

## Research Article

# Protection System Design of Induction Motor for Industries

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The fundamental and durable structures of induction motor, as well as their low manufacturing cost, make them popular components in a wide range of current applications. Providing a safety net for employees is a must-have for businesses. This project's motivation for improvement is to provide industrial motors, lift motors, pumps, and so on with safety. An induction motor's primary goal is to protect it from problems, such as single phasing and overheating, as well as other issues. Providing industrial motors, pumps, lift motors, and other similar devices with security is a major motivation behind the emergence of this issue. Any of the three phases missing or the motor temperature above the predetermined threshold causes the motor to stop instantly. Three one-stage transformers are connected to a three-phase power supply in the system. Power will be cut to the transformer circuit if any phase is available. Motors can be turned off by relays sending a signal to the four-pole contactor. As a result, the motor's three-phase power supply has been cut off. Temperature readings are taken from a thermistor (DHT22) that is attached to the motor. At higher temperatures, the three-phase supply will be cut off by a four-pole contactor, and the motor will shut off. This manuscript resolves the uses transformers to solve the problem of single phasing. Also, our project addresses the issue by using microcontroller. It senses all the three phases and decides whether to supply power to induction motor or to disconnect. It deals with the temperature problem, and it uses a thermistor to disconnect the circuitry, whereas in our project, a microcontroller senses the overwhelming temperature and acts accordingly, i.e., give a signal and then move towards disconnection.

## 1. Introduction

It is the most popular type of electric motor utilized in most applications. Due to its lower synchronous speed, it is also known as an induction motor. Consistently fast, rotational speed of a rotating machine determines the magnetic field, while the frequency and number of poles determine the strength of the magnetic field. Due to the stator's revolving magnetic field, which does not match the rotor's magnetic flux, an induction motor's rotational speed is always slower than that of a synchronous motor. The rotor's stator current never approaches the synchronous speed, which is the speed at which the rotor's magnetic field rotates. An induction motor's output power supply determines which type of induction motor it is. Single-phase and three-phase induction motors are among them. Neither single-phase nor three-phase induction motors can be considered autostart-

ing. Double excitations are required to run a machine in the majority of cases. In a DC motor, for example, the stator receives one power supply and the rotor receives another power supply via under the brush arrangement.

*1.1. Principle Operation of Induction Motors.* Induction motors provide only one power source, so to understand how it works would be fascinating. It is a piece of cake because the induction procedure is evident in the name. In fact, it flows through the coil when power is given to the stator windings, resulting in a magnetic flux in the coil. The windings on the rotor are now connected to the rotor itself.

Due to Faraday's law of electromagnetic induction, when the rotor coil is reduced in length, current will begin to flow from the rotor coil. The rotor generates a second current when the first one is flowing. In this case, the stator flux will be 8 and the rotor flux will be behind it, as seen in the

diagram. Thus, the rotor will be rotated in the direction of the rotating magnetic flux by means of a torque. Consequently, it is possible to adjust the rotor's speed by isolating the AC power source. A sort of induction motor is able to operate in a manner similar to this.

There are a number of different types of induction motors to choose from.

## 1.2. Induction Motor Type

*1.2.1. Single-Phase Induction Motor.* It was found that the single-phase induction motor could be broken down into four distinct categories.

- (1) Motors with a split phase induction
- (2) Induction motor with capacitance start
- (3) Starting the induction motor with a capacitor
- (4) Induction motor with a shady pole arrangement

*1.2.2. Three-Phase Induction Motor.* There were two types of three-phase induction motors, each with a distinct characteristic.

- (1) Motor with squirrel cage induction
- (2) Induction motor with solid ring slip

Three-phase induction motors are a type of electric motor. They use electricity to create mechanical work. A three-phase induction motor is the most widely used motor for three-phase AC operation, as this type of motor does not require a starter or can be referred to as a self-starting induction motor.

This motor's essential structural elements will help you better comprehend the three-phase induction motor's operating principles. The motor consists of two parts: a rotor and a stator.

There are multiple slots carved into the stator of a three-phase induction motor so that an AC three-phase power source can be linked to the three-phase wind circuit. To generate a spinning magnetic field, the three-phase winding is inserted into the slot.

A cylindrical laminated core conductor with parallel slots can be mounted on the rotor of a three-stage induction motor's rotor. Heavy copper or aluminum bars that fit into each slot rotate through the end bell as a conductor. Because the slots are not built parallel to the shaft axis, the design decreases the magnetic humming noise and avoids motor failure.

*1.3. Working of Three-Phase Induction Motor.* With a 120-degree electrical angle, the motor stator is made up of overlapping windings. Connecting the primary stator or semi-conductor to a three-phase AC power supply generates an equal-speed spinning magnetic field. In regard to rotation, there is a secret. Electromagnetic fields (EMFs) can affect the pace at which the magnetic flux moves across a circuit. When an unstable motor's rotor winding is closed by an external resistance or by a short circuit straight via end ring,

the revolving magnetic field of the stator is reduced, which results in an EMF being included in the copper rod. Because of this EMF, the rotor generates current. According to the law of the lens, to diminish the cause, i.e., the relative motion between the spinning current and the stationary rotor conductor, the rotor will rotate in the same direction. Accordingly, the rotor speed should not exceed the synchronous speed generated by the stator in a three-phase asynchronous motor, which is based on the concept of functioning. No torque will be generated if the rotors' speeds are the same, as the EMF is not contained in the rotor and the current does not flow. Because of this, the rotor cannot reach the synchronous speed. Stator (synchronous speed) is different from the rotor (the difference is termed slip). An induction motor's magnetic field rotation has the advantage of requiring no electrical connections to the rotor. Single-phase lines with 120-degree phase differences form a three-phase system. Thus, the rotating magnetic field has the same phase difference as the rotor's movement. A, B, and C are three phases, and when phase A is magnetized, the rotor travels to phase A's winding, which in turn magnetizes phase B and finally phase C. Consequently, the rotor keeps on turning. Removal of any phase in a three-phase induction motor will result in a reduction in speed and distorted vibrations. Moreover, a temperature higher than the standard value will result in insulation damage in the winding.

Therefore, the breakdown of the paper is as follows: Section 2 discusses the literature review, and different kinds of fault will be covered in Section 3. Section 4 covers single phasing and overtemperature protection. Further implementation of the proposed system will be discussed in Sections 5 and 6.

## 2. Literature Review

When one phase of the power supply stops working, a three-section induction motor will still run, according to Kersting [1]. If a motor's fuse blows or a protective device is activated, this could happen at the transformer or the feeder end. Single phasing is a dangerous situation for three-phase induction motors; hence, they should be removed from service as soon as possible to prevent overheating. The stator and rotor losses increased tenfold, and the shaft output power plummeted to zero once the phase opens at the step-down transformer or feeder end. Although the losses are doubled compared to steady state losses, when single phasing occurs at motor terminals, the shaft power is reduced by around 70%. All terminals on the motor should be left open to protect it. Sutherland and Short [2] explained that on distribution feeders, 3-phase reclosers are commonly utilized in the event of a single-phase malfunction. Single-phase faults are the most common. Due to the distribution line being used to supply the load to single-phase customers, the other two-phase consumers are negatively affected. Problems arise for the 3-phase industry if three-phase reclosers do not open for the service. Single-phase faults occur 70% of the time, two-phase faults 20% of the time, and three-phase faults 10% of the time.

