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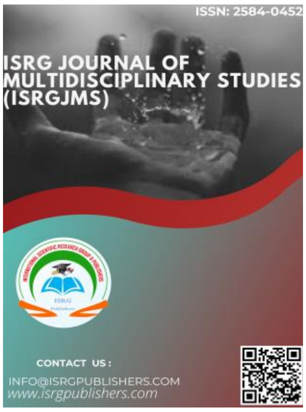

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DESIGN AND CONSTRUCTION OF A THREE PHASE PROGRAMMABLE SWITCH FOR INDUCTION MOTOR/PUMPS

Omofuma Osamonyi Ighodalo

Department of Electrical/ Electronics Engineering, Ogun State Institute of Technology, Igbesa, Nigeria.

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***Corresponding author:** Omofuma Osamonyi Ighodalo
Department of Electrical/ Electronics Engineering, Ogun State Institute of Technology, Igbesa, Nigeria.

Abstract

This research presents the development of a versatile programmable three-phase motor system tailored to the specific needs of both industrial and agricultural sectors. The system's core advantages, encompassing precise scheduling, automation, and programmable control, result in substantial operational efficiency and adaptability enhancements, effectively addressing the distinct requirements of these diverse applications. The study follows a comprehensive structure, covering introductory, rationale, objectives, literature review, methodology, results, and discussion sections, culminating in valuable findings with broad implications. The research contributions underscore its potential to optimize motor-driven processes in industrial and agricultural contexts, offering a promising solution to evolving motor control demands. Furthermore, as we peer into the future, it becomes evident that the industrial landscape is transforming by integrating automation, IoT, and AI technologies in Nigeria. This evolution extends to the system, with the time switch component poised for expanded programmable settings, enhanced utility through the UNL2003 MOTOR DRIVER, and advanced security features. The envisioned addition of Bluetooth and Wi-Fi capabilities for remote machinery shutdown and scalability for various industrial motor capacities will redefine industrial operations and safety protocols, positioning Nigeria at the forefront of industrial automation and efficiency.

Keywords: *programmable logic controllers, three-phase motor, industrial, and agricultural use*

1. INTRODUCTION

A programmable controller for a 3-phase motor that automatically turns the motor on and off can be developed using a programmable time switch, allowing for a maximum of eight time durations to be set. This system includes two programmable time switches to establish the motor's starting and stopping times, along with two control circuits that interface with the start and stop switches of the

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3-phase motor starter (Bureau, 2019). In manufacturing automation, there has been a notable convergence of programmable logic controllers (PLCs) and power electronics with electric machine applications, owing to the advent of motion control technology (Fabian & Hellgren, 1998). Electric motors, serving as pivotal components in this realm, operate by converting electrical energy into mechanical motion, relying on the principles of electromagnetism. Among the diverse array of electric motors available, the three-phase induction motor has garnered prominence due to its cost-effectiveness and operational efficiency, particularly in industrial and agricultural settings. Its utility extends to precision sensor measurements, facilitating optimised water distribution in agriculture to enhance water resource utilisation. Additionally, it finds application in conveyor systems and machinery requiring alternating rotation directions. This versatility in industrial contexts is further accentuated when coupled with monitoring and control systems, enabling high-performance variable-speed applications while adhering to stringent speed requirements for cost-effective operation.

The focal point of this study is developing a programmable control system for a three-phase induction motor, showcasing a comprehensive programmatic functionality. This system empowers users to predetermine motor activation and deactivation schedules based on specific timeframes and days, eliminating the need for manual intervention. Safety enhancements are incorporated by integrating an Infrared (IR) sensor, designed to detect and respond to environmental conditions, bolstering the system's overall safety (Zagade et al., 2021). Furthermore, a password-based access control mechanism is integrated, adding an extra layer of security by mandating authorised password inputs for circuit operation, effectively curbing unauthorised access. The system is fortified with protective features to safeguard the three-phase motor against operational contingencies like overloading, single-phasing, phase imbalances, alterations in phase sequences, and short circuits, ensuring its longevity and reliability.

