DESIGN AND IMPLEMENTATION OF A THREE-PHASE FAILURE DETECTION SYSTEM WITH AUDIO FEEDBACK FOR MOTOR CONTROL

Supported by tetfund TERTIARY EDUCATION TRUST FUND

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Received: February 14, 2025, Accepted: April 28, 2025

Abstract: This research focuses on designing and implementing a three-phase failure detection system with audio feedback for motor control, utilizing an Arduino Nano. The Arduino Nano controls motor switching, which is monitored by sensors in each phase of the circuit. These sensors input signals into the Arduino's analog pins, where the analog signals are converted into digital signals. The system provides both audio and visual feedback when a phase failure is detected and rectified. The system's software was written in C++ using the Arduino Integrated Development Environment (IDE), and simulations were carried out with Proteus CAD software. The system successfully switches off the motor in response to phase outages.

Keywords: Detection System, Microcontroller, Audio Feedback, Liquid Crystal Display Motor Control, Proteus CAD software

Introduction

An electric motor is a device that converts electrical energy into mechanical energy. Among the various types, the three-phase induction motor is the most commonly used for AC (Alternating Current) applications because it does not require an external starting device. These motors are self-starting, simple in design, durable, cost-effective, and require minimal maintenance. They operate at a nearly constant speed from no-load to full load, making them ideal for industrial use. (IEC, 1990).

In an induction motor, the rotor rotates at a speed slightly lower than the stator's magnetic field. This relative motion induces a current in the rotor, which in turn generates a magnetic field that interacts with the stator's rotating field. The induced current follows Lenz's Law, opposing the change that caused it, leading the rotor to rotate in the same direction as the stator field. The rotor accelerates until the generated torque balances the applied mechanical load. Since the rotor must always lag slightly behind the synchronous speed to maintain induction, an induction motor never operates at synchronous speed. (Udoha, G. & Ofualagba, E.E., 2017).

For current induction in the rotor, there must be a speed difference (slip) between the rotor and the stator's magnetic field. If the rotor were to match the synchronous speed, no relative motion would exist, preventing current induction. The slip increases when the rotor slows down, thereby inducing more current and producing greater torque. The ratio between the rotor's induced magnetic field speed and the stator's rotating field speed is referred to as "slip." (IEC, 1990).

Three-phase induction motors are widely used due to their robust construction and ease of operation. However, they are susceptible to issues such as under voltage, overvoltage, overheating, single phasing, and phase reversal, which can affect efficiency and performance. (I.Y., 2019). Single phasing occurs when one phase is lost due to a blown fuse, mechanical failure, broken power line, transformer winding fault, or lightning strike. If the supply voltage falls below the required level, the motor may fail to start. A comparator measures the single-phase supply voltage against the required voltage, sending a signal to a microcontroller to shut down the motor when necessary. (Ezema, L.S., Peter, B.U. & Harris, O.O., 2012).

An Automatic Phase Selector and Changeover circuit is used to maintain an uninterrupted power supply. This system consists of three transformers connected to each phase of the public utility supply. The transformers' output is rectified, regulated, and processed by an Atmega328 PU microcontroller. The microcontroller identifies the most stable phase and activates a switching circuit to ensure a continuous power supply. (Ovbiagele, et al., 2019).

The research focused on providing uninterrupted household power but did not accommodate other three-phase equipment or include a feedback mechanism such as audio or wireless alerts. A single-phase voltage and current measurement system was implemented using a phase sequence detector. The system used a PIC16F877A microcontroller to compare real-time voltage, current, and phase sequence against predefined limits. The results were displayed on an LCD, and based on the comparison, signals were sent to a relay to control power distribution. (Ofualagba, et al., 2017). (Dinesh et al. 2019).

Related Works

A related study presented a thesis on designing a control system for detecting phase failure and identifying unbalanced phase sequences in an induction motor. The system utilized an Atmega328 microcontroller to control the process. Three-phase voltage was tapped using transformers, then rectified and regulated before being fed into the microcontroller's ADC pins. An Operational Amplifier (Op Amp) was used to convert the sine wave into a square waveform, allowing the software to compare and verify the phase sequence. The software determined the sequence status and transmitted it as a logic bit (0 or 1) to a computer. If an incorrect phase sequence was detected, the controller would cut off power and display a warning message on an

LCD screen. (Hussam, 2018). The primary drawback of this design was the complexity of using software for phase sequence detection and the lack of an effective alert and feedback system in case of faults in the phases.

To address these limitations, a three-phase fault detection and analysis system was developed using a PIC microcontroller and GSM technology. The PIC microcontroller was interfaced with a GSM module to send alerts to operators whenever a fault was detected in any of the phases. GSM technology was employed for feedback and notifications; however, its dependence on network availability posed a major limitation, particularly in areas with poor or no coverage. (Tanjil, et al. 2017).