To guard against the single phasing of a three-phase induction motor, Sudha and Anbalagan [3] devised a strategy. PIC16F877 microcontrollers were utilized to convert the values of each phase into low ac voltage using a transformer during this method. ADC converters are used to transform analogue signals into digital ones. Whenever a fault occurs, the controller opens the close contactor and cuts off the power to it. It does this by repeatedly comparing the digital value to the reference value. If any of the following conditions are met, the 2 kW motor will be isolated: single phasing, under voltage, and over voltage protection. Pillay et al. [4] examine the 3-phase induction motor under the influence of under voltage and over voltage. During a complex industrial system, the voltage at the motor terminals may also exceed the par value and may fall below the nominal value in a severely loaded industrial system. It has been defined differently by IEEE, NEMA, and alternative power organizations. There is no need for a lot of sophisticated algebra in these definitions. This work uses complex algebra to calculate voltage imbalance and compares the results to NEMA standards. According to Faiz et al. [5], unbalanced voltages have a negative impact on the performance of 3-phase induction motors. This document compares the NEMA, IEEE, and IEC (International Electrotechnical Commission) definitions of voltage unbalance. The NEMA, IEEE, and IEC definitions are three times more difficult to calculate than the IEC definitions, according to the study. However, each of the three offers only a plan to correct the imbalance in proportions. When a fault occurs at the distribution transformer or substation feeder, Javed and Izhar [6] have designed the protection of a three-phase induction motor based solely on voltage measurements, which is not sufficient to protect the motor. If a problem occurs at the motor's terminals, voltage testing will keep it safe. There must be a protective device in place for this assessment device to work. They have also suggested a device to measure the phase difference of voltages, because if the fault occurs somewhere other than the motor terminals, the faulted phase can draw negative sequence current and act as a voltage generator. This would allow the phase difference to be determined. As a result, a faulty phase change's phasor dissimilarity cannot be detected with the measuring setup, but the voltage created is close to the line voltage. According to Chattopadhyay et al. [7], the stator current of a three-part induction motor was examined using a variety of methods. An 8085 microprocessors will be used to measure the single phasing using the zero crossing detection approach. Increasing the sampling duration will increase precision. By using a microprocessor, it is possible to measure the phase shift. Any rise or decrease in phase difference is guarded by the shift in the phase of the motor. For the 3-phase motor, Lee [8] explains the effects of imbalanced voltages. All various under- and overvoltage effects have been discussed in detail. Motor efficiency is reduced in the most extreme circumstances of three-phase undervoltage. The power factor and efficiency are affected by both positive and negative sequence voltages. When voltage imbalances are present, NEMA MG1 Standards recommend that a motor's ide rating be increased. Thermal problems were studied by Ransom and Hamilton

[9]. As a result of overheating, the motor's useful life will be reduced. The thermal insulation of a motor is impacted by its operation at low voltage. Depending on the type of starting, different thermal relay settings are required. Numerous disadvantages of electrical machine planning have been outlined by Stone et al. [10]. As a result of international trade, the market will become more competitive among producers. The price of the machine has been decreased by lowering the size of the motor to maintain the same output. Improve W/kg. ratio 14 times in the past. Motors manufactured by leading firms in the previous ten years have also shown an increase in failure rate compared to the past 50 years. Cunkas et al. [11] create an induction motor protection system using the PIC16C84 microcontroller under a variety of situations, such as voltage over- or under- or current overbalance. For this, a potential transformer and a current transformer are used. In the ADC converter, the values from these transformers are converted into digital values. A delay has been added to the tripping circuit. Venkataraman et al. [12] conferred the induction motor's heat protection algorithm. IEEE and EPRI [13–15] studies have demonstrated that motor failure rates are high. Several different types of security measures have been raised. Case studies have been included in the presentation of an overheating protection technique for high inertia loads. It is necessary for the designer of a motor protection system to examine the motor's electrical, mechanical, and physical qualities. Research by Lin et al. [16] center tapped rectifier ZVS convertor. The secondary side of the center-tapped rectifier is used to obtain full-wave rectified output. Stress on the converter is measured in terms of voltage and current. Clamped circuits have long been used to improve the converter's efficiency. Squirrel-cage induction motors can be operated with single-phase power with improved speeds or variable speed exploitation by means of electronic circuits, according to Rashid and Rao et al. [17, 18]. Using NASA's suggested 1978 power factor correction approach, induction motors are highly efficient at low weights. To increase the motor's power factor, phase correction methods and PWM control have been demonstrated for use with a three-phase inverter and three-phase motor. A three-phase induction motor with a zigzag transformer can be run with a single phasing condition, according to the work by Basu and Mukerji [19]. According to this research, a three-phase synchronous motor cannot be started with a negative sequence current because it does not have enough power to do so. A zigzag transformer is recommended for use in this application. Das [20] gave consideration to the induction motor's response to voltage dips. Induction motors are also stable for a fixed period of time with a specific magnitude of voltage dip and should be suitable to put off the trip circuit that can isolate the motor from the supply for putting-off. It is possible to pinpoint the causes and effects of induction motor voltage drop. Induction motors have five different types of protection schemes, each with a different tripping delay for voltage dips of a specified period. Sensor-based three-phase induction motor protection is defined by Bayindir et al. [21]. A comparison has been made between PLC-based and PIC-based protection. The cost-effectiveness of

PLC has been demonstrated. PLC exploitation has done away with the requirement for an ADC card. PLC can be imposed on a wide range of motor types with very minor alterations. According to Kastha and Bose, it was determined that the voltage-fed inverter system for a three-phase induction motor had a number of problems. The PWM inverter system for the induction motor has been described as having a variety of malfunction types. Various sorts of fault probabilities relating to an inverter system fault have been investigated in this article. The inverter system's reliability can be improved by implementing fault tolerance [22]. Maier [23] protected the squirrel cage induction motor and used the instantaneous power for the motor. The starting and running condition protection schemes have been discussed. Short circuits and phase failure were also included in the strategy. Voltage and load variations can cause it to malfunction. Low conduction and switching losses throughout the inverter operation were designed by Kernstock and Plasnegger [24]. To softswitch the MOSFET, a resonance circuit has been employed. The technique has been used in a three-stage inverter so far. Comparing the results of hard and gentle switching has been done. Soft switching implies that there is less conduction and loss during the changeover. Research by Bellini et al. [25] took a look back at the past decade's studies on 3-phase induction motor protection schemes. The investigation of electrical problems, mechanical defects, the signal process for monitoring the induction motor, and the use of artificial intelligence for selection making were all finished in the analysis activity. It has been recommended that the induction motor be thoroughly inspected for safety.

Gomez et al. [26] examine the effect on a three-phase induction motor with a short interruption in power supply and voltage sag. This is the worst case scenario for a three-phase induction motor. Most of the time, induction motors are unaffected by short-term voltage drops. When a noninterfering failure occurs, the motor should not restart since the protection mechanism is not set up correctly. St. Microcontroller control of a nine-level inverter has been laid out by Christopher et al. [27]. Using this method, the overall system cost has been reduced. Microcontroller capabilities reduce the number of components required and result in a system that is both tiny and cost-effective. The head of state of the country, one of the authors [28] proposed the usage of a standby system for the control of VSI. If the primary VSI controller breaks during operation, the system will be more reliable if it has a secondary standby system. The controller has been used on numerous FPGA boards. An error on the primary boards causes the secondary boards to override the primary boards during the traditional manner of communication.

