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SMART PROTECTION FOR INDUCTION MOTORS: FAULT MONITORING AT ITS BEST

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Abstract
In the realm of electrical motors, a diverse array of faults can manifest, falling broadly into two categories: external and internal. External faults may stem from environmental conditions or other extraneous factors, whereas internal faults are typically rooted in circuit-related issues. This paper delves into the realm of fault mitigation, with a primary focus on ensuring the protection of motors against the perils of overheating, overvoltage, and under-voltage.
Overheating, a common motor issue, often arises from overloading. To ensure continuous monitoring of temperature, the DS1820 sensor is deployed, allowing for precise temperature measurement. Furthermore, well-defined upper and lower voltage thresholds are established to guarantee the motor's seamless operation. Regulating temperature and voltage levels within the motor is entrusted to the ARDUINO Nano controller, a sophisticated component known for its adeptness at temperature sensing and voltage monitoring. In the event that the sensors detect values that veer beyond the predefined operational limits, they promptly communicate with the ATmega328P microcontroller.
The ATmega328P, a robust 8-bit microcontroller boasting a 32KB Flash memory, belongs to the esteemed ATmega AVR MCUs series, developed by Atmel. It serves as the central decision-making hub for the motor's protective actions.
Keywords: Temperature sensor, Arduino-Nano.

1.Introduction

This paper offers an extensive examination of the multifaceted realm of motor faults, meticulously dissecting the intricate web of internal and external elements that contribute to the malfunction of these indispensable mechanical devices. Electric motors, the backbone of numerous industries, face an array of challenges that can compromise their operational integrity. These challenges encompass the rigors of prolonged and demanding usage, deficiencies in grounding, suboptimal installation practices, intricate mounting procedures, and the possibility of manufacturing imperfections, all of which collectively impact the dependability of these mechanical workhorses. Within the domain of electric motors, these formidable machines frequently contend with two broad categories of faults: those of an electrical nature and those with mechanical origins. In the realm of electrical faults, a spectrum of issues arises, including unbalanced supply voltage or current, single phasing, deviations in voltage or current exceeding prescribed limits, reverse sequencing of phases, earth faults, overloads, inter-turn short-circuit faults, and the intriguing phenomenon known as "crawling." These challenges underscore the intricacies of electrical systems. Concurrently, mechanical faults present their own set of complexities, encompassing a wide range of potential problems, such as fractured rotor bars, mass imbalances leading to uneven weight distribution, eccentricities in the air gap between components, bearing damage, rotor winding failures, and disruptions in stator windings.

Environmental variables further contribute to this intricate motor landscape, with factors such as ambient temperature and external moisture levels exerting palpable influences on motor performance. Vibrational irregularities may also surface, triggered by environmental conditions or structural deficiencies, resulting in discernible machine vibrations that impact operational efficiency.

In the context of this comprehensive exploration, the paper's central objective is to systematically address specific issues related to overvoltage, under-voltage, and temperature-induced faults. For instance, problems associated with overheating often stem from persistent overloads, elevated ambient temperatures, inadequate ventilation, imbalances in supply voltage, and an array of other potential culprits. Notably, an increase of 25% in current within the motor's phase with the highest current induces a corresponding temperature rise. Simultaneously, a modest voltage imbalance of 3.5% per phase can exacerbate the temperature issue. Furthermore, frequent and abrupt starts and stops within condensed time frames can trigger rapid temperature surges within the winding. Should the motor's operation continue beyond its temperature threshold under such circumstances, even the most resilient insulation may succumb to premature failure, underscoring the urgency of strategies to mitigate these faults.

In conclusion, this paper embarks on a comprehensive journey to unravel the intricacies of motor faults, aiming to enhance their reliability and performance while navigating the labyrinth of multifaceted factors contributing to motor malfunctions.

2.Cause of faults

The issue of motor overheating is a multifaceted problem with several key elements that warrant a more extensive examination:

1. Motor Sizing Considerations: The size of a motor is of utmost importance. It is imperative to carefully select a motor that aligns with the specific requirements of the application, taking into account the working environment, and the expected duty cycle. Inadequate motor size can impede the dissipation of heat and result in the onset of overheating.
2. Environmental Factors: The ambient temperature in which a motor operates plays a pivotal role. Proper motor insulation is a prerequisite. Prior to motor installation, it is essential to verify that the selected motor complies with the appropriate insulation class based on the prevailing environmental conditions.
3. Duty Cycle Management: Applications featuring intermittent duty cycles demand meticulous management of operational parameters. Adhering to or operating below the recommended duty cycle is crucial. Allowing sufficient intervals for complete cooling between cycles is vital for