In the industrial sector, the programmable three-phase motor proves invaluable for tasks requiring precise and automated machinery and equipment control, enhancing production efficiency and minimising downtime. Its programmability and incorporation of safety measures make it adaptable to various industrial environments, where equipment and personnel safety are paramount. Conversely, in agricultural contexts, this technology could revolutionise irrigation practices. It promotes water conservation and crop yield optimisation by enabling precise scheduling and control of water distribution. The system's adaptability extends to real-time monitoring and adjustment through sensor integration and data analytics, ensuring efficient resource utilisation.

This research aims to realise a programmable three-phase motor system that serves the dual purposes of industrial and agricultural applications, aligning with the growing demand for versatile and efficient motor control solutions. The system's advantages encompass precise scheduling, automation, and programmable control, collectively contributing to enhanced operational efficiency and adaptability. These benefits align closely with the nuanced requirements of industrial and agricultural applications, underscoring the system's value in optimising motor-driven. Block diagram of the system is shown in Fig. 1. The structure of this research comprises an introductory section, followed by the rationale behind the proposed system and its objectives. The following section outlines a brief literature review. Subsequent sections outline the research methodology, present results, and discuss comprehensively. The concluding section encapsulates the study's findings and implications, summarising the research's contributions and potential applications in industrial and agricultural contexts.

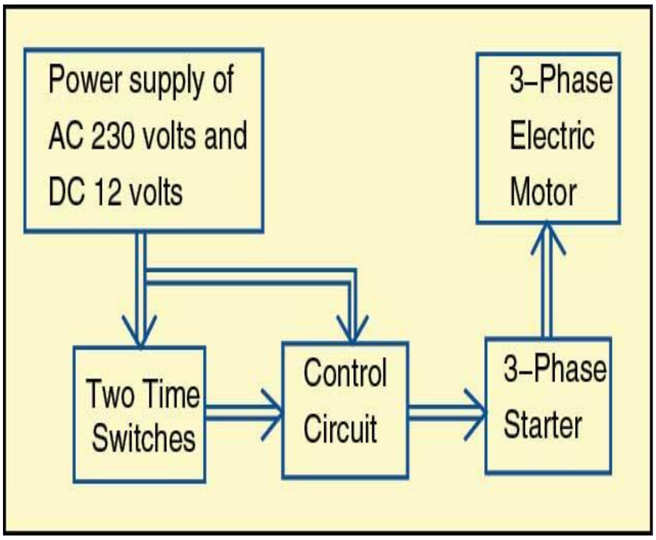

Fig. 1: Block diagram of the 3 phase motor programmable controller

Source: Bureau (2019)

1.1. The rationale behind the proposed system

Suppose both time switches are synchronised to the same clock settings. For instance, if the start time for Timer 1 in ON mode is set to 8:00 AM, the OFF mode will be programmed to 8:01 AM in the same switch. Similarly, if the stop time for Timer 2 in ON mode is set to 9:00 AM, the OFF mode will be configured to 9:01 AM.

At 8:00 AM, the start time switch energises the primary winding of transformer X1 by connecting it to a 230V AC supply. The output from the power supply is directed to the reset pin 4 of IC1. Resistor R4 and capacitor C3 function as self-triggering elements. Consequently, the output of the monostable circuit at pin 3 is driven high for a duration determined by 1.1×R5×C4, which is approximately five seconds.

The establishment of the proposed system is underpinned by several compelling imperatives, each contributing to its necessity and significance:

i. Motor safety enhancement: The proposed system focuses on improving the safety and reliability of motors, which is particularly important in industrial and agricultural applications. Motors face various operational challenges, and the system is designed to enhance their durability, reduce downtime, and improve industry efficiency while ensuring consistent performance in motor-driven agricultural systems.

ii. Operator well-being: The proposed system prioritises the safety of personnel operating motors in industrial and agricultural settings. It aims to implement safety measures to protect individuals, emphasising the importance of both motor functionality and the well-being of operators and maintainers, especially in contexts with frequent human-machine interaction.

