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Research Article

Monitoring and Controlling a Single-phase Induction Motor using Arduino Uno Technology

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Abstract

Although current motors are designed near saturation points for improved core material use, ancient motors had robust designs. Increasing the V/Hz ratio causes air gap flux saturation, which causes motor heating and, in turn, insulation breakdown, which causes the electric motor winding to burn. To prevent overheating, some motors use thermistors and thermal overload protection. The motor windings can burn out because the time it takes to utilize the bimetallic strip technique to shut off the power supply is sufficient to do so. The project's goals were to connect the ATmega328P to the current sensor, voltage sensor, and motor relay that controls the induction motor. It also aimed to design software for the ATmega328P that processed input signals from the ACS712CTR-30A-T current and voltage sensors to generate the desired output signal.

Keywords: Single-phase Induction Motor; Artificial Intelligence; Arduino Uno Technology

Introduction

In many sectors, the AC electric motor is a required and indispensable source of power [1]. An induction motor is an electric motor in which the magnetic field of the stator winding is used to electromagnetically induct the electric current into the rotor, which is necessary to produce torque. According to [1,2], the main advantages of induction motors include dependability, low cost, and ease of production. Due to their robust programming single-segment and three-phase induction machines are particularly popular in the industries [3,4]. Because induction motors are the most frequently used motor for home appliances, induction control, and automation, they are strong, durable, and reliable [5,6]. The induction motor typically has under-voltage, over-voltage problems, and overheating problems. These electrical issues cause the motor's winding to heat up, which leads to insulation failure and shortens the motor's lifespan. Overvoltage, which causes the induction motor to overheat, occurs when it is provided with more voltage than it can handle. The motor cannot start when the supplied voltage is under voltage, which is lower than the rated voltage.

Induction motor longevity is greatly influenced by how safe they are. Small-scale businesses cannot afford to provide pricey protection for the drives that are in use because doing so will increase their capital worth. As a result, a low-cost, small-footprint design has been implemented to protect induction motors from under-voltage, overvoltage, undercurrent, and overcurrent. The harm caused by induction cars in small-scale companies needs to be resolved due to the low quality of the energy. To ensure continuous operation and functioning, it is crucial to safeguard them against flaws along the process. While there are numerous parameter controlling and monitoring solutions available for various types of systems, the induction device's controlling and monitoring due to their expensive setup costs and practical limitations, structures aren't employed very often. An Arduino-based device is utilized to overcome the limitations in monitoring and controlling, making it simple and affordable [7]. Induction motors have unique management and parameter estimation strategies, although the best partial results were found. It is controlled by gathering data on the stator flux and motor speed. As a result, the induction motor safety system based on Arduino is practical and can be accurately implemented for use in business automation.

Literature Review

This literature covers the faults in induction motors, artificial intelligence techniques, and Arduino technology.

Faults in induction motor

Electrical and mechanical problems that develop in an electrical system might have an impact on it. Overloading, overheating, and other problems may result from the flaws. The machine displays a variety of symptoms and behaviors for each fault incidence. Induction motor faults can be divided into the following categories.

Electrical faults: Unbalanced supply voltage or current, single-phasing, under or overvoltage of current, reverse phase sequence, earth fault, overload, inter-turn short-circuit fault, and crawling are a few examples of electrical defects [8,9]. Mechanical faults: Broken rotor bars, mass imbalances, air gap eccentricities, bearing damage, rotor winding failure, and stator winding failure are a few examples of mechanical problems [10,11]. Environmental faults: The performance of the induction motor is also impacted by some environmental factors and these include the surrounding temperature, outside dampness, and machine vibrations brought on by installation and foundation issues [12,13]. Induction motors are widely used in various industrial applications due to their reliability, efficiency, and simplicity. However, they are not immune to faults, which can cause significant downtime, reduced productivity, and increased maintenance costs. Common faults in induction motors include bearing failures [14]; winding faults [15]; rotor faults [16]; stator faults [17] and thermal faults [18]. These faults can be caused by various factors such as mechanical wear and tear, electrical overload, and poor maintenance. Early detection of these faults is crucial to prevent catastrophic failures and reduce maintenance costs.

Artificial intelligence technique

Artificial intelligence (AI) techniques have been increasingly used in recent years to improve the detection and diagnosis of faults in induction motors. Some common AI techniques used include neural networks [19]; support vector machines [20]; decision trees [21] and fuzzy logic [22]. These techniques have been used to analyze data from various sensors, including vibration sensors, temperature sensors, and current sensors, to detect faults in induction motors. AI-based systems can provide accurate and real-time fault detection, which can help reduce downtime and improve overall system efficiency.