maintaining performance within the manufacturer's specified ratings. Deviations from the recommended duty cycle can lead to prolonged heat buildup, heightening the risk of overheating.
4. Voltage Supply Challenges: Inadequate power supply can give rise to overcurrent conditions, especially when the motor contends with heavy loads or inertial challenges, particularly during standstill periods. In such scenarios, the motor's operational current exceeds its designated rating. A suboptimal power supply significantly contributes to motor overheating.
5. Environmental Impact: Motors operating in harsh environmental conditions are susceptible to heightened heat accumulation. Effective ventilation is indispensable, and it is critical to ensure that the motor's ventilation openings remain unobstructed to facilitate efficient heat dissipation.

Addressing the challenge of motor overheating entails the assessment of motor winding temperature by evaluating winding resistance. Typically, this is achieved by introducing a minor direct current component into the motor's electrical circuit. Often, an asymmetric resistance device is incorporated into the circuit for this purpose. The resistance of the motor winding is then determined by analyzing the direct current component and its corresponding voltage. An alert or indicator system can be configured to activate when the current falls below a predetermined level, indicating a resistance value associated with an overheating condition.
The formula for calculating the total winding temperature (T(t)) is as follows:

$$T_t = T_c + \frac{R_h - R_c}{R_c * (T_c + 234.5)} \dots\dots (1)$$

Breaking down the components of this formula:
- T(t): Total winding temperature.
- T(c): Cold motor (ambient) temperature.
- R(h): Hot motor resistance.
- R(c): Cold motor resistance.
- 234.5: A constant value specific to copper windings.

In addition to the aforementioned approach, motor temperature assessment can also be achieved through the use of transducers and specialized devices designed for this explicit purpose.

In summary, a comprehensive grasp of the factors contributing to motor overheating is essential to ensure effective motor operation and prevent potential damage or malfunction resulting from excessive heat.

Voltage variation

The motor's optimal performance relies on maintaining a consistent voltage level within a defined range. Fluctuations in the power supply voltage can lead to two critical challenges: over-voltage and under-voltage conditions. Over-voltage puts excessive strain on the motor's insulation, potentially causing insulation breakdown and other electrical problems. Conversely, under-voltage scenarios result in elevated line currents, leading to an undesirable increase in the motor's winding temperature, which can eventually harm the motor.

To address these concerns and ensure the motor's safe and efficient operation, standard practice involves the use of over/under voltage relays for monitoring voltage levels and detecting potential faults. However, in this paper, a more sophisticated approach is taken by implementing DS1820 sensors for temperature measurement and voltage sensors for voltage level monitoring. This integrated sensor system offers precise monitoring and analysis of both temperature and voltage, enabling early detection of any impending issues and thereby enhancing the motor's overall reliability and performance.

3. Design

The implementation of motor overheating protection stands as a pivotal cornerstone in ensuring the longevity and reliable operation of the motor. Its primary mission is to shield the motor's windings from potential harm due to extreme temperature fluctuations. To execute this vital function, a DS1820 sensor takes the stage, intricately connected to the heart of the system - the ARDUINO Nano controller. The DS1820 sensor assumes a central role in this protective ensemble by diligently and continuously monitoring the temperature of the motor's windings.

When the temperature exceeds a predetermined safety threshold, the DS1820 sensor rapidly transmits a signal, setting into motion the intelligence of the ATmega328P microcontroller. This microcontroller is a versatile and high-performance 8-bit powerhouse, boasting a generous 32KB of Flash memory. Its primary role within the system is to enable real-time decision-making. When the temperature breaches the predefined safety parameters, the ATmega328P springs into action, orchestrating a prompt and effective response, which may involve an immediate shutdown of the motor to prevent overheating-induced damage.

The broader system's architecture encompasses three core elements: the three-phase power supply, the three-phase induction motor, and the indispensable control unit. This control unit serves as the brain of the system and features a dedicated DC power supply that is indispensable for the flawless operation of the microcontroller circuit and temperature sensor.

At the heart of this intricate setup, the ARDUINO Nano takes centre stage. This remarkable microcontroller board is meticulously crafted by Arduino. cc in Italy combines versatility with compactness. While retaining full compatibility with breadboards, it offers the same extensive functionality as the Arduino UNO but in a more compact and space-efficient form factor. Operating at a steady 5V, the ARDUINO Nano exhibits flexibility by accommodating input voltages ranging from 7 to 12V. Its comprehensive pin configuration includes 14 digital pins, 8 analog pins, 2 reset pins, and 6 power pins. Each of these pins boasts the ability to serve multifaceted roles, with their primary function dynamically adjusted to cater to the unique input or output requirements of the specific application at hand.