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iii. Precision in motor control: The proposed system emphasises precise motor control, vital in the industrial and agricultural sectors. It aims to provide advanced tools for operators to achieve fine-grained control over motor operations, ensuring alignment with specific goals and enhancing efficiency and productivity in these contexts.

1.2. Research objectives

The objectives of this research endeavour align with the pursuit of efficient and secure motor operation within industrial and small-scale manufacturing contexts. These objectives, which are informed by the imperatives of contemporary automation and safety standards, are enumerated as follows:

i. simplify the motor control process, rendering it more efficient and cost-effective.
ii. facilitate the automation of machinery within the milieu of small-scale industries.
iii. ensure the motor operates with precision and ensures optimal operational efficiency and resource utilization.
iv. provide control over line voltage while concurrently upholding the highest security standards.
v. provide for instantaneous machine stoppage in response to faults or emergency conditions, with the sole aim of prioritising the safety of both equipment and personnel, mitigating potential hazards.
vi. operate the load using contemporary circuit breakers, aligning with modern technological advancements, and
vii. provide comprehensive protection to machinery against electrical faults, safeguarding equipment integrity and operational continuity.

2. LITERATURE REVIEW

The application of three-phase induction motors encompasses a broad and diverse spectrum of industrial and technological domains. These applications extend to areas such as developing energy-efficient electric propulsion systems for agricultural machinery, as Khalina et al. (2022) demonstrated. Moreover, three-phase induction motors are helpful in the crucial realm of elevator and lift operation, a facet underscored by DEVIANTO's work in 2021. Beyond vertical transportation, their significance extends to power generation, exemplified in the study conducted by Alim et al. in 2019. Additionally, these motors play a pivotal role in the actuation of green tire-building machinery, a critical component of tire manufacturing, as substantiated by the research by Hendarto and Triyana in 2014. Their versatility further extends to propelling electric vehicles, as explored by Purwanto et al. in 2011.

The ubiquity of three-phase induction motors across such varied domains can be attributed to a trifecta of compelling factors. First and foremost, their cost-effectiveness makes them an attractive choice for diverse applications, aligning with the economic imperatives of industries and enterprises. Secondly, their ease of operation renders them accessible and manageable within a wide array of contexts, reducing the threshold for adoption. Finally, as elucidated by Nasution et al. in 2020, the motors' minimal maintenance requirements bolster their appeal, as they offer sustained operational efficiency with reduced upkeep demands. These attributes collectively contribute to the widespread utilization of three-phase induction motors, underpinning their significance in contemporary industrial and technological landscapes. One pivotal characteristic driving the ubiquity of three-phase induction motors is their seamless rotation direction control capacity. Such control is particularly vital in the realm of conveyor systems or conveyor belts (Syafrudin & Hasibuan, n.d.). Numerous studies have endeavoured to design systems for managing the direction of rotation of induction motors, exemplified by diverse approaches, including reverse starting via an SMS controller utilizing the Bascom programming language (Denis et al., 2013), rotation direction control facilitated by an Arduino Uno and Bluetooth module HC-06 (Kurnianto, 2019), as well as circuitry for reversing the forward and reverse electric motor direction using relay configurations (Wahyudi, 2020). Furthermore, research has extended into more sophisticated implementations, such as PLC-based star-delta connections for three-phase induction motor rotation direction control (Sihombing, 2008), the realization of PLC Omron CP1E-based control systems (Rahmansyah & Satriadi, 2015), three-phase induction motor control via Arduino Mega with a Human Machine Interface (Mariani & Hastuti, 2020), and the design of control and IoT-based monitoring systems for three-phase induction motors (Syahreja, 2018).