The most widely used motors, particularly in industry, are induction motors because of their dependability and simplicity [23]. Throughout operation, these motors encounter a variety of defects and engineers have struggled with the essential challenge of protecting these motors. Protective relays were utilized to keep an eye on these defects and to shut off the engine if necessary. Power system equipment is protected against defects like induction motor faults using protective relays [24]. Because of their increased flexibility, improved reliability, quick reaction times, and economic viability, microprocessor-based protective relays have largely supplanted conventional protective relays based on electromechanical and solid state devices. The idea of artificial intelligence (AI) originated from the premise of implementing human intelligence in a computer, thus it can carry out the same kinds of tasks that characterize human thought processes [25,26]. These methods can handle nonlinear issues and deal with enormous amounts of data; after training, they can create a model for the forecasting of fresh data. Numerous fields, including engineering, economics, medicine, and the military, have used AI approaches.

Arduino technology

The Arduino platform is known for its simplicity, flexibility, and ease of use, making it an attractive option for developing embedded systems. Arduino boards can be used to interface with various sensors and actuators, making them suitable for a wide range of applications. In the context of induction motor fault detection and diagnosis, Arduino technology has been used to develop low-cost and scalable systems that can detect faults in real time. Researchers have used Arduino boards to develop vibration-based fault detection systems [27] and temperature-based fault detection systems [28].

Arduino Uno microcontroller board is an open-source platform for creating electronics projects that are entirely based on the ATmega328P, Chasokela., *et al*. (2022). It contains 6 analog inputs, a sixteen MHz quartz crystal, a USB connection, a strength jack, an ICSP header, and a reset button. It also has 14 virtual input/output pins, of which 6 can be used as PWM outputs. Everything required to sustain the microcontroller is contained in it. It is obvious how to power it with an AC-to-DC adapter, a battery, or a USB connection to a computer. One can experiment with your UNO without worrying too much about making a mistake; in the worst case, you could replace the chip for a few dollars and start over. The word “Uno” means “one” in Italian, and it was chosen to signify the launch of Arduino Software 1. zero. The Uno board and Arduino software 1. zero were the foundational versions of Arduino, which have since grown into more recent editions. The Uno board is the first in a line of USB Arduino forums and the standard version of the Arduino platform. The Arduino index of boards has a comprehensive list of all current, previous, and obsolete boards.

Experimental set up of a single phase induction motor using arduino technology

The design that involves monitoring and managing the induction motor’s AC voltage and current consumption. Additionally, the project’s hardware and software components were configured. The system model’s hardware consists of an Arduino Uno, current and voltage sensors, a 16x2 LCD, a relay, and an NPN resistor. This project will make use of the Proteus software development tool. Proteus is an all-inclusive platform for product development, from idea to finished design. Its benefits include automatic PCB layout and wiring, intelligent principle layout, hybrid circuit simulation and accurate analysis, single-chip software debugging, and single-chip and peripheral circuit co-simulation. Proteus Design Suite for simulation and Arduino IDE for programming are two pieces of software that are needed. The system prototype is described in detail and is given illustrations and the suggested system was shown using a block diagram, circuit diagram, and hardware connections.

Block diagram of a single-phase induction motor using Arduino Uno technology

Figure 1 shows the block diagram of the main components that make up the system and how they are interconnected.

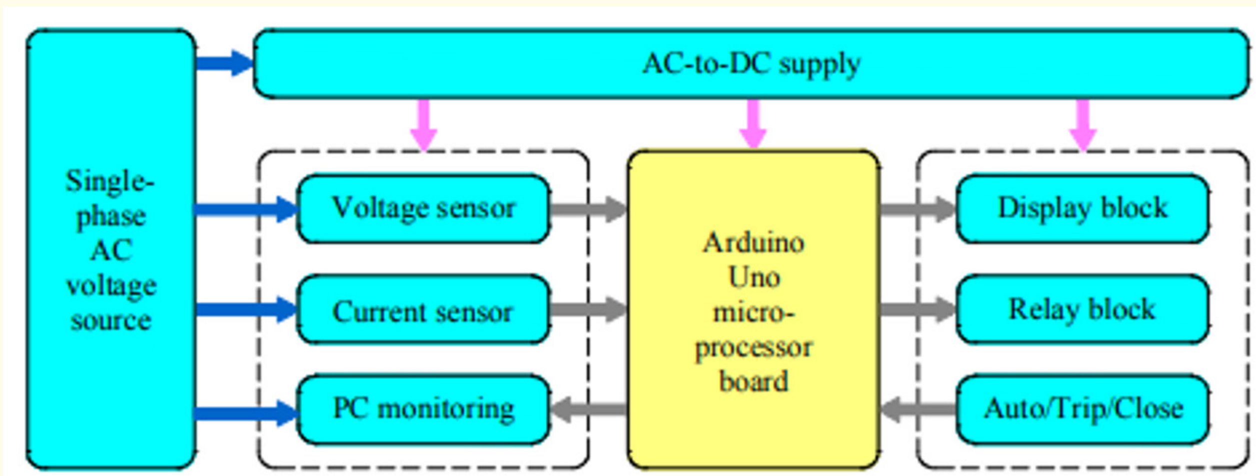

Figure 1: Block diagram of a Single-phase induction motor using Arduino Uno technology.
Source: Designed by Chasokela., *et al.* 2024.