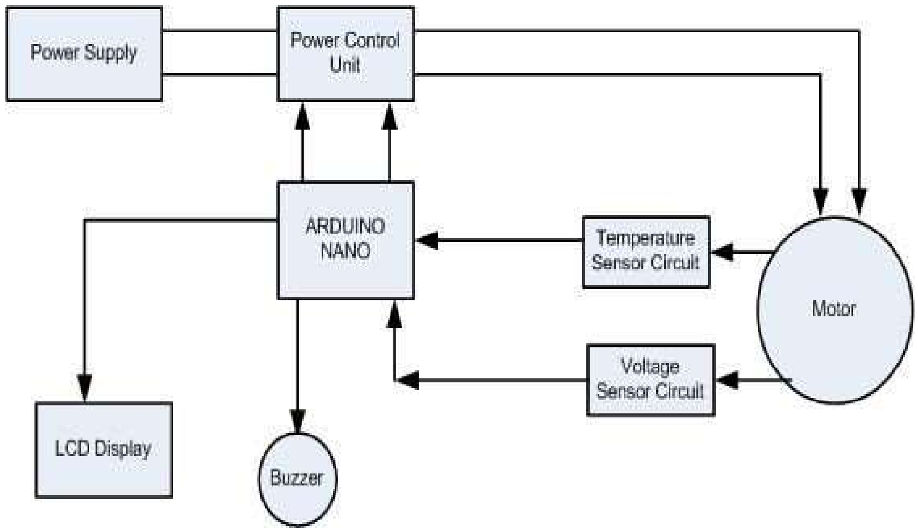

Figure 1: System Block Diagram of Protection System

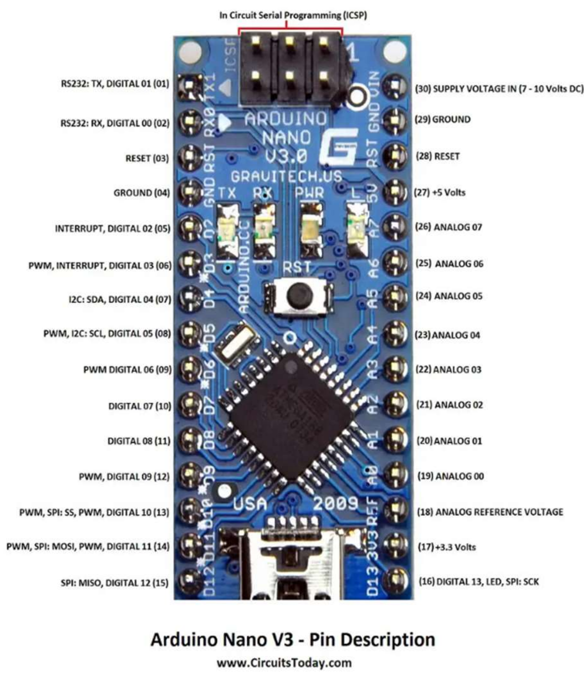

Figure 2: Pin Diagram of Arduino Nano

In the realm of DC power circuits, one of the critical components is the rectifier circuit, featuring the renowned 1N4007 diode. This diode plays a pivotal role in ensuring the unidirectional flow of current, specifically directing it from the anode to the cathode. To make it easily distinguishable, the cathode terminal is thoughtfully marked with a distinct gray-colored ring. The 1N4007 diode boasts impressive specifications, including a remarkable maximum current-carrying capacity of 1A. This makes it a suitable choice for applications with current requirements falling below this threshold. What's more, it exhibits the remarkable ability to withstand peak currents of up to 30A, further enhancing its versatility and robustness. It's worth noting that the diode's reverse current, which is a mere 5uA, can be considered negligible. Moreover, the diode possesses a notable power dissipation rating of 3W, underscoring its capabilities in handling power loads effectively.

Now, turning our attention to temperature sensing, the DS18S20 sensor takes center stage as a highly capable digital thermometer. It excels in providing precise 9-bit Celsius temperature measurements and further augments its utility with an alarm function that features nonvolatile user-programmable upper and lower trigger points. One of the most distinctive features of the DS18S20 is its communication protocol, which operates seamlessly over a 1-Wire bus. This ingeniously designed protocol requires only a single data line and a ground connection for interaction with a central microprocessor. Furthermore, the DS18S20 exhibits the remarkable ability to draw power directly from the data line, eliminating the need for an external power supply. Each DS18S20 sensor is endowed with a unique 64-bit serial code, a feature that simplifies the coexistence of multiple DS18S20 sensors on the same 1-Wire bus. This remarkable attribute streamlines the management of temperature sensing across extensive areas, allowing a single microprocessor to efficiently oversee and control numerous DS18S20 sensors dispersed throughout a large facility.