According to Lai et al. [29], the inverter's soft-switching strategy should be defined to break the overvoltage and overcurrent problem. Each phase of this inverter has its own inductor to keep the voltage across the main switch at zero volts. The MOSFET is protected against switching voltage spikes by a variety of procedures. For single- and three-phase inverter MOSFET protection, inductors are described as a means of doing so.

Li et al. [30] probed MOSFET snubber diode gate drive ON resistance loss. To safeguard MOSFETs, a snubber cir-

cuit was designed with low switching losses and only one set of characteristics. A 1kW 230 V motor was used in the experiment. For a better understanding of the inverting process, the sequence step is used to illustrate each step on a single-phase inverter. Journal of the American College of Cardiology, Division of Cardiovascular Diseases Snubbers for the inverter circuit are RCD and RLD. There are three levels of inverter-based inverter snubber circuits. There is a correlation between the outcomes and these snubber circuits. The results show that a circuit without a snubber circuit has multiple switch states; however, the switching is reduced when a snubber circuit is used. MOSFET false triggering and switching losses can be reduced as a result of this. It is the joint work of Hanna and Schmitt [31, 32].

### 3. Methodology

In this project, the primary goal is the development of inexpensive and dependable 3-phase induction motor protection systems. Phase failure, overheating, and SMS alerts should be sent to notify the user of the protection system's failure. We will keep working to make single-phase motor operation even more efficient.

Therefore, these research objectives are as follows:

- (i) Protection mechanisms for three-phase induction motors that are single-phase are designed and built
- (ii) As of right now, mentoring using a single-phase induction motor
- (iii) Building a three-phase induction motor's thermal safety system
- (iv) Actuality temperature monitoring of induction motors

### 4. Different Kinds of Fault

As the industry's workhorse, induction motors are known for their adaptability, toughness, and low production costs. Pulp and paper sector machinery has a failure rate of up to 12 percent for induction machines; this figure is typically 3%. In the workplace, downtime can be costly. Safety, dependability, and motor overheating protection can all be improved using a protection system. It is explained that the external motor is having issues:

- (i) A single phase effect [1]
- (ii) It can cause overheating as well

*4.1. Single-Phase Effect.* When a single-phasing problem occurs while the motor is running, the negative sequence current in the faulty phase heats up the motor winding. Internal connections of the three-phase induction motor make it possible for the two phases to be supplied with power, while the defective phase produces a negative sequence current because they are all coupled to each other. If a single phase failure occurs, it can occur in three different places (Figure 1).

Location 1 fault: opening a primary side of the substation transformer is the first location of the fault.

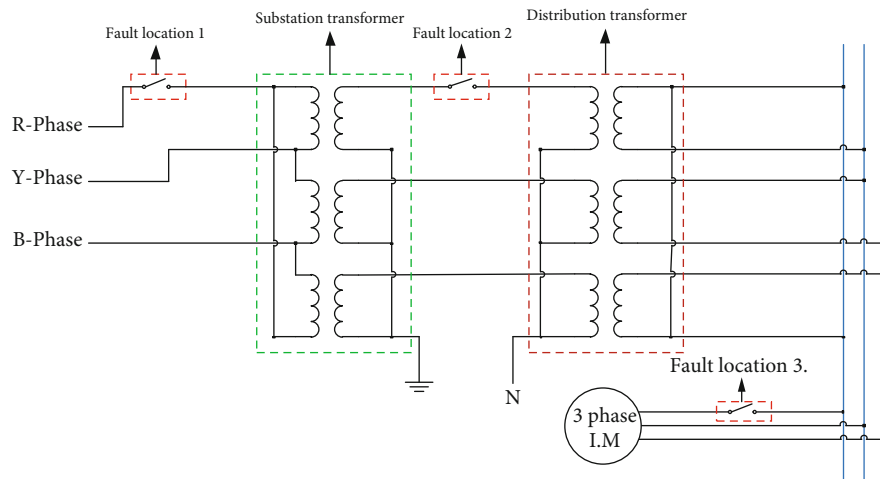


FIGURE 1: Single phasing fault at substation and distribution transformer.

Location 2 fault: the primary side distribution transformers opened phase.

Location 1 fault: the motor terminals have been opened up to allow for one phase [1].

**4.1.1. Opening of the Phase at the Substation or Transformer of Distribution.** There are three areas where a phase open can occur: at the distribution step, transformer, or the feeder end. One hundred times more powerful. Additionally, the shaft's output power is near-null. Single phasing can occur when the motor is running; however, the motor cannot be started under this condition because it is unable to rotate. When the motor is running in this condition, it will quickly overheat and need to be removed from operation. A lockout current of 6-8 times the normal running current will be drawn if an overload protective device is used to disconnect the motor from the main supply while it is in single phasing and if the motor is later attempted to be started while it is still in that condition. The motor will be destroyed. It is worse than unbalanced voltages [3] to have a single phase. A further issue arises for voltage magnitude fault detecting systems at motor terminals when faults occur at the substation or distribution transformer ends. The third phase of the motor will draw the negative sequence current if a fault occurs at either the substation or the distribution transformer, and the torque will be generated by the other two phases if the failure occurs. The faulty phase winding will act as a generator, and the voltage generated is virtually identical to the line voltage [6]. The motor's winding insulation will be irreversibly damaged by the excessive current. Whenever a single phase fault occurs other than the motor terminal, the faulted phase will receive the generated voltage from the other two phases because the three phases are connected. This presents a problem for the voltage sensing protective devices. The voltage generated is virtually equal to the line voltage, thanks to the negative sequence current applied to the third phase. The generated voltage is not in phase, and the phase measurement equipment can detect this. Voltage magnitude sensing is a better option for circuit breakers since it will not trip when there is too much current. There

will therefore be a high current flowing through the motor's three windings, as depicted by the other loads connected to the same phase. The motor windings will be harmed by a large current surge. Single-phase loads connected to the defective phase will not respond to any voltage or current protection device installed there, because the motor is drawing the current needed to power that load, and the voltage is likewise at its nominal level. The faulty phase will disable any protective device that uses voltage and current monitoring at a single-phase load [6]. The current profile will change if any one of these three phasing faults occurs, i.e., at the motor terminals, at the substation end, or at the distribution transformer. That is why with the voltage sensing protection, current sensing protection is more effective. There will be no ground voltage on the secondary windings of a single phase in case of primary faults in a wye-wye transformer. However, in the case of a delta-wye transformer, there will be ground voltages of 58 p.u. for one phase, 1 p.u. for the other two, and 0.58 p.u. for the third. Because of the delta-wye transformer's lower output, all three phases will show voltage, but the second and third phase voltages are reduced. Wye-wye transformers have two phases that are connected in series; however, the faulted phase will be disconnected from the other two. To measure single phasing conditions, a distribution transformer with eye-wye winding is required. It is not possible to accurately assess a delta-wye transformer's phasing state because two of its three secondary windings will indicate 58 p.u. The motor can be protected successfully by using a current and voltage measurement device.

**4.1.2. Phase Opening at Motor Terminals.** There may be less of a problem with the motor terminals than in the previous example. When the phase is opened at the motor terminal, the current increases by two to three times, and the shaft power output drops by roughly 70%. It is imperative that all phases of the transformer be disconnected from the power supply to prevent overheating.