The Programmable Logic Controller (PLC) has enjoyed widespread popularity since its inception, mainly due to its capability to supplant relay-based control functions. Relay-based control circuits are notorious for their complexity and substantial cost requirements for altering control functions. PLCs have emerged as indispensable tools for directing the rotation of DC motors, exemplified in applications such as the design of a control mechanism for power window motor direction based on Panasonic PLC and Human Machine Interface (Alfitri & Setiono, 2016), as well as the utilization of PLCs for regulating the direction of rotation in DC motors powering miniature substations (Aripin & Moediyono, 2013). Among the PLCs gaining significant traction in the field, the Omron PLC type CP1E stands out, distinguished for its versatility and utility. Figure 1(a) and (b) provide insight into the input and output wiring configuration of the PLC Omron CP1E (Maulana, 2022).

More importantly, the Human-Machine Interface (HMI) is pivotal in integrating humans and machinery within operational contexts. This interface is meticulously designed to function as a visual medium, strategically crafted to facilitate the interaction between operators and the control systems they oversee. A distinguishing characteristic of HMI systems is their incorporation of touchscreens, enabling operators to issue instructions to the control system with unparalleled ease. Operators can effortlessly engage with the control system by pressing physical buttons or inputting data via the Graphical User Interface (GUI) presented on the touchscreen interface.

Implementing HMI designs often entails the utilization of microcontrollers in tandem with Thin-Film Transistor (TFT) screens, synergistically enhancing the control system's functionality. Within this context, one notable HMI model that lends its support to Omron Programmable Logic Controllers (PLCs) is the HMI NB7W-TW00B. Figure 2 and 3 visually represents this specific HMI model (Omron, 2017). This HMI is a crucial intermediary in the control and monitoring processes, bridging the gap between human operators and the intricate machinery they oversee.

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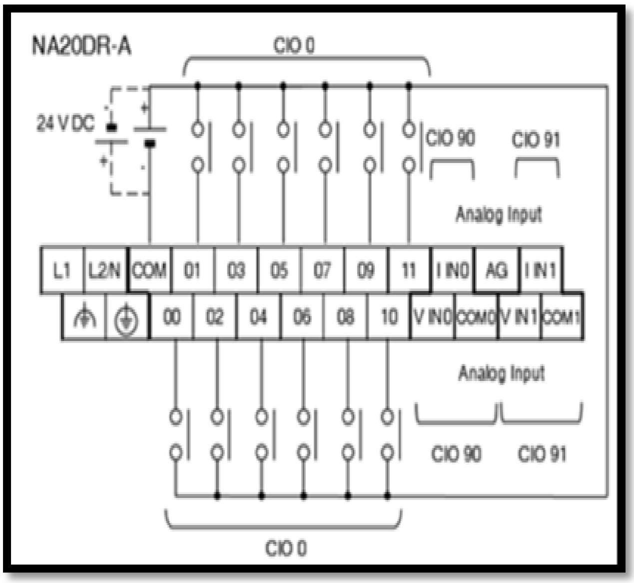
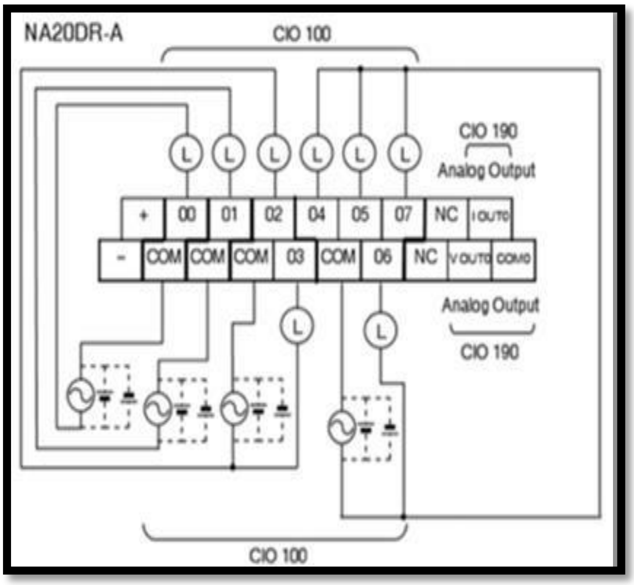
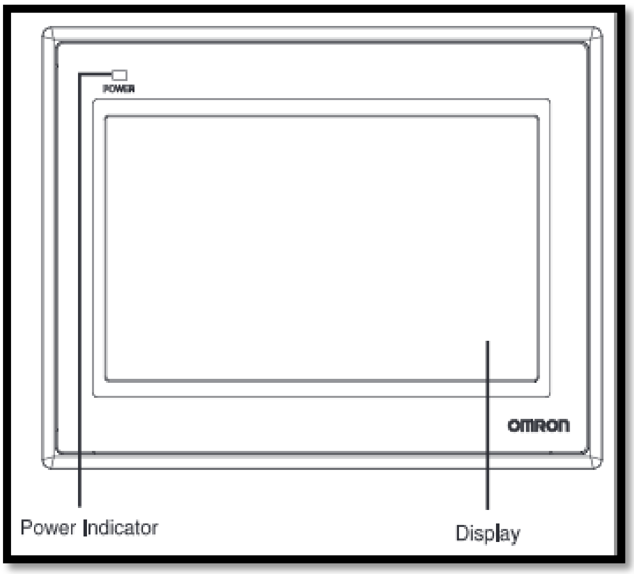