The versatility and scalability of the DS18S20 sensor find application in a wide array of scenarios. These encompass HVAC environmental control, temperature monitoring within buildings, machinery, and equipment, as well as process monitoring and control systems. The sensor's adaptability and its capacity to efficiently handle multiple temperature sensing points make it an indispensable asset in situations where comprehensive temperature monitoring and control are imperative.

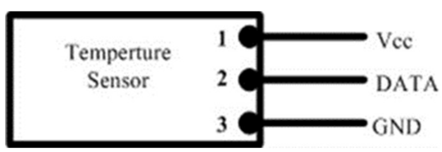

Figure 3: Pin Diagram of Temperature Sensor

Figure 4: Temperature Sensor DS18S20

A relay, a fundamental component in electrical systems, assumes the role of an electrically operated switch, and it encompasses a rich tapestry of operational principles. While the conventional relay predominantly employs an electromagnet to initiate a mechanical switching mechanism, the world of relays is characterized by a spectrum of diverse operating principles. In the realm of solid-state relays, a significant departure from their electromechanical counterparts is evident, as they take charge of power circuits without the presence of moving parts. Instead, these relays harness semiconductor devices, frequently employing silicon-controlled rectifiers or triacs, to adeptly execute the task of switching.

Moreover, the analog switch emerges as a novel addition to the relay family, demonstrating innovative engineering. This ingenious device leverages the capabilities of two MOSFET transistors, meticulously arranged in a transmission gate configuration, to function as a switch. In its operation, the analog switch closely resembles the traditional relay, but it brings forth a unique set of advantages while also bearing certain inherent limitations when contrasted with electromechanical relays. The analog switch embodies the continuous evolution and adaptability of relay technology, offering inventive solutions for a wide range of electrical switching applications in the modern age of electronics.

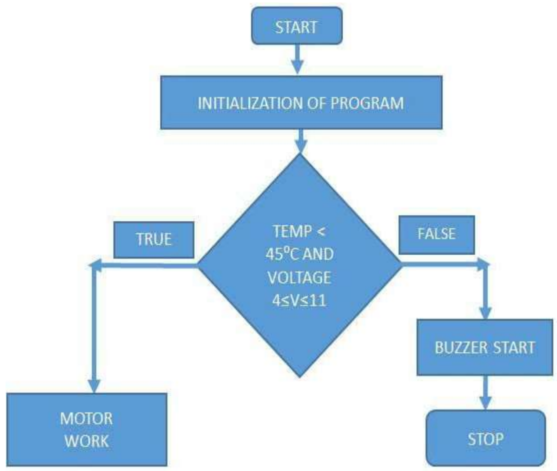

Figure 5: Flow chart

To design a comprehensive system for safeguarding a motor from under-voltage, over-voltage, and temperature-related faults, an intricate circuit has been assembled. This circuit comprises several key components, including a voltage sensor, a DS1820 temperature sensor, relays, an LCD display, a buzzer, an Arduino Nano, an ATmega328P microcontroller, a DC buck converter, a potentiometer (POT), a DC motor, and more. The entire hardware setup is visually depicted in the accompanying figure, which provides a comprehensive view of the system's components and their interconnections.

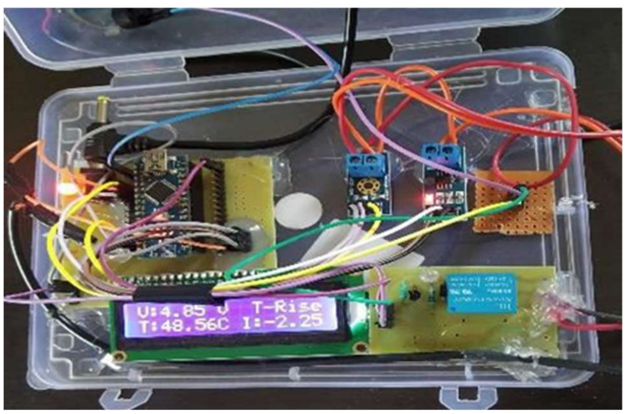

Figure 6: Hardware Implementation

4. Result and Conclusion

Elevated motor temperatures can result from a variety of factors such as motor overloading, bearing seizures, or obstructions preventing the motor shaft from turning freely. Additionally, motor startup issues may arise due to faulty starting windings. This paper focuses on addressing temperature-related faults in the motor. To detect and mitigate the risk of overheating, the DS1820 temperature sensor is employed. This sensor is intricately connected to the inputs of a comparator. The DS1820 sensor plays a pivotal role by continually monitoring the temperature of the motor's winding. Should the temperature exceed a predefined threshold, the comparator generates a signal, which is then transmitted to the microcontroller. This signal serves as an early warning system, enabling timely intervention to prevent potential damage caused by excessive heat in the motor winding.