For implementing various protection mechanisms, specific protection schemes were incorporated. The microcontroller monitored the motor's voltage and current values, detecting any faults and displaying warning signals on an LCD. In the event of a fault, the system would trip the motor. The detected faults included overload, overcurrent, and overvoltage, under voltage, unbalanced voltage, phase reversal, and single phasing. (Tanjil, et al. 2017).

Description of Components
The components description are as follows
Arduino Nano

The Arduino Nano is a compact, breadboard-friendly microcontroller board based on the ATmega328. It provides the core functionality of the Arduino Duemilanove but is smaller in size and lacks a DC power jack, using a Mini-B USB cable for connectivity. It operates with a 16 MHz clock speed and has 32 KB of flash memory, with 2 KB used by the bootloader. Its power consumption is 19 mA as shown in figure 1. (Hussam, 2018)

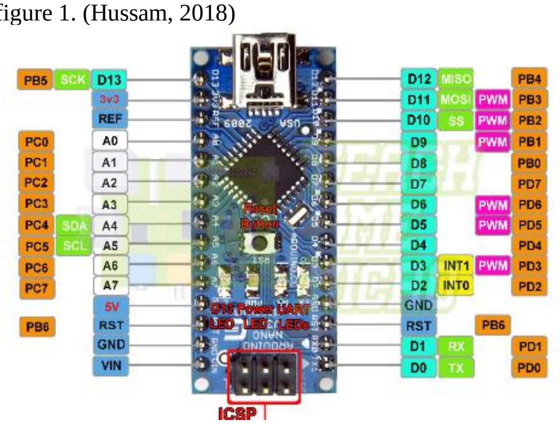

Figure 1: layout of the Arduino Nano

Liquid Crystal Display (LCD)

Displaying information in an easily accessible way is a critical component of most electronic systems. A Liquid Crystal Display (LCD), as shown in Figure 5, is a thin, flat device used for displaying data, enabling users to easily interpret, access, and utilize it. It is defined as an electronic component that converts electrical signals from other devices into visual optical signals that are visible to the human eye. Electronic displays can be categorized as active or passive types. These displays work with logic circuits that decode binary-coded decimal (BCD) numbers, triggering the corresponding segments to form a selected digit. LCDs are widely used in various applications due to their programmability and cost-effectiveness compared to other types like seven-segment displays or LEDs. A 16x2 LCD, for instance, can show 16 characters per line across two lines as shown in figure 2. (Hussam, 2018)

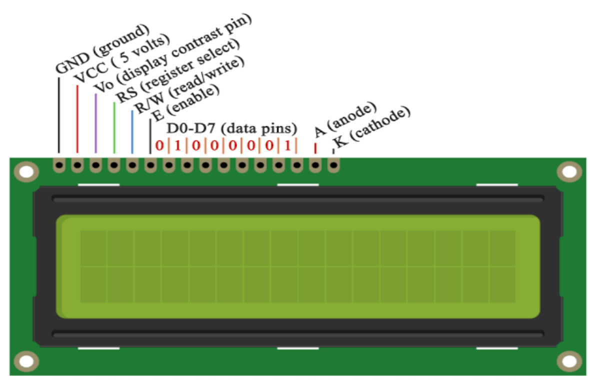

Figure 2: Liquid Crystal Display (LCD)

DF-Player Module

The DF-Player Mini MP3 Player for Arduino is a small and affordable MP3 module that directly outputs sound to a speaker as shown in figure 3. It can function independently with an attached battery, speaker, and push buttons, or be integrated with an Arduino Nano using UART (Universal Asynchronous Receiver-Transmitter) for enhanced functionality (dfrobot.com). In this system, the DF-Player module is connected to the Arduino Nano using pulse width modulation (PWM) techniques to provide audio feedback (Hussam, 2018). The specifications for the module are as follows

1. Supported sampling rates: 8/11.025/12/16/22.05/24/32/44.1/48 kHz
2. 24-bit DAC output, dynamic range support of 90dB, SNR of 85dB
3. Supports FAT16, FAT32 file systems; max 32GB TF card and 32GB USB drive
4. Various control modes: I/O control, serial mode, AD button control
5. Advertising sound feature: Pauses music for advertisements, then resumes playing afterward
6. Folder organization for audio files: Supports up to 100 folders, each containing up to 255 songs
7. Adjustable volume levels (30 levels) and EQ settings (6 levels)

and the applications of the DF player module are as follows

1. Car navigation voice alerts
2. Toll stations, transport inspectors voice prompts

3. Railway stations and bus safety announcement systems
4. Commercial and business environments for voice notifications
5. Vehicle entry/exit verification with voice prompts

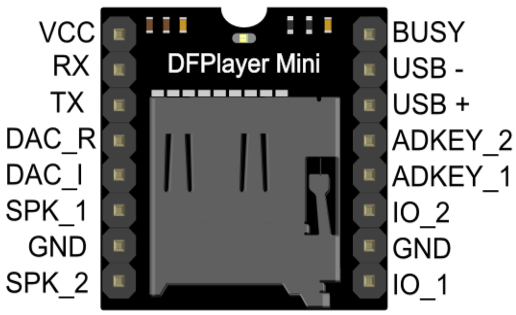

Figure 3: A DF player module.

