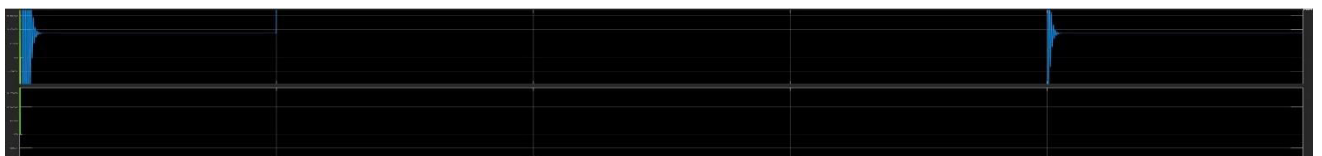


Figure 3.7. MATLAB Model Simulink Result – Real Power and Reactive Power of Induction Motor



Figure 3.8. MATLAB Model Simulink Result – Flux observed of Induction Motor

Now, a MATLAB Model of the Induction Motor using star-delta starting is shown in Figure 4 along with various parameter measured from the scope output. Following figures, namely Figure 4.1 to Figure 3.6, show the measured parameters from the scope output of the MATLAB model of Figure 4. It works using the fundamental principle, to switch from star to delta, after sometime or as soon as synchronous speed is approximately reached.

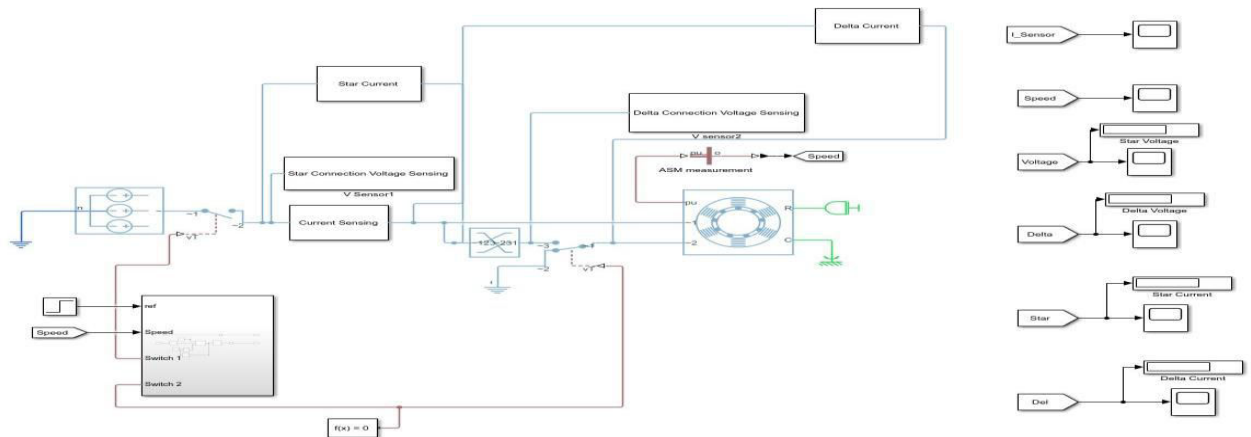


Figure 4. MATLAB Model of Induction Motor using Star-Delta Starter for various parameter measurements

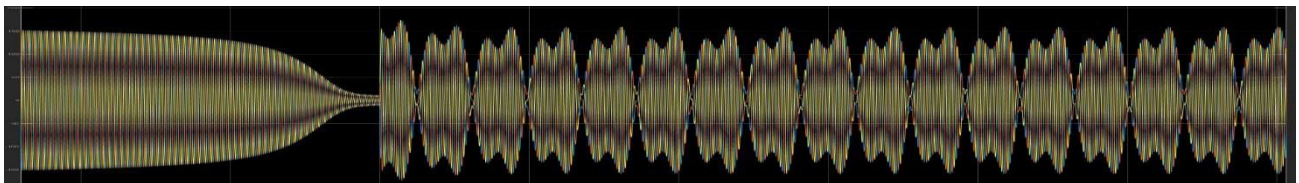


Figure 4.1. MATLAB Model Simulink Result – Current Sensor

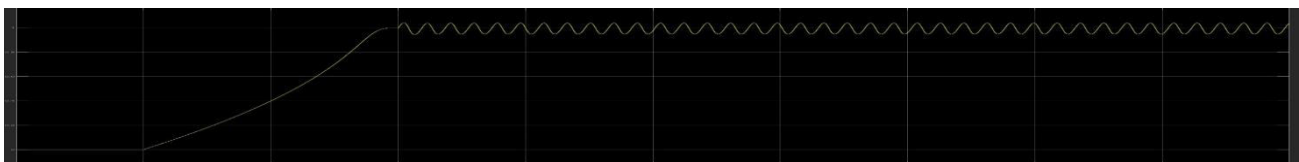


Figure 4.2. MATLAB Model Simulink Result – Speed sensed in Per Unit

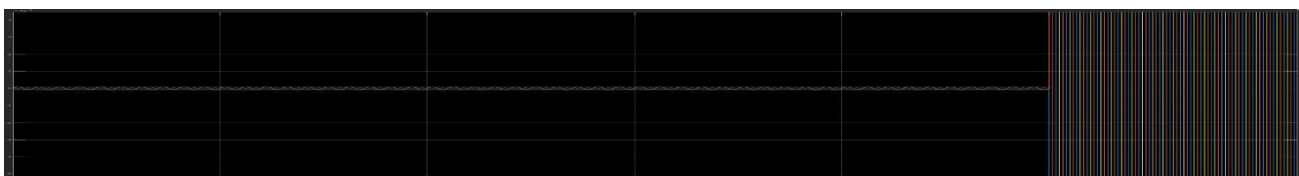


Figure 4.3. MATLAB Model Simulink Result – Star Connection Currents of Induction Motor