**4.1.3. Basic Protection from Single Phasing.** Unbalanced voltage can have a significant impact on the performance of

motors. Using a negative sequence, stator current creates a local heating of the rotor iron due to a counter-rotating flux field. Compared to a balanced condition, negative sequence currents cause the motor to overheat by 25-30 percent. If you are using a single phase, the suggested protective relay time delay is 4 seconds. When the current imbalance is 40% or more of the nominal amount, the multiline 469 typically trips with a delay of 2 seconds. In a three-phase rectifier, the current in the remaining two phases can increase by up to three times during a single phasing. Controlled rectifier DC drives are susceptible to misfiring SCRs, commutation failures, and other issues. There is a risk of metal oxide surge arresters being damaged by high voltages caused by ferroresonance in transformers because of the capacitance in the cabled line feeding the transformer. Since the single phase fault capacitance power is not entirely dissipated in the transformer core resistance when it happens, ferroresonance also occurs in transformers with low core loss. Ferroresonance can be eliminated by using a wye transformer that is grounded. [2].

*4.1.4. Single Phasing Prevention, Recloser Advantages, and Disadvantages.* Single-phase faults on the distribution transformer can be tripped and allowed to go unnoticed because all three phases are connected to a variety of single-phase and multiphase customers. In the second option, all three phases are closed. As you can see, both of them have their advantages and drawbacks. Even though the single-phase consumer connected to the other two phases will not be disrupted, the three-phase customer will have problems with its three-phase machine if we close one phase. If the main supply is not cut off, the three-phase load will be damaged. On the other hand, if all three phases are closed, then both single-phase and three-phase customers will be without power until the fault is fixed [2].

*4.2. Overloading Effects.* Hot spots can form inside a three-phase induction motor when it is overloaded, potentially exceeding its thermal limits. Overheating can be dangerous if left unchecked for long periods of time. Because the core, conductor mass, and structural members of an induction motor store a substantial amount of heat, even a brief period of overload will not damage the motor's windings [13]. When the rotor is locked in the closed position, the current rises quickly and the motor's other components are not exposed to much heat. Winding insulation can reach its thermal limit in a matter of seconds.

*4.2.1. Design of Polyphase Induction Motor according to NEMA MG1 Standard.* According to NEMA,

- (1) For at least two minutes, the stator current of the induction motor must be capable of withstanding 1.5 times the rated current [13, 14]
- (2) To use an engine designed for one frequency system to another, the horsepower and voltage ratings must be adjusted in accordance with volts/hertz
- (3) In addition, the locked rotor current should be able to sustain the motor for 12 seconds. Continuous

motors are governed by the National Electric Code NEC (NFPA 70-2011), which defines the 125% of the rated current to be tripped. For low and medium voltage motors, there are a variety of NEMA designs to choose from, each with its own set of performance characteristics. The layouts are numbered A through E. A locked rotor current, draw up torque, break down torque, slip and typical applications for poly-phase induction motors are discussed here

*4.2.2. Effect Starting to Prevent Overheating.* Winding insulation breakdown is also influenced by starting an induction motor. Induction motors of medium to large size should be started with lower voltages. Starting current can be reduced by lowering the voltage [15].

Due to its near-identical effect to that of the 50% tap from the primary reactor and autotransformer, wye start is commonly used with motors. Wye starters, however, are significantly less expensive than autotransformers and primary reactors. During start-up, the rotor can become overheated due to the motor's design. To reach its rated speed, the motor must draw more current while starting slowly, which causes it to heat up more quickly. A low voltage may be to blame. When the air gap is closed, all energy that passes through it is converted to heat. The law of conservation of energy dictates this. The heat reduces as the rotor speeds up. When starting a motor, it is important that the voltage is at the correct level, as stated on the motor's nameplate. For example, according to IEEE 620-1996, starting the motor at decreased voltages and running it at reduced voltages for an extended period of time will reach the rated current [9].

*4.3. Maintenance Environmental and Manufacturing Effects*

*4.3.1. Ventilation Effects.* Due to clogged or partially clogged ventilation increasing the temperature of the motor, it is required for the engine to be ventilated. A blocked ventilation system might destroy a tiny motor. Sensors that detect ventilation inadequacies, such as airflow detectors and temperature monitoring devices, can aid with motor protection.

*4.3.2. Effects of Manufacturing.* The machines are presently being manufactured and sold all over the world. As a result, producers now face more competition. This has put designers under pressure to lower the machine's cost. These are a few of the techniques they employ:

Conductor cross section area reduction, insulation thickness reduction, reduction of steel core material, and the development of quick manufacturing procedures to cut labour costs are all examples of how to reduce costs [9, 10].

## 5. Single Phasing and Overtemperature Protection

Overheating occurs when a motor's operating temperature rises above a safe threshold. Motor overloading, distortion in the supply voltage, reduced cooling capacity, unbalanced supply voltages, etc., are all factors that contribute to motor overheating. Problems such as electrical fire, insulation failure, and reduced motor lifespan owing to earlier wear and tear of

the motor windings can all occur as a result of overheating. Therefore, for three-phase induction motors, all three phases of supply must be present, and the motor temperature must be within the permitted range. The motors must be protected from mechanical damage and overheating to extend their service life; hence, phasing protection is essential.

*5.1. Phase Failure.* For three-phase motors to work effectively, they must be linked to a standard voltage. It is possible for the motor to continue to run even if one or more of the phases that power it are disconnected. Phase failure or single phasing is the term for this. Vibrations will continue to occur if one of the three phases of a three-phase motor is lost. In the remaining phases, the current will likewise increase significantly, causing the motor components to overheat inside. The motor will burn out if it is not turned off right away because of the rise in temperature.

Even if the engine is not running, this failure might be hazardous since the engine can start even if only two phases are connected, depending on the load. For an induction motor, a phase failure is never a good thing, and proper precautions should always be taken to avoid it.

#### 5.1.1. Causes of Phase Failure

- (i) One phase of the supply has been cut off
- (ii) One of the motor's power cords has been damaged
- (iii) Vibrations or deterioration of the connection terminals cause them to break
- (iv) Incorrectly tightened connection terminals
- (v) A three-phase circuit breaker has tripped
- (vi) Damaged or rusted starter contactors leave an open phase
- (vii) Relay contacts that have been damaged
- (viii) Awkward security setup

*5.1.2. Effects of Phase Failure.* When the engine is running at a lower RPM, it loses a significant amount of power. The remaining phases' current rises dramatically as a result of the increased reliance on 2 phases for all electricity. Motor windings are unable to tolerate the increased current and heat because of the insulation's failure. A short circuit in the winding occurs when the insulation is compromised, resulting in the motor overheating. Overloading the generator can occur. If the motor is not running at the time of failure, it may not start when needed, and if it does, it will burn up.

*5.1.3. Single Phasing Protection.* When power is supplied to only one phase and the supply voltage is less than the specified value, a single phasing is said to occur. With this voltage, the motor will not start. In order for electric motors to function properly, they require a specified voltage range, and operating them outside of that range will result in damage and reduced lifespan. A well-protected three-phase induction motor system is necessary to withstand any mal-

function. When the voltage goes outside of the range that the motor is intended for, the equipment is instantly disconnected. There are numerous ways to identify and safeguard induction motors. Artificial neural networks and programmable logic controllers (PLCs) are two examples of these systems. Since parametric monitoring using microcontrollers eliminates the use of additional sensors, the goal of this paper is to develop a low-cost and reliable protection system based on microcontrollers. This contrasts with other condition monitoring controls that require specialized tools and sensors that are expensive. Electrical failures can be detected and controlled by this microcontroller-based protection system.