(a) Wiring Input

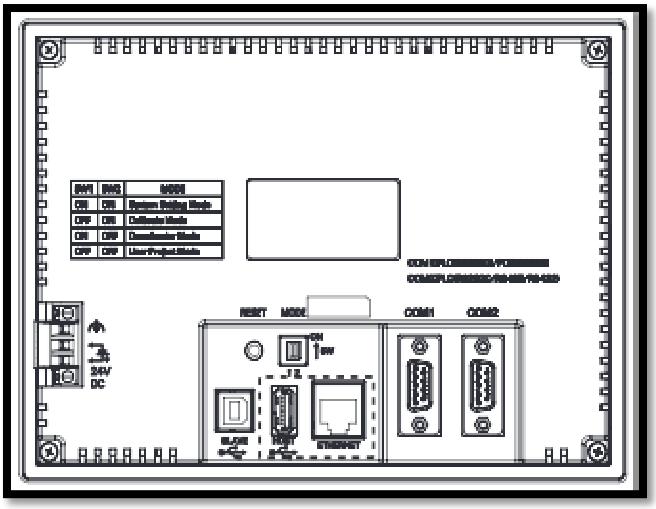


(a) Wiring Input

Figure 2. PLC Omron CP1E



(a) Front view



(b) Back view

Figure 3. HMI NB7W-TW00B

Source: Nrartha, Riswandi & Supriono (2022)

3. MATERIALS AND METHODS

The three-phase programmable switch for induction motors or pumps is an advanced control device designed to manage the operation of three-phase electrical equipment efficiently. This sophisticated switch incorporates programmable logic controllers (PLCs) or microcontrollers to offer precise timing, sequencing, and monitoring of motor functions. It enables users to set custom operating schedules, define start-up and shutdown sequences, and implement safety protocols such as overload protection and phase loss detection. The switch can monitor various parameters including current draw, voltage fluctuations, and power factor, allowing for real-time adjustments and preventive maintenance. Advanced models may feature remote operation capabilities through SCADA systems or mobile applications, facilitating integration into smart industrial networks. Additionally, the switch can be programmed to optimize energy consumption by adjusting motor speed or implementing soft start/stop functions, thereby reducing wear on the equipment and lowering operational costs.

Importantly, the sequence of operation for the research comprises several distinct stages. The first part is dedicated to the preliminary preparations and data collection, mainly focused on creating a power circuit tailored for a three-phase induction motor. In the second part, emphasis shifts towards developing a control circuit that effectively manages the direction of rotation for the induction motor, employing a relay circuit. The third part extends this trajectory by delineating the design of an induction motor rotation direction control circuit, employing a PLC-HMI (Programmable Logic Controller-Human-Machine Interface) system. Finally, the last part entails a comprehensive discussion of the research outcomes and draws pertinent conclusions based on the findings.