Figure 4.4. MATLAB Model Simulink Result – Delta Connection Currents of Induction Motor

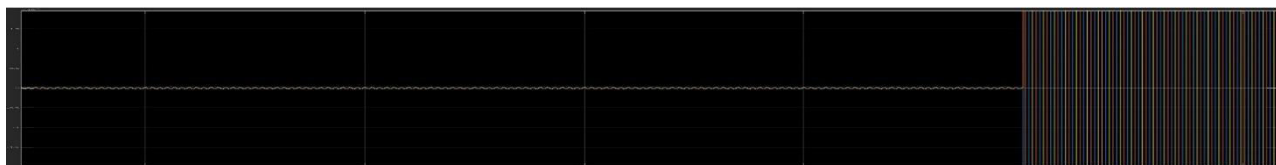


Figure 4.5. MATLAB Model Simulink Result – Star Connection Voltages of Induction Motor

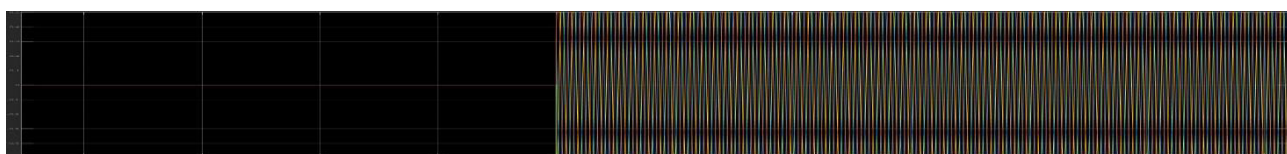


Figure 4.6. MATLAB Model Simulink Result – Delta Connection Voltages of Induction Motor

Using the above obtained parameters, the motor can be monitored using Blynk IoT Platform. It can be seen in the Figure 5(a) how the switching from star to delta can be delayed using simple user interface in the mobile application. Figure 5(b) depicts the monitoring of Induction motor temperature parameter. The same can also be viewed by a user from a desktop computer as shown in Figure 6 below.



(a)



(b)

Figure 5. IoT based Mobile Application (a) remote starting using star-delta starter (b) monitoring of the Induction Motor

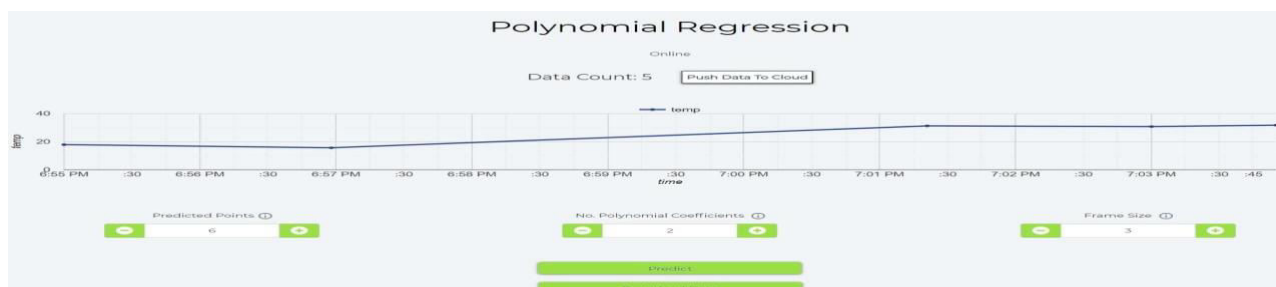


Figure 6. Induction motor monitoring in Desktop Computer

It is easily inferred from the above experimental analysis and simulation that the system proposed for monitoring and analysis can also be used for efficient energy management and auditing based on the utilization and data recorded. Thus, the data can be utilized for current energy performance, annual energy usage, evaluation of various opportunities and

future expansion, which is very vital for energy auditing. On-site energy auditing for measurement planning can be simplified with the help of recorded data analysed continuously via the monitoring system proposed here.

V. CONCLUSION

This paper proposes economic starting of Induction Motor via Star-Delta Starter using IoT with effective monitoring system for increased safety and reliability. Monitoring the motor under various conditions will help in future fault detection at incipient stages and maintenance of the motor with the help of recorded data. Further, the recorded data is useful for targeting potential energy saving opportunities and motor energy management. The proposed system possesses features like remote starting, parameter and health monitoring for speed, current, vibration and temperature. Experimental investigations at various conditions like no-load and full-load conditions were simulated and associated parameters were studied. The results confirmed the viability of this approach. It could be foreseen that this would enhance the reliability and accuracy of the methods used presently. Thus, will improve efficiency and workflow of the system or plant.

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