*5.2. Overheating Problem of Electric Motor.* In this section, we will talk about the issue of thermal overloading of electric motors or overheating of electric motors. Overloading is the first thing that comes to mind when we think of engine overheating. Motor overheating occurs as a result of the supply being overloaded mechanically and drawing more current than necessary. Any external mechanical force could cause the rotor of the motor to be mechanically locked, causing the motor to overheat. When the motor is overloaded, it will draw an excessive amount of current from the power source, which might lead to overheating of the electrical motor. Additionally, a low supply voltage might lead to overheating. In order for the motor to maintain the required torque at a lower supply voltage, the motor will demand more current from the mains, resulting in a higher current draw. In addition to thermal overload, single phasing also causes motors to overheat. During a power outage, the remaining two phases take more current to maintain the required load torque, which causes the motor to overheat. Overheating of the motor winding is also caused by an unbalanced supply system, which results in negative sequence current in the stator winding. Again, the motor may overheat if the supply voltage is suddenly lost and then restored. As a result of the sudden loss of supply voltage and the subsequent reestablishment of voltage, the motor is ide-accelerated and consumes more current from the supply because of this. To ensure proper motor thermal overload protection, the motor should be protected against the following conditions: overheating and insulation failure

- (1) Overloading of mechanical systems
- (2) Stall of the motor's gearbox
- (3) Low level of power supply
- (4) Reducing the number of supply phases
- (5) Supply lines that are out of balance
- (6) Rebuilding of the supply voltage after a sudden drop in voltage

Overheating is the most common cause of motor failure, according to an IEEE and EPRI report on industrial motor failures. The causes of motor failure are outlined in Table 1 [13].

*5.2.1. Studies on Reason of Failure by IEEE EPRI.* Cutting-edge technology is reducing the size and power consumption

TABLE 1: Motor failure percentage [13].

IEEE study		EPRI study		Average %
Study name	%	Study name	%	
Electrical related	30.6	Electrical related	36	33
Mechanical related	30.7	Mechanical related	32	31
Abnormal frequency	0.6	Bearing seals	6	
Abnormal voltage	1.5	Frame	3	
High ambient temp.	3	Wedges	1	
Abnormal moisture	5.8	Oil leakage	1	Maintenance, environmental and other related failure reasons
Poor ventilation	3.9	Other components	21	
Abrasive chemicals	4.2			
Other reasons	19.7			
Total	38.7	Total	32	36

of motors. Fiberglass and silicone resins have better dielectric properties than cotton and varnish because of their use. However, they are more susceptible to overheating. Setting the relay's thermal limit correctly can also help keep it from overheating. The thermal limit can be overstated at times. Relay protection systems can be more accurately designed utilizing an algorithm based on a microprocessor or microcontroller.

Protecting the windings of a motor against overheating is called overheating protection. Overloaded motors, bearing seize-ups, and other motor-shaft-locking issues are the most common causes of this overheating. The motor simply will not start, and this can be caused by a bad start in the winding of the motor. The DHT22 sensor is used to monitor the temperature. The 5V supply is connected to this sensor. When the temperature of the winding surpasses a certain threshold, the sensor transmits a signal to a microcontroller [13–15].

## 6. Implementation of Proposed Protection System

Block diagram of the protection technique is given below in Figure 2.

The objective of the dissertation is to protect the three-phase induction motor under single phasing and overtemperature fault.

In this protection technique, we have the following:

- (i) Three step-down transformers
- (ii) Three regulator IC (LM7805)
- (iii) One atmega328p microcontroller
- (iv) Four-pole contactor
- (v) One temperature sensor (DHT22)
- (vi) GSM module (SIM 800L)
- (vii) 5 V supply for Arduino and GSM
- (viii) 9 V battery supply

**6.1. Simulation Model.** Figure 3 below shows the simulation model of Proteus with its various working components. In the figure, we use three-phase supply with three single-phase step-down transformers i220v to i6v and rectify it by using diode, and then, by using LM7805 IC, we get a regulated 5v dc. If 5v is present across the microcontroller terminal, there is no single phasing condition, but if i5v is not present, there is a single phasing fault. iDHT22 temperature sensor senses the temperature of motor, and if it is greater than three limit, then it sends a signal to the microcontroller and the microcontroller sends signal to four-pole contactor through the relay to turn off the motor and alert the user by sending a message through the GSM module.

**6.2. Results of Single Phasing.** If any phase is missing out of 3-phase as shown in the Figure 4, where the open switch represents the phase failure.

As shown in Figure 4, when switch one is open (phase failure condition), then the relay will operate and the phase loss message is displayed on the screen.

**6.3. Results of Temperature.** As shown in Figure 5, if the temperature is greater than the threshold value, the sensor sends the signal to the microcontroller to turn off the supply.

### 6.4. Operation Way

- (1) Press the set button and go on pressing the NC button to increase the critical temperature value of the motor, i.e., 50°C
- (2) We can use the DEC button to decrease the critical temperature value that we have set
- (3) Then, press SET button again
- (4) Press the start/STOP button to start the motor
- (5) If we want to stop the motor, we can press the start/STOP button again
- (6) In Display, we can view the actual temperature and set temperature



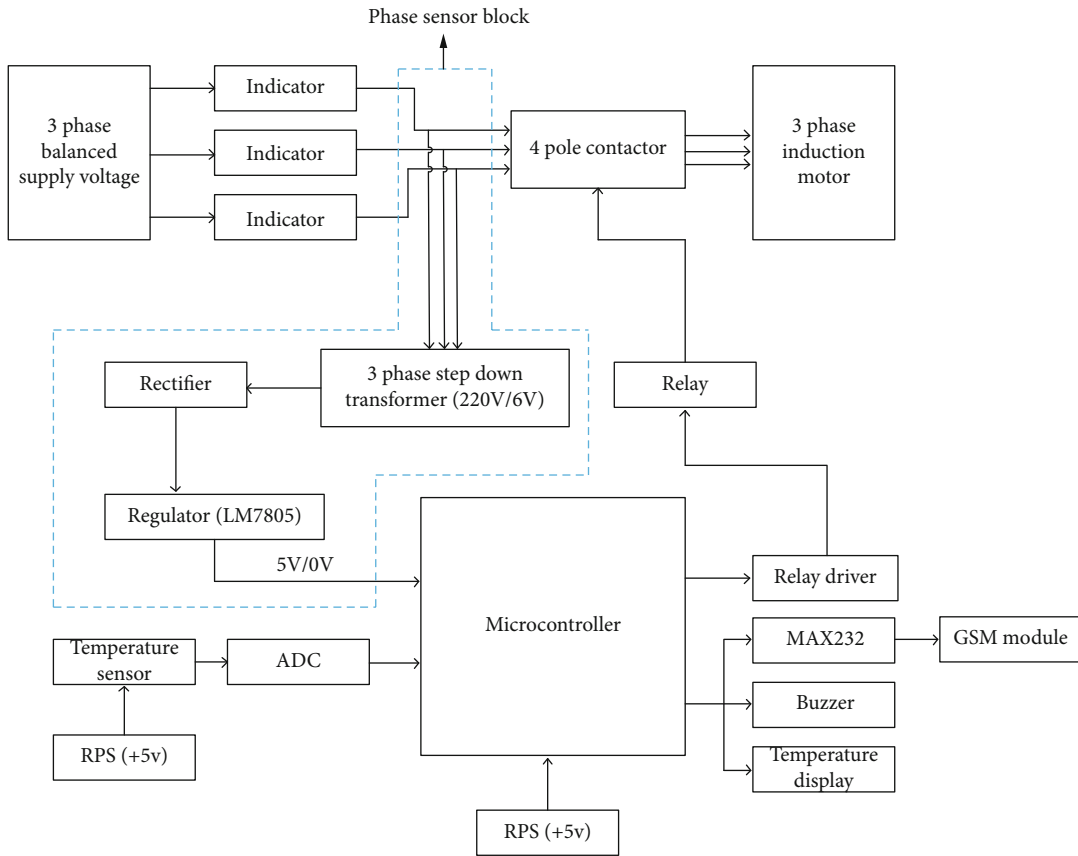


FIGURE 2: Block diagram of the protection technique.