Working principle

The proposed motor protection system's overall block diagram is displayed in Figure 1. A microcontroller board called the Arduino Uno block is based on the ATmega328P. Relative measuring circuits are represented by voltage and current measuring circuit blocks. Through an interface circuit that links the measuring circuit and the controller, the measured results are sent to the corresponding pins of the controller. The related protecting circuit is represented by a protecting circuit block. When necessary, the controller will send an operational signal; as soon as this happens, the motor-protecting devices will operate the drive circuit in the proper and timely manner. The setup includes a controller, a relay unit, a voltage-measuring circuit, and a current sensor. Initially, a development tool is used to program the controller. Circuits for measuring voltage and current are used in monitoring line current and voltage under operational conditions, respectively.

Current and voltage measurement circuits are used to digitally convey the data received from voltage sensing and current sensing circuits to the controller. The controller has an analog-to-digital converter (ADC). In one assembly arrangement, the controller-based motor protection system integrates the functions of controlling, monitoring, and protecting an induction motor against impending failures. The system offers under and overvoltage, as well as under and overcurrent, schemes. The potentiometer is used to provide the system with input data (limit values). The output data and fault state are displayed on the display unit, which serves as an output device.

The prototype model is created and tested using a 230V, 2A single-phase induction motor, and the test results meet the design requirements. The induction motor is protected from severe over and under-current conditions when the maximum allowable under-current and over-current limits are exceeded. The controller generates a trip signal when these limits are exceeded, which causes the induction motor to shut off and display a message indicating an undercurrent or overcurrent fault.

Hardware connections

The hardware connections include the current sensor, voltage sensor, relay, LCD, and indicator LEDs.

Current sensor

The ACS712CTR-30A-T, a fully integrated linear current sensor IC in an 8-pin SOIC package based on the Hall Effect, is the current sensor utilized in this project. The component comprises a linear hall sensor circuit that is accurate, low offset, and has a copper conduction channel close to the die's surface. The magnetic field produced by the applied current flowing through this copper conduction line is measured by the integrated hall IC and transformed into a proportional voltage. The magnetic signal's proximity to the hall transducer improves device accuracy. The low offset, chopper destabilized BICMOS Hall IC, which is controlled after packaging, provides a precise proportional voltage.

Voltage sensor

A voltage sensor is a straightforward module that may be used with an Arduino or other microcontroller that accepts input voltages up to 5V to measure external voltages that are higher than that amount. In the case of an Arduino, the highest allowed value is 5V. The voltage sensor is essentially a voltage divider made of two resistors with resistances of 30k and 7.5M, or a voltage divider of 5 to 1.

Relay

Relay is an electrically operated switch that works on the electro-magnetism principle. It has three pin contacts named NC for normally closed, NO- for normal open, and COMMON pin for connecting NC or NO. P1 and P2 pins are for providing the control signal to relay. The relay is illustrated in the figure 2 below.

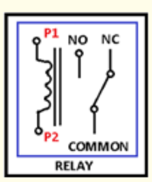

Figure 2: Relay.

Now working principle of the relay is very simple when P1 and P2 get a certain amount of voltage then the coil between P1 and P2 gets energized and creates a magnetic field around it. For this magnetic field, the metal switch liver which is attached to the common pin is attracted towards the NO pin, and a connection is made between NO and the common pin.

LCDs and indicator LEDs

The status of the motor can be viewed from the LCD. It displays information on the immediate voltage and current of the motor. A 16×2 alphanumeric LCD with a Hitachi HD44780 controller was used and 4-bit communication with the PIC was preferred to save I/O pins. Red, amber, and green LEDs were used to show the status of the motor too, the Red LED is switched on if overcurrent is detected and all other LEDs are off, the Green LED shows normal operation condition. The Amber LED one only lights when an undercurrent is detected.

Advantages of using Arduino Uno with Single-phase Induction Motor

Using Arduino Uno with a single-phase induction motor has advantages such as:

- Easy to implement and program
- Low cost and low power consumption
- Flexibility to adapt to different applications
- Ability to control multiple motors simultaneously
- Ability to monitor and control motor parameters remotely

Using Arduino Uno with a single-phase induction motor also has disadvantages such as:

- Limited current handling capacity
- Limited voltage handling capacity
- Limited precision and accuracy of motor control
- May require additional components such as drivers and sensors
- May require additional programming and calibration for complex applications

The circuit diagram of a single-phase induction motor using Arduino Uno technology.

The circuit diagram is indicated in Figure 3 below.

Simulation – modelling and experiment results

The circuit was simulated and results were obtained as follows.

Circuit testing

When the circuit is switched on, all three LEDs light up showing that the system is checking for any abnormality. Circuit testing is illustrated in Figure 4 below.

Complete circuit Simulation

All the LEDs are now switched off and the LCD now displaying Induction Motor Protection showing that the circuit is now ready for operation. Circuit simulation is illustrated in Figure 5 below.

Case 1

Motor Running Normal Current is indicated on the LCD on the condition of normal operation and the Green LED is switched ON. The motor is running as illustrated in Figure 6 below.