It is worth noting that the features align with the advanced control capabilities required for managing three-phase induction motors or pumps, allowing for precise timing, scheduling, and potentially energy-efficient operation based on programmed parameters. The programmable nature of the switch, as illustrated in this flowchart, enables customization of motor operation to suit specific industrial or commercial needs. The program for the circuit was written in assembly language. The type of assembly language is the MPASM. The codes were compiled by this compiler and downloaded to the PIC16F876A.

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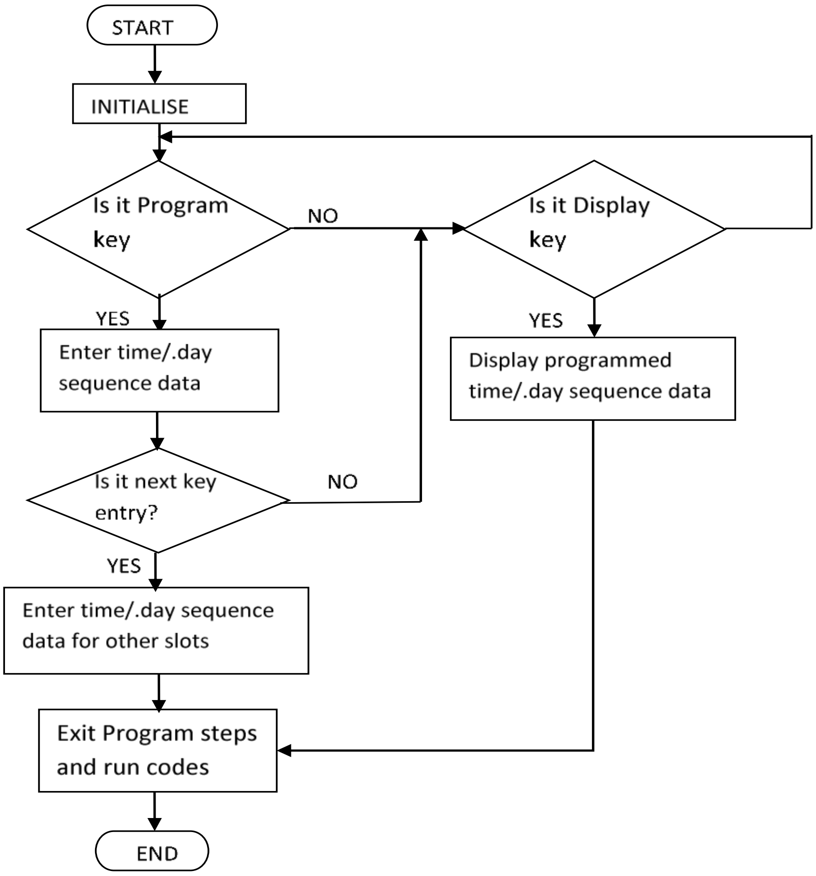