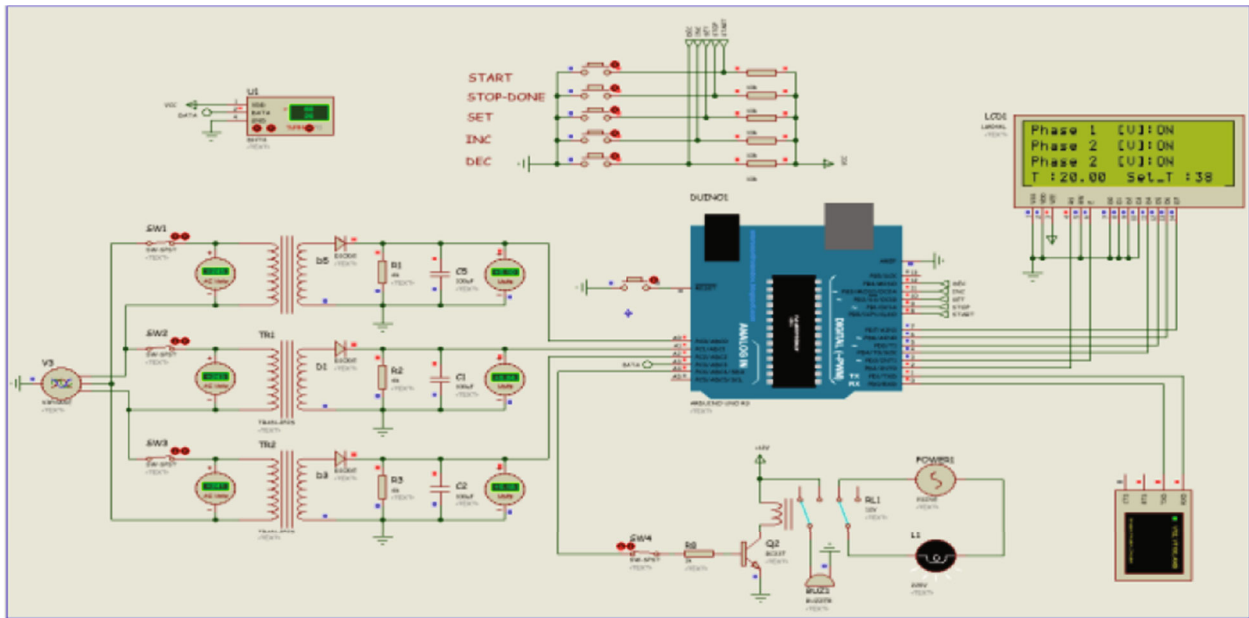


FIGURE 3: Simulation model of single phasing and overtemperature by using Arduino.

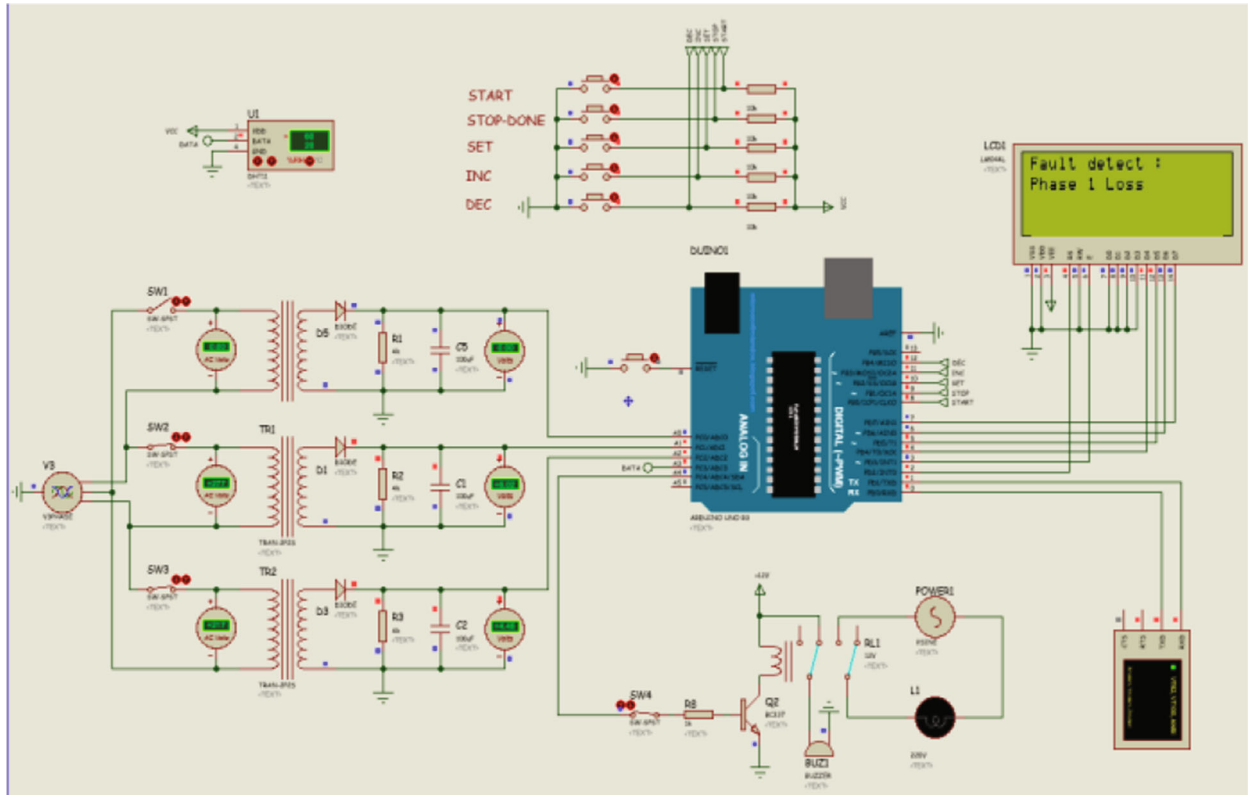


FIGURE 4: Single phasing conditions.