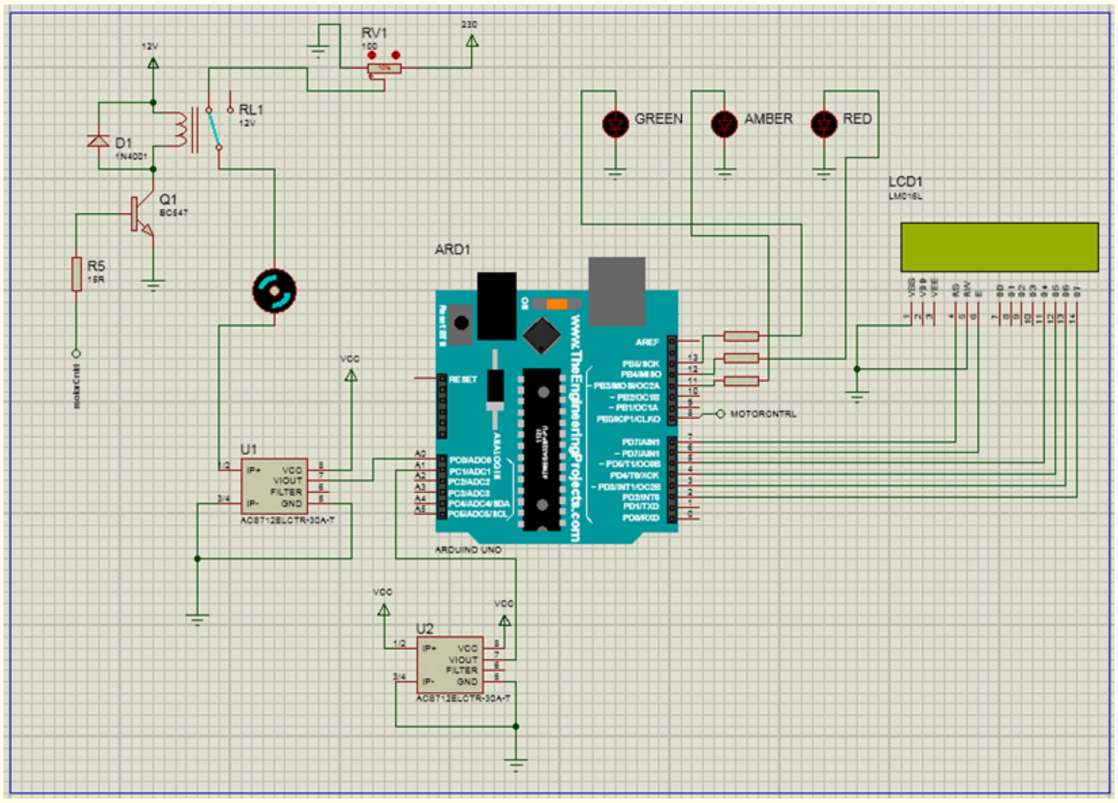

Figure 3: The circuit diagram of a single-phase induction motor using Arduino Uno technology.

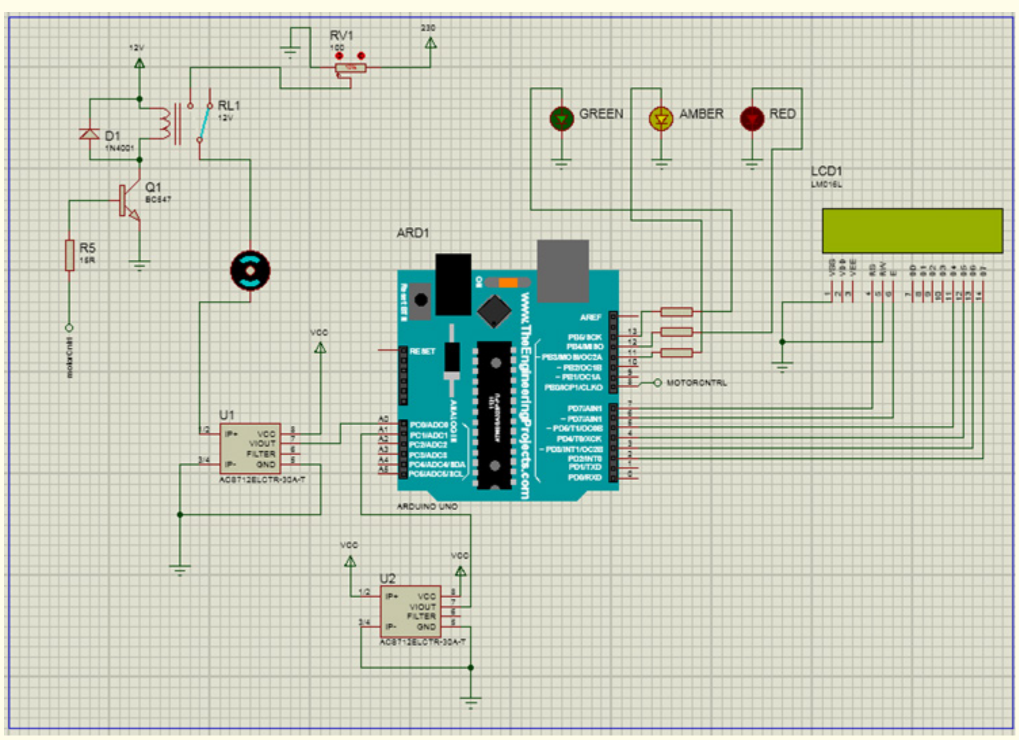

Figure 4: Circuit Testing.