Figure 4: Flowchart for codes development of for microcontroller

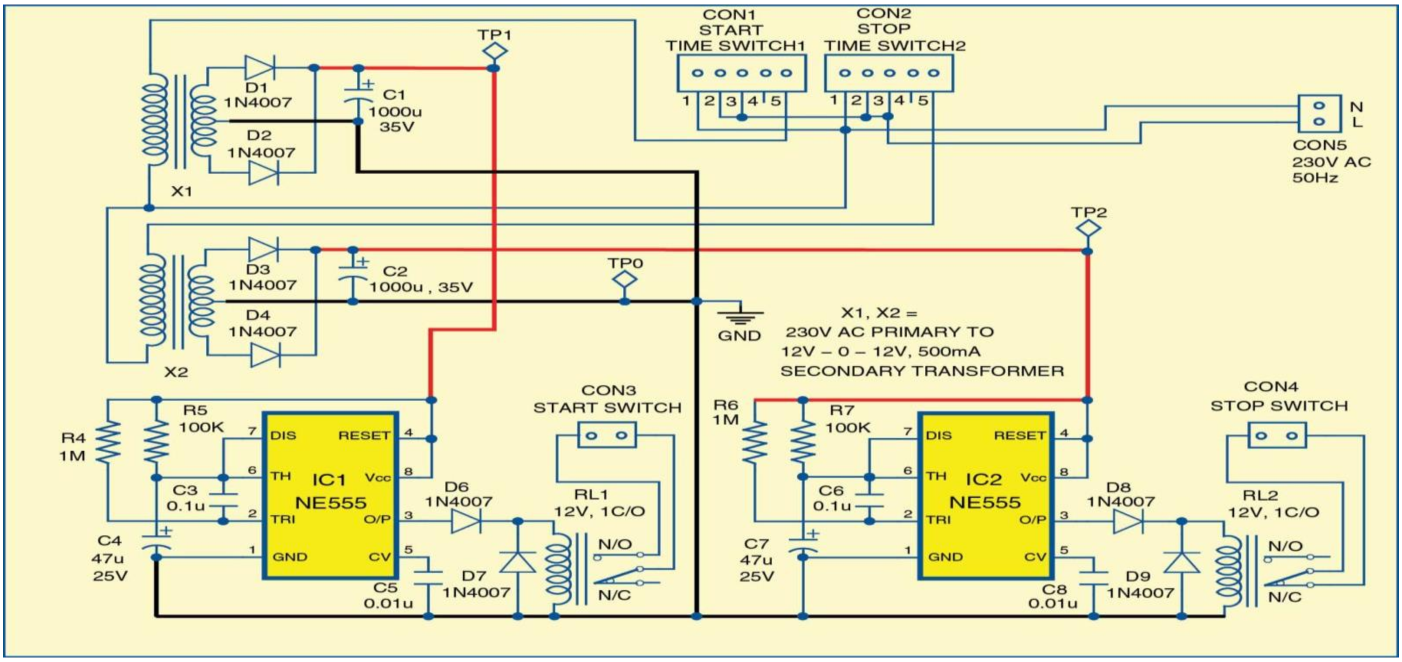

Fig. 5: Circuit diagram of the 3 phase motor programmable controller
Source: Adapted from Bureau (2019)

When pin 3 of IC1 goes high, relay RL1 is activated for five seconds, energising the relay and effectively shorting the start switch, thereby supplying 3-phase power to the motor and simulating the manual pressing of the motor starter's start button for five seconds. At 9:00 AM, the stop switch (second time switch) applies 230V AC to the primary winding of transformer X2, and through a full-wave rectifier and filter circuit, 12V DC is provided to the second monostable circuit, controlling relay RL2 in the same manner as earlier. The normally-closed (N/C) terminal of the relay is connected in series with the motor starter’s stop switch, allowing the relay to break the circuit and stop the motor.