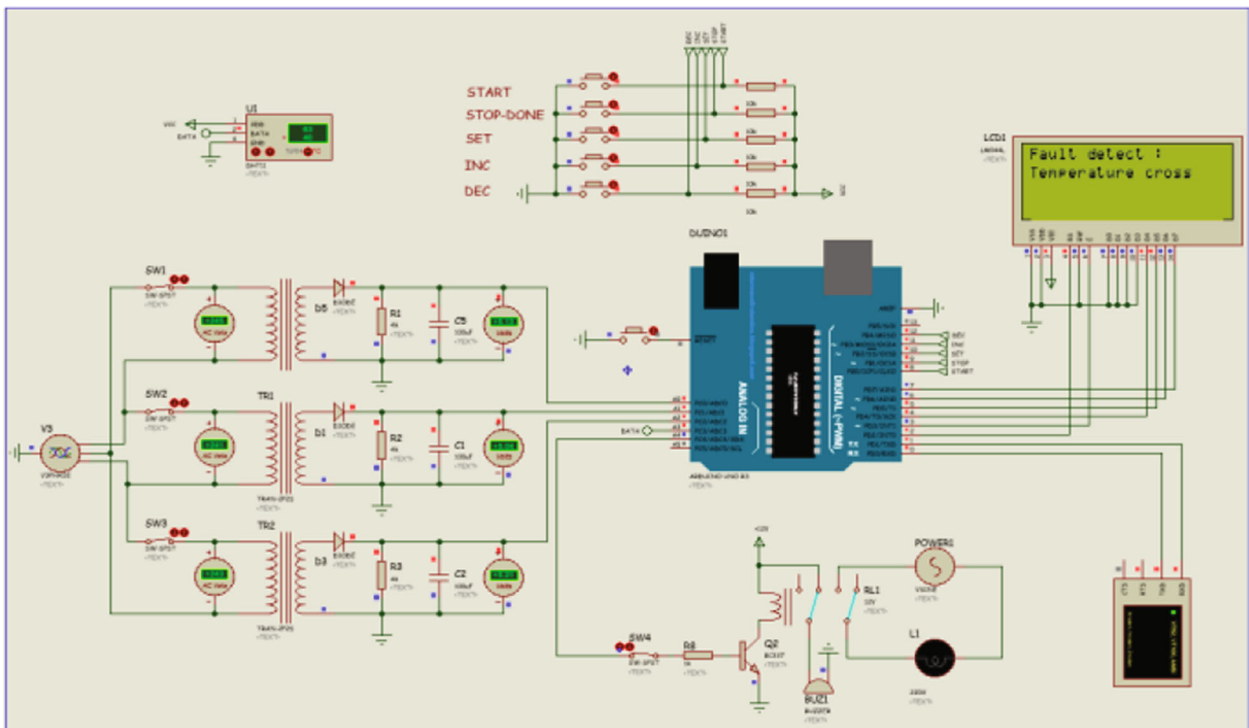


FIGURE 5: Overtemperature condition.

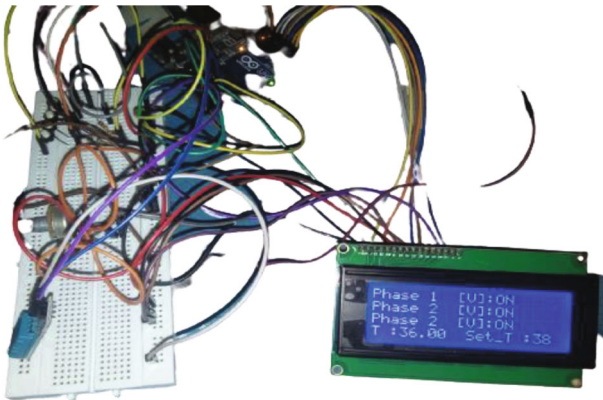


FIGURE 6: Real-time photos of single phasing and overtemperature protection.

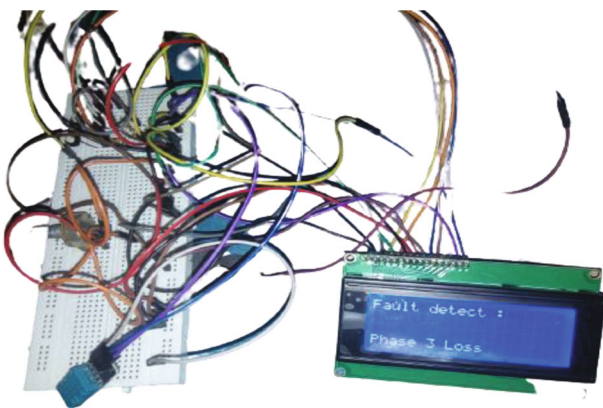


FIGURE 7: Real-time photo of phase failure condition.

- (7) If the actual temperature reaches the set temperature, the contactor trips the motor, and the buzzer is alarmed and sends SMS to the user's mobile
- (8) If anyone of the three phases R, Y, and B fails, the same process happens
- (9) Hence, we can save the motor from damage from single phasing and overheating

6.5. *Experimental Results.* There are so many experiments that were performed on our designed project; the results of the observation are as follows.

6.5.1. *Experiment # 1.* Figure 6 shows real-time photo of single phasing and overtemperature protection, when all three phases are present and temperature in set limit.

6.5.2. *Experiment # 2.* It is when phase 3 is missing; phase failure condition is shown in Figure 7.

When there is missing of any phase, the fault is displayed on the screen and the microcontroller sends the signal to the contactor to turn off the motor.

6.5.3. *Experiment # 3.* It is when the temperature is greater than the threshold value as shown in Figure 8.

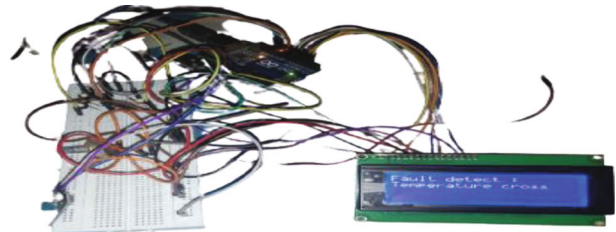


FIGURE 8: Real-time photo of overtemperature condition.



FIGURE 9: Three-phase induction motor running with protection system.

Temperature is displayed continuously on the screen, here the temperature is a digital data, and if the temperature is greater than the limit then the microcontroller sends the signal to the contactor to turn off the motor.

6.5.4. *Experiment # 4.* Three-phase induction motor running with single phasing and overtemperature protection is shown in Figure 9.

## 7. Conclusion

The dissertation focuses on the use of microcontrollers, GSM modules, step-down transformers, and protective relays to safeguard three-phase induction motors operating in single-phase mode. The system is a lot less expensive than the current options on the market. Protecting three-phase induction motors from single-phase, overheating, and SMS alerts can be accomplished utilizing the GSM module in the protection system. With this project, we are able to safeguard the motor from overheating and single phasing during abnormal situations. Whenever an abnormal state is detected, a chime is sounded. Contactors are used to disconnect the motor from the three-phase supply when any of the failures occur. Additionally, the user is alerted through SMS to the single phasing or overheating condition via the GSM modem. Using a microcontroller setting button, the critical temperature of the three-phase load can be set to our specifications and motor rating. Changing the message sent to the user during any abnormal situation is as simple as making a change to the microcontroller programmed.