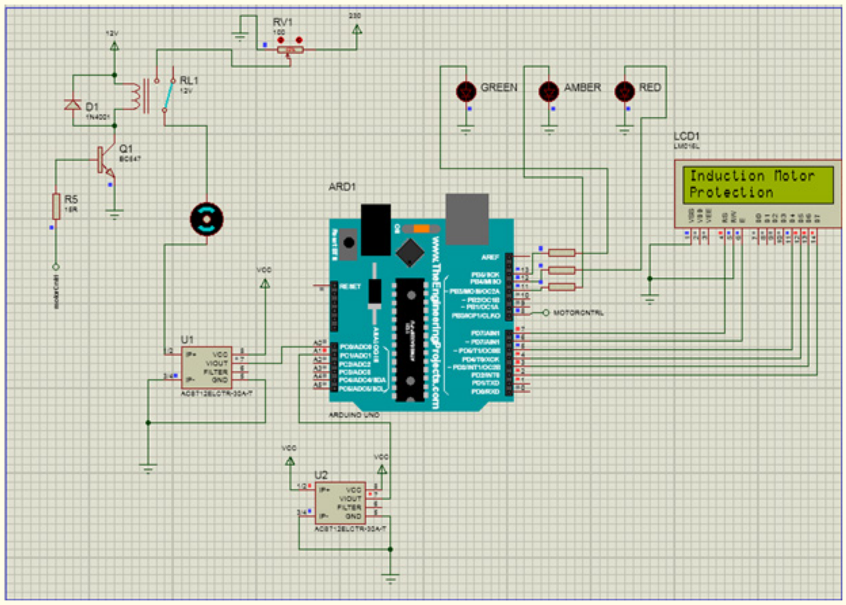

Figure 5: Circuit Simulation.

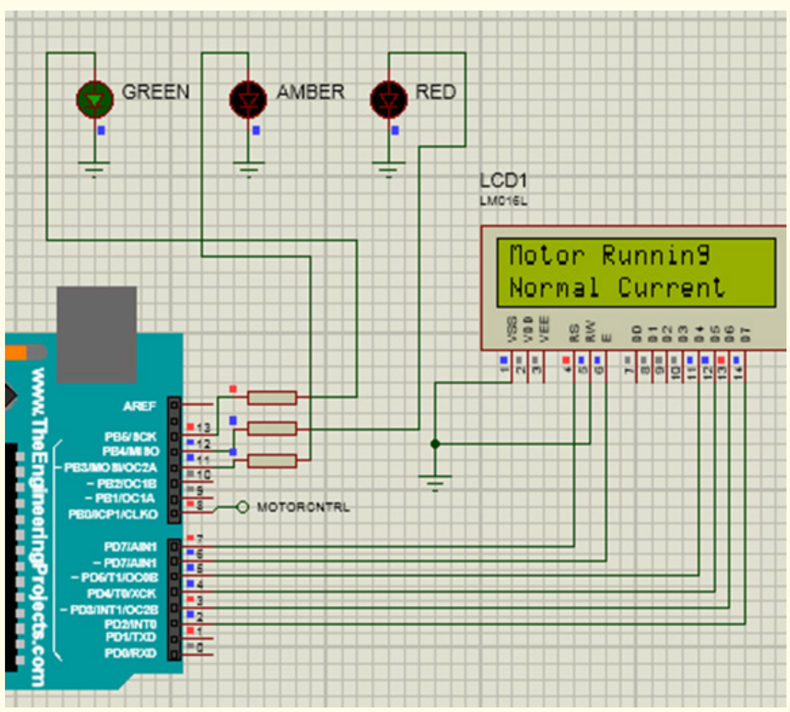

Figure 6: Motor running at normal current.

Case 2

Motor Cut off Overvoltage is indicated on the LCD on the condition of over voltage/current and the Red LED is switched ON and motor stops. This is illustrated in Figure 7 below.

Case 3

Motor Cut off Undercurrent is indicated on the LCD on the condition of under voltage or current and the Amber LED is switched ON and motor stops in Figure 8 below.