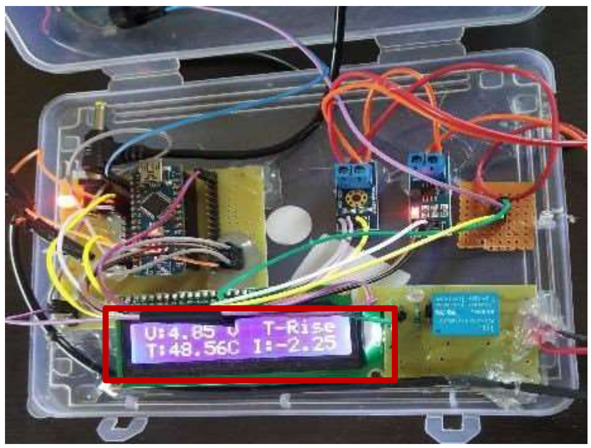

Figure 7: Temperature sensor results

The circuit design incorporates protective measures to prevent motor damage under extreme conditions. When the temperature surpasses 45°C, the relay detects this excessive heat and triggers a signal to the Arduino Nano. Subsequently, the circuit is shut down, resulting in the motor coming to a stop. This proactive approach safeguards the motor from overheating.

Furthermore, in situations where the voltage exceeds 11V, the relay is programmed to identify this overvoltage condition. Once detected, it communicates with the Arduino Nano, leading to the circuit's interruption and motor shutdown. This mechanism effectively safeguards the motor against the risks associated with overvoltage.

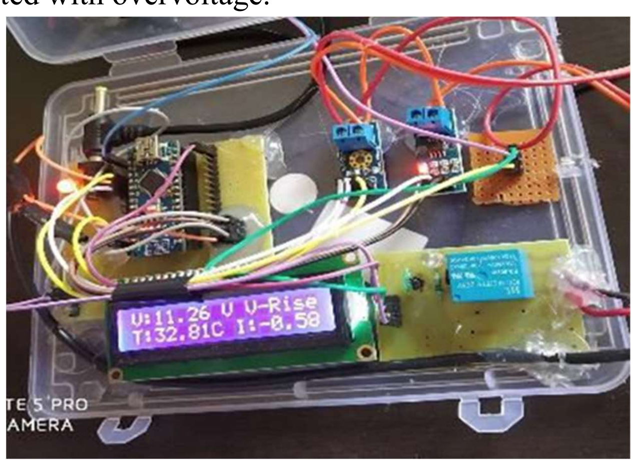

Figure 8: Output of Overvoltage

The circuit design incorporates protective measures to prevent motor damage under low voltage conditions. If the voltage drops below 4V, the relay detects this under-voltage condition and signals the Arduino Nano. Consequently, the circuit is interrupted, resulting in the motor coming to a stop. This approach effectively safeguards the motor from the potential risks associated with insufficient voltage, ensuring the motor's safe operation.

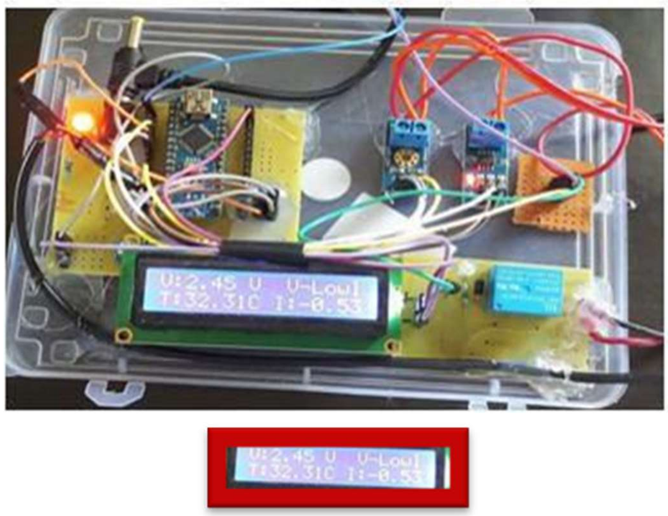

Figure 9: Output of under-voltage

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