## Data Availability

The data used to support the findings of this study are included within the article.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

## References

- [1] W. H. Kersting, "Causes and effects of single-phasing induction motors," *IEEE Transactions on Industry Applications*, vol. 41, no. 6, pp. 1499–1505, 2005.
- [2] P. E. Sutherland and T. A. Short, "Effect of single-phase reclosing on industrial loads," in *Conference Record of the 2006 IEEE Industry Applications Conference Forty-First IAS Annual Meeting*, vol. 5, pp. 2636–2644, Tampa, FL, 8–12 Oct. 2006.
- [3] M. Sudha and P. Anbalgan, "A novel protecting method for induction motor against faults due to voltage unbalance and single phasing," in *IECON 2007 - 33rd Annual Conference of the IEEE Industrial Electronics Society*, pp. 1144–1148, Taipei, 2007.
- [4] P. Pillay, P. Hofmann, and M. Manyage, "Derating of induction motors operating with a combination of unbalanced voltages and over or undervoltages," *IEEE Transactions on Energy Conversion*, vol. 17, no. 4, pp. 485–491, 2002.
- [5] J. Faiz, H. Ebrahimpour, and P. Pillay, "Influence of unbalanced voltage on the steady-state performance of a three-phase squirrel-cage induction motor," *IEEE Transactions on Energy Conversion*, vol. 19, no. 4, pp. 657–662, 2004.
- [6] A. Javed and T. Izhar, "An improved method for the detection of phase failure faults in poly phase Induction machines," in *2009 Third International Conference on Electrical Engineering*, pp. 1–6, Lahore, 9–11 April 2009.
- [7] S. Chattopadhyay, A. Chattopadhyaya, and S. Sengupta, "Analysis of stator current of induction motor used in transport system at single phasing by measuring phase angle, symmetrical components, skewness, kurtosis and harmonic distortion in park plane," *IET Electrical Systems in Transportation*, vol. 4, no. 1, pp. 1–8, 2014.
- [8] C.-Y. Lee, "Effects of unbalanced voltage on the operation performance of a three-phase induction motor," *IEEE Transactions on Energy Conversion*, vol. 14, no. 2, pp. 202–208, 1999.
- [9] D. L. Ransom and R. Hamilton, "Extending motor life with updated thermal model overload protection," *IEEE Transactions on Industry Application*, vol. 49, no. 6, pp. 2471–2477, 2013.
- [10] G. C. Stone, M. Sasic, D. Dunn, and I. Culbert, "Recent problems experienced with motor and generator windings," in *2009 Record of Conference Papers - Industry Applications Society 56th Annual Petroleum and Chemical Industry Conference*, pp. 1–9, Anaheim, CA USA, 14–16 Sept. 2009.
- [11] M. Cunkas, R. Akkaya, and A. Ozturk, "Protection of AC motors by means of microcontrollers," in *2000 10th Mediterranean Electrotechnical Conference. Information Technology and Electrotechnology for the Mediterranean Countries. Proceedings. MeleCon 2000 (Cat. No.00CH37099)*, vol. 3, pp. 1093–1096, Lemesos, Cyprus, May 2000.
- [12] B. Venkataraman, B. Godsey, W. Premerlani, E. Shulman, M. Thaku, and R. Midence, "Fundamentals of a motor thermal model and its applications in motor protection," in *58th Annual Conference for Protective Relay Engineers, 2005*, p. 127, College Station, TX, USA, April 2005.
- [13] IEEEguide for AC motor protection, "IEEE Std C37.96-2012," pp. 1–160, 2013.
- [14] A. H. Bonnett and G. C. Soukup, "NEMA motor-generator standards for three-phase induction motors," *IEEE industry applications magazine*, vol. 5, no. 3, pp. 49–63, 1999.
- [15] "IEEE guide for the presentation of thermal limit curves for squirrel cage induction machines," in *IEEE Std 620-1996*, IEEE, 1996.
- [16] B. R. Lin, S. C. Tsay, and C. S. Yang, "Analysis and implementation of ZVS forward converter with centre-tapped rectifier," *Proceedings Electric Power Applications*, vol. 153, no. 5, pp. 642–652, 2006.
- [17] M. H. Rashid, *Power Electronics Circuits Devices and Applications*, Pearson, 3rd edition edition, 2011.
- [18] G. S. Rao, S. Ananthi, and K. Padmanabhan, "Phase balancing of 3- $\phi$  motors running on single phase using electronic variable speed circuit," in *7th IEEE conference on industrial electronics and applications, ICIEA 2012*, pp. 34–39, Singapore, July 2012.
- [19] K. P. Basu and S. K. Mukerji, "Experimental investigation into operation under single-phasing condition of a three-phase induction motor connected across a zigzag transformer," *IEEE Transactions on Education*, vol. 47, no. 3, pp. 365–368, 2004.
- [20] J. C. Das, "Effects of momentary voltage dips on the operation of induction and synchronous motors," *IEEE Transactions on Industry Applications*, vol. 26, no. 4, pp. 711–718, 1990.
- [21] R. Bayindir, I. Sefa, I. Colak, and A. Bektas, "Fault detection and protection of induction motors using sensors," *IEEE Transactions on Energy Conversion*, vol. 23, no. 3, pp. 734–741, 2008.
- [22] D. K. Kastha and B. K. Bose, "Investigation of fault modes of voltage-fed inverter system for induction motor drive," *IEEE Transactions on Industry Applications*, vol. 30, no. 4, pp. 1028–1038, 1994.
- [23] R. Maier, "Protection of squirrel-cage induction motor utilizing instantaneous power and phase information," *IEEE Transactions On Industry Application*, vol. 28, no. 2, pp. 376–380, 1992.
- [24] H. Kernstock and B. Plassnegger, "High efficiency soft switched 3-level MOSFET inverter for an electric vehicle PMSM drive," in *15th international power Electronicsand motion control conference, EPE/PEMC, 2012*, pp. DS1b.9-1–DS1b.9-5, Novi Sad, Serbia, 4–6 sept. 2012.
- [25] A. Bellini, F. Filippetti, C. Tassoni, and G. A. Capolino, "Advances in diagnostic techniques for induction machines," *IEEE Transactions on Industrial Electronics*, vol. 55, no. 12, pp. 4109–4126, 2008.
- [26] J. C. Gomez, M. M. Morcos, C. A. Reineri, and G. N. Campetelli, "Behavior of induction motor due to voltage sags and short interruptions," *IEEE Transactions on Power Delivery*, vol. 17, no. 2, pp. 434–440, 2002.
- [27] I. W. Christopher, J. Parthiban, B. Saravanan, R. Kumar, S. Pallavan, and R. Ramesh, "Microcontroller based single-phase simplified nine-level inverter fed induction motor," in *IEEE 5th India international conference on power electronics (IICPE)*, pp. 1–6, Delhi, India, 6–8 Dec. 2012.
- [28] A. L. Julian, G. Oriti, and S. T. Blevins, "Operating standby redundant controller to improve voltage-source inverter reliability," *IEEE Transactions on Industry Applications*, vol. 46, no. 5, pp. 2008–2014, 2010.

- [29] J. S. Lai, R. W. Young, G. W. Ott, C. P. White, J. W. McKeever, and D. Chen, "A novel resonant snubber based soft-switching inverter," in *Tenth Annual Applied Power Electronics Conference and Exposition, 1995 APEC '95*, vol. 2, pp. 797–803, Dallas, TX, 5-9 Mar 1995.
- [30] T.-h. Li, J.-j. Wang, and H. S.-H. Chung, "An investigation into the effects of the gate drive resistance on the losses of the MOSFET-snubber-diode configuration," in *IEEE Energy Conversion Congress and Exposition (ECCE)*, pp. 362–369, Atlanta, CA, Sept. 2010.
- [31] J. Al-Nasseir, C. Weindl, and G. Herold, "Dual-inductive snubber circuit design for three-level inverter," in *European conference on power electronics and applications, 2007*, pp. 1–10, Aalborg, sept. 2007.
- [32] R. Hanna and D. W. Schmitt, "Failure analysis of 7500 HP induction motors driving reciprocating compressors with three years service," in *57th Annual Petroleum and Chemical Industry Conference (PCIC), 2010*, pp. 1–6, San Antonio, TX, 20-22 Sept. 2010.