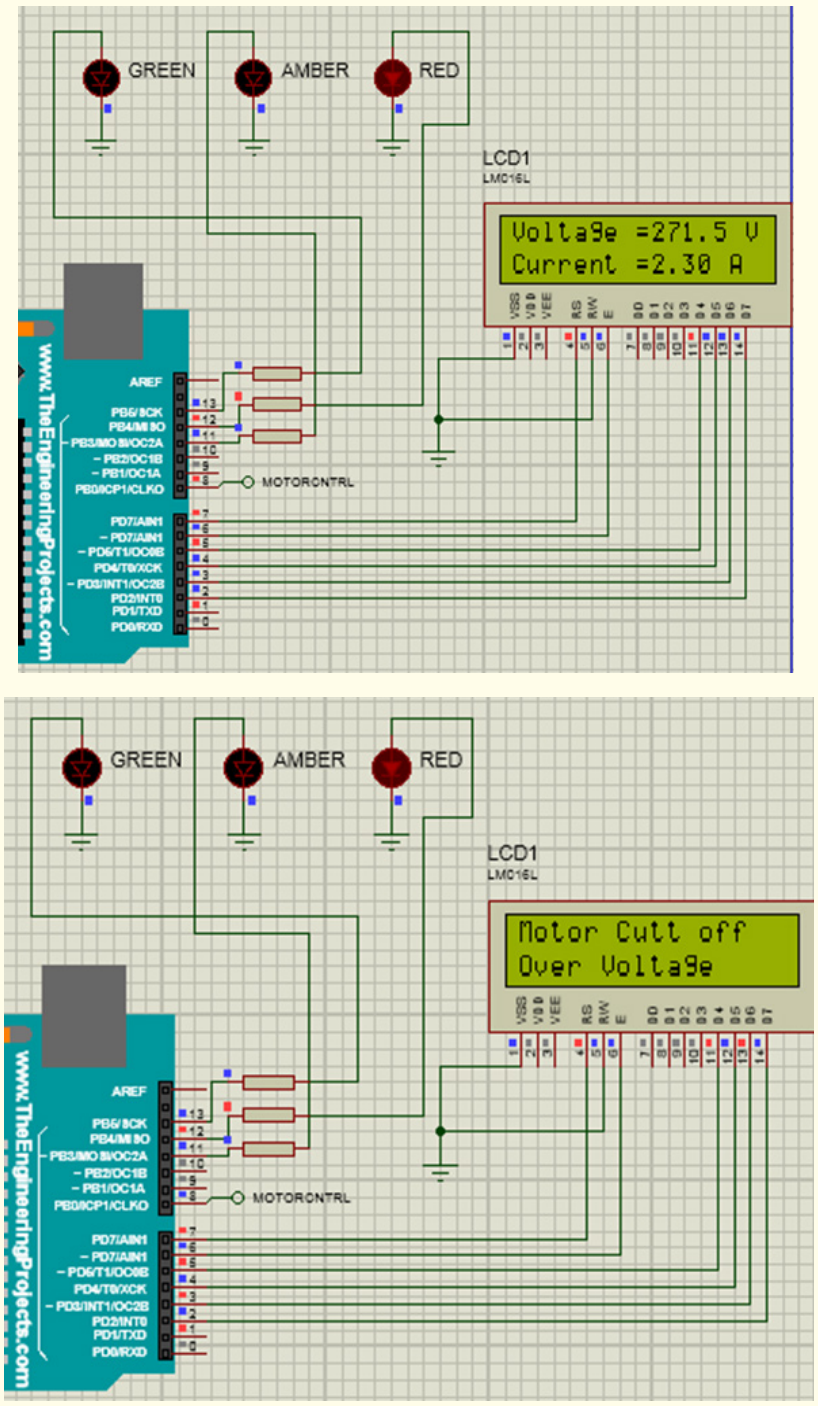

Figure 7: Motor cut off overvoltage.