Relay

A relay is an electromechanical switch operated by an electromagnet as shown in figure 4. It consists of an electromagnet, an armature, a spring, and a set of electrical contacts. A small electrical current activates the electromagnet, causing the armature to move and either complete or break the circuit. Relays are used to isolate electrical circuits from one another or to control multiple circuits with a single signal. (Hussam, 2018).

Figure 4: A Relay

System Design and Implementation

Building on the theoretical concepts outlined in the block diagram and component breakdown, design calculations were performed for various system sub-blocks. These calculations are aimed at determining component ratings, selecting an appropriate transformer, and estimating the current demands of each element. The design process was completed in stages, following the structure of the system's components. The overall circuit diagram was developed by integrating the design of each block, forming a complete system diagram.

The design approach in this work is divided into hardware and software design. The relationship between different units is represented pictorially in blocks to simplify understanding of the system's operation. The design methodology used in this work is split into hardware and software design. The interconnections between various components were illustrated in block diagrams as shown in figure 5 to help visualize how the system operates.

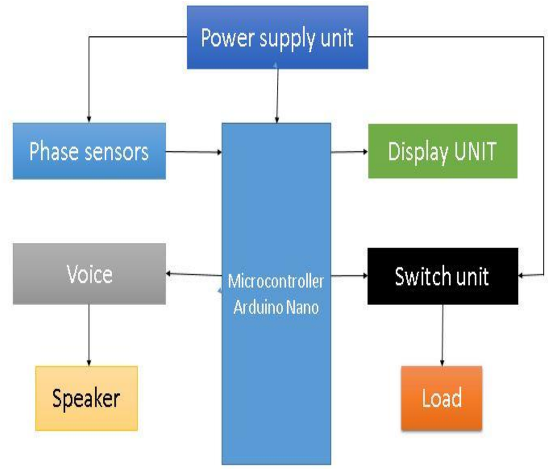

Figure 5: Block diagram of the system

Proteus CAD Software

Proteus is a comprehensive Computer-Aided Design (CAD) software developed by Labcenter Electronics, widely used for electronic circuit design, simulation, and PCB layout as shown in figure 6. It integrates circuit schematic capture, microcontroller simulation, and PCB design into a single platform. Proteus is popular in both academic and professional settings due to its user-friendly interface and strong simulation capabilities. It is particularly useful for testing embedded system designs without hardware, helping save time and resources. For students and engineers working with embedded electronics, Proteus serves as a powerful tool for prototyping and a debugging. Its key features are schematic capture which Allows users to draw electronic circuits with a vast library of components, simulation which supports simulation of analog, digital, and embedded systems, especially microcontrollers like PIC, AVR, ARM, and Arduino, PCB Layout which offers tools for designing and routing multi-layer printed circuit boards and the virtual system modeling (VSM) which enables co-simulation of microcontroller code and connected peripherals in real-time. (Ovbiagele, et al., 2019)

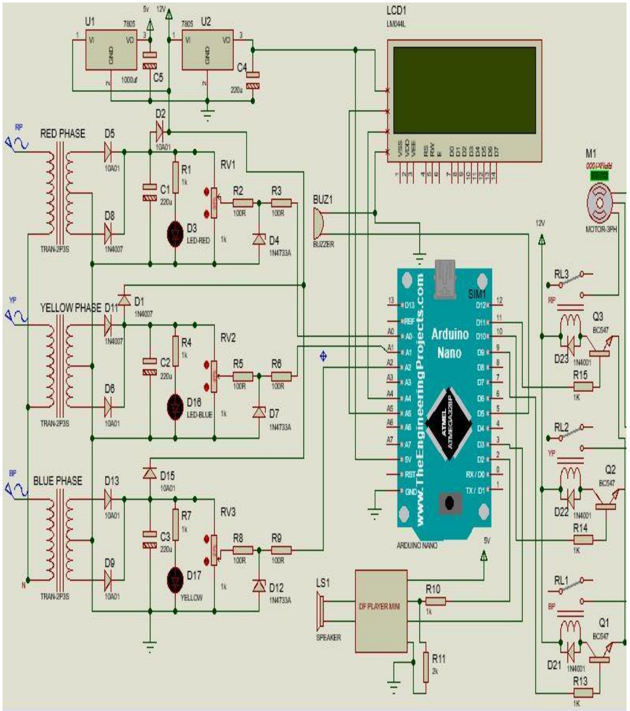

Figure 6: Proteus CAD software

Implementation Procedure

The implementation procedure are as follows:

1. Two diodes were soldered onto the Vero board to convert the alternating current (AC) to direct current (DC). This was connected to a voltage regulator, which adjusted the input voltage to the desired level. Then, it was linked to a capacitor that filtered out any remaining ripples, ensuring the output was a clean, regulated signal as shown in figure 7.
2. At this point, an IC base was soldered onto the Vero board, and the Arduino Nano was mounted on it. The regulated voltage was supplied to the Arduino Nano to power it.
3. The three transformer terminals—red, yellow, and blue—were connected to their respective diodes. From the diode outputs, the signal was routed to a capacitor, and then to a variable resistor. The output of the variable resistor was connected to the sensing unit, which consisted of a voltage divider made up of two 100Ω resistors and a Zener diode (1N4733A). The output from this sensing unit was connected to the controller pins.
4. The display was connected to the Arduino Nano via I2C modules, using four pins (VCC, GND, SDA, and SCL). VCC and GND were connected to the Arduino Nano's 5V and GND pins, respectively. SDA and SCL were connected to the A5 and A6 pins of the Arduino Nano.
5. The switching unit, which consisted of relays, transistors, diodes, and resistors, was connected to the controller pins. The input voltage was linked to the switching unit, and the motor was connected to the relay terminals.
6. The speaker terminals were connected to the DF-Player, with an SD card inserted into the player. The DF-Player was linked to the Arduino Nano via a voltage divider.
7. The regulating, sensing, display, control, audio feedback, and switching units were all interconnected to form the complete system.
8. The system was programmed using the Arduino IDE, employing C and C++ programming languages.
9. A suitable box and stickers were used to house the components as shown in figure 8.

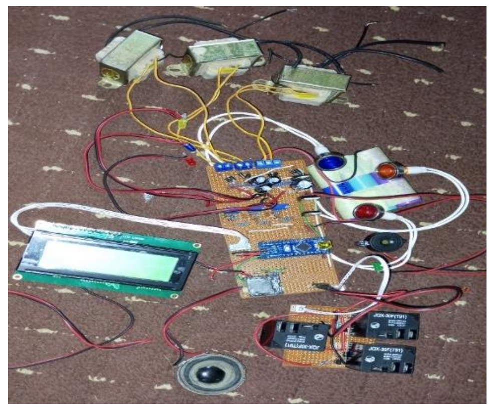

Figure 7: Interface of all the system

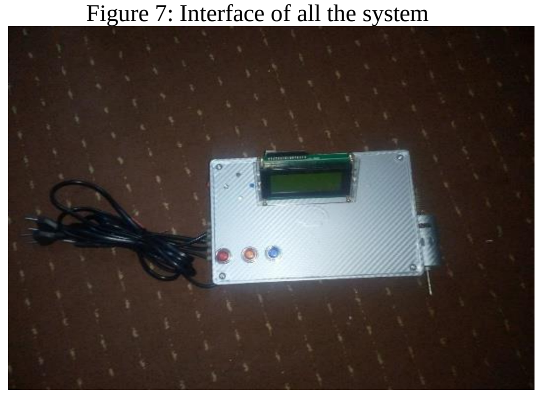

Figure 8: The casing of the system

Testing

System testing was conducted after integrating all components to ensure compliance with the system's specifications. The goal of this testing was to identify any inconsistencies between the integrated units and verify the system's overall performance. Testing took place during and after construction to confirm that no faulty components were used and that the system met all the required specifications.

Results and Discussion.

The results shown in Table 1 provide a comparison between the expected and measured input and output voltages of the system.

Table 1: Results Breakdown

Component	Transformer	Rectifier diode	Regulator(5 V)	Regulator(9 V)
Measured value of	215	12	16.1	17
Expected value of input	240	12	17	16.1
Measured value of	12	16.1	4.98	8.98
Expected value of	12	17	5	9
Voltage regulation in	2.5	2.8	2	1.11

The test results for the various power supplies demonstrate that the outcomes closely match the theoretical design. For example, the 12V central power supply showed a voltage regulation of 2.5%, the 5V power supply had a 2% regulation, and the 9V power supply exhibited a 1.11% regulation. The audio player performed as expected, and the LCD display functioned well. The system also successfully shut off the load in the event of a phase outage. Based on these tests and results, the system can be easily troubleshot if any issues arise.

Conclusion

Given the rising frequency of power failures in developing countries like Nigeria, this research could help mitigate such challenges if implemented in industries and workshops. The design and implementation have ensured that the load is only powered when all three phases are available. In conclusion, the system has successfully met its objectives.

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