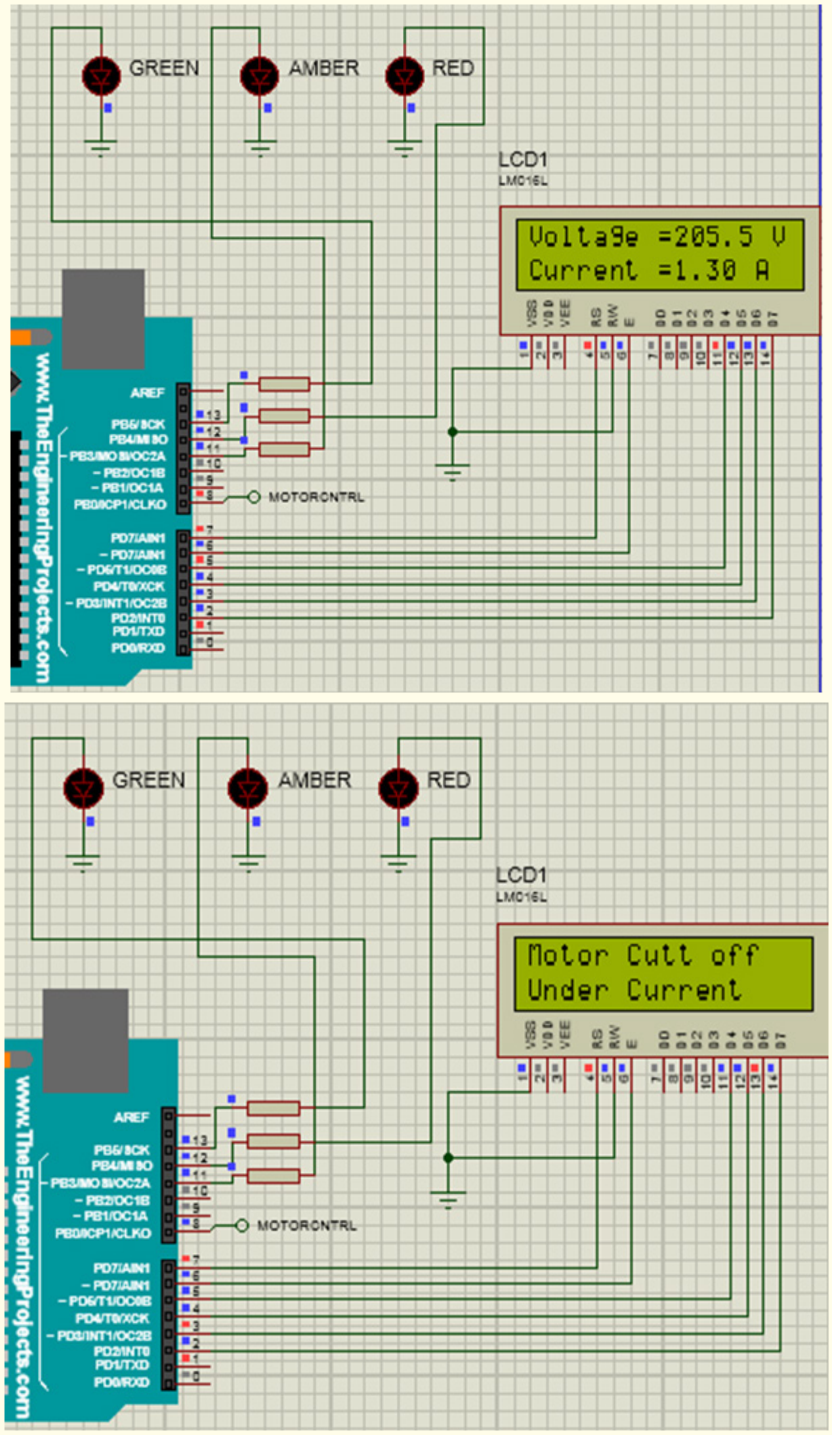

Figure 8: Motor cut off undercurrent.

Application of a single-phase induction motor using arduino uno technology

Single-phase induction motors are widely used in many applications, including household appliances, industrial equipment, and automotive systems. However, controlling the speed and direction of these motors can be challenging. In this project, we will explore how to control a single-phase induction motor using Arduino Uno technology. A single-phase induction motor is a type of AC motor that uses an induction motor principle to operate. The applications of a single-phase induction motor using Arduino Uno technology include:

- **Speed Control:** This uses the Arduino Uno board to generate a PWM (Pulse Width Modulation) signal to control the speed of the single-phase induction motor. The PWM signal is sent to the L293D driver IC, which amplifies the signal and provides sufficient current to the motor. The speed of the motor can be adjusted by changing the PWM value, which determines the frequency of the motor's rotation. This application is useful in applications where a variable speed motor is required, such as in conveyor belt systems or robotic arms.
- **Direction Control:** Uses the Arduino Uno board to generate a PWM signal to control the direction of the single-phase induction motor. The PWM signal is sent to the L293D driver IC, which amplifies the signal and provides sufficient current to the motor. By changing the direction of the PWM signal, the motor can be made to rotate in either a clockwise or counterclockwise direction. This application is useful in applications where a motor needs to be controlled in both directions, such as in robotic arms or vacuum cleaners.
- **Motor Protection:** Uses the Arduino Uno board to monitor the voltage and current of the single-phase induction motor. The Arduino board can detect overvoltage, under-voltage, or overcurrent conditions and take action to prevent damage to the motor. For example, if an overvoltage condition is detected, the Arduino board can switch off the motor until the voltage returns to a safe level. This application is useful in applications where a motor needs to be protected from electrical faults or malfunctions.
- **Motor Efficiency Monitoring:** Use the Arduino Uno board to monitor the efficiency of the single-phase induction motor. The Arduino board can measure the current and voltage of the motor and calculate its efficiency based on these values. This application is useful in applications where energy efficiency is critical, such as in industrial processes or HVAC systems.
- **Motor Control using sensors**: Uses sensors such as Hall Effect sensors, encoders, or strain gauges to monitor the position, speed, or torque of the single-phase induction motor. The Arduino board can use this data to control the motor speed, direction, or braking. This application is useful in applications where precise control of the motor is required, such as in robotics or CNC machines.
- **Solar Tracker:** Uses an Arduino Uno board to control a single-phase induction motor to track the sun's movement and adjust the position of a solar panel to maximize energy output. The Arduino board can read data from a solar sensor and use it to control the motor's speed and direction. This application is useful in applications where energy efficiency is critical, such as in solar-powered systems.
- **Water Pump Control:** Uses an Arduino Uno board to control a single-phase induction motor to pump water from a well or reservoir. The Arduino board can read data from a sensor to monitor the water level and use it to control the motor's speed and direction. This application is useful in applications where water management is critical, such as in irrigation systems or firefighting systems.
- **HVAC System Control:** Uses an Arduino Uno board to control a single-phase induction motor to control the airflow and temperature of a heating, ventilation, and air conditioning (HVAC) system. The Arduino board can read data from sensors to monitor temperature and humidity levels and use it to control the motor's speed and direction. This application is useful in applications where indoor climate control is critical, such as in commercial buildings or residential homes.
- **Automatic Feeder:** Uses an Arduino Uno board to control a single-phase induction motor to feed animals or pets automatically. The Arduino board can read data from a sensor to monitor the food level and use it to control the motor's speed and direction. This application is useful in applications where animal feeding is critical, such as in farms or pet stores.
- **Automatic FAN Control:** Uses an Arduino Uno board to control a single-phase induction motor to control the speed of a fan. The Arduino board can read data from a temperature sensor to monitor the temperature and use it to control the motor's speed and direction. This application is useful in applications where air circulation is critical, such as in computer servers or industrial settings.
- **DC-DC Converter:** Uses an Arduino Uno board to control a single-phase induction motor to convert DC power to DC power. The Arduino board can read data from a sensor to monitor the input voltage and use it to control the motor's speed and direction. This application is useful in applications where DC power is required, such as in battery-powered devices or electronic devices.
- **Power Factor Correction:** Uses an Arduino Uno board to control a single-phase induction motor to improve the power factor of an electrical system. The Arduino board can read data from a sensor to monitor the current and voltage levels and use it to control the motor's speed and direction. This application is useful in applications where power efficiency is critical, such as in industrial settings or power plants.
- **Motor Fault Detection:** Uses an Arduino Uno board to detect faults in a single-phase induction motor. The Arduino board can read data from sensors to monitor the current, voltage, and temperature levels of the motor and use it to detect faults such as overheating, overvoltage, or overcurrent. This application is useful in applications where reliability is critical, such as in industrial settings or aerospace systems.

- **Motor Protection:** Uses an Arduino Uno board to protect a single-phase induction motor from electrical faults such as overvoltage, undervoltage, or overcurrent. The Arduino board can read data from sensors to monitor the current and voltage levels of the motor and use it to take action such as switching off the motor or disconnecting it from the power supply. This application is useful in applications where safety is critical, such as in medical devices or consumer electronics.

Conclusion

This chapter evaluates the system against the set objectives and summarizes all the shortcomings during the entire system development. The project helps in the control and protection of the induction motor. The use of Arduino technology has been successfully designed and tested to protect single-phase induction motors and monitoring. The presence of every module has been reasoned out and placed carefully, thus contributing to the best working of the unit. It also put forward a cost-effective model for controlling and monitoring of induction machine. The protection system initiates the tripping of the motor under abnormal conditions. The parameter set values are stored in the microcontroller. If the values show any slight variations from the set values then the relay circuit energizes the motor it motor stops. This method is very sensitive, and fast and detects faults while running and before starting. The system is designed to provide real-time monitoring and control of the motor's speed, current, and temperature, enabling efficient and reliable operation. The proposed system uses a combination of sensors and actuators to monitor and control the motor's speed, current, and temperature. The Arduino Uno board is used as the central processing unit, which receives data from the sensors and sends control signals to the actuators. The system has been tested and validated through experimental trials, demonstrating its ability to accurately monitor and control the motor's speed, current, and temperature. The results show that the system can effectively detect faults in the motor and take corrective action to prevent damage or downtime. The proposed system has several advantages over traditional motor control systems such as low cost and ease of implementation; real-time monitoring and control capabilities; ability to detect faults and prevent damage and scalability and modularity. Overall, the proposed system demonstrates the potential of Arduino technology in monitoring and controlling single-phase induction motors. The system can be used in a wide range of applications, including industrial automation, robotics, and IoT projects.

Recommendations

The next innovation should incorporate setting the current values for no load and inrush currents until the motor attains its full speed. It is recommended that the next innovation should include temperature sensing and measurement mechanisms to protect the motor windings from overheating. The project should in the future be aimed at protecting three-phase motors rather than single-phase motors as these are the major ones in the industry today. Functionalities to be added then include protection against single phasing, unbalanced phase voltage and currents, and earth faults. It is further recommended to house the system in a metallic casing immune to vibrations due to the environment in which it is supposed to operate. While the proposed system has demonstrated its effectiveness in monitoring and controlling a single-phase induction motor, several areas require further research and development. Other future works include developing more advanced algorithms for fault detection and diagnosis; improving the system's ability to adapt to changing operating conditions; integrating additional sensors and actuators to expand the system's capabilities and developing more advanced communication protocols for remote monitoring and control.

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