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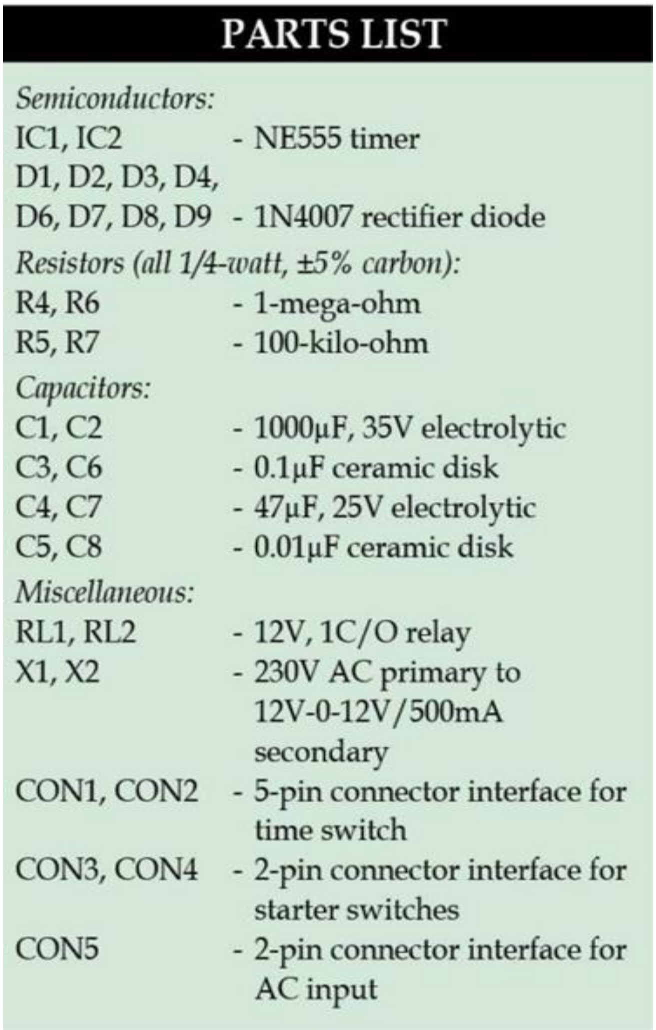
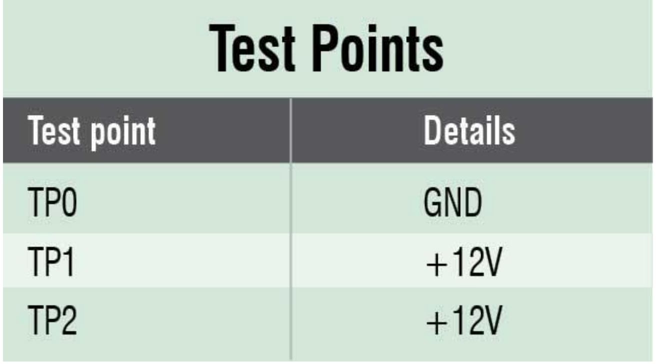


PARTS LIST

Semiconductors:
IC1, IC2 - NE555 timer
D1, D2, D3, D4,
D6, D7, D8, D9 - 1N4007 rectifier diode
Resistors (all 1/4-watt, ±5% carbon):
R4, R6 - 1-mega-ohm
R5, R7 - 100-kilo-ohm
Capacitors:
C1, C2 - 1000µF, 35V electrolytic
C3, C6 - 0.1µF ceramic disk
C4, C7 - 47µF, 25V electrolytic
C5, C8 - 0.01µF ceramic disk
Miscellaneous:
RL1, RL2 - 12V, 1C/O relay
X1, X2 - 230V AC primary to 12V-0-12V/500mA secondary
CON1, CON2 - 5-pin connector interface for time switch
CON3, CON4 - 2-pin connector interface for starter switches
CON5 - 2-pin connector interface for AC input

Figure 5a: Parts List



Test Points

Test point	Details
TP0	GND
TP1	+12V
TP2	+12V

Figure 5b: Test Points

This system allows for programming up to eight time intervals, such as the example of an 8:00 AM to 9:00 AM duration, to automatically control the 3-phase motor's operation. Additionally, the controller can be configured to function on specific days, such as Monday to Friday, Monday to Saturday, all days of the week, or even just a single day. This flexibility makes it ideal for a variety of applications, including managing water pumps in multi-storey commercial buildings to fill overhead tanks, as well as for use by farmers, industrial facilities, or railway stations where 3-phase motors are frequently needed.

Circuit operation

Two identical power supply circuits, built around transformers X1 and X2, provide 12V DC to two control systems using 555 timer ICs (IC1 and IC2) in monostable mode, as shown in Fig. 5. The system utilises two Frontier-made time switches, model TM-619-2, operating on 230V AC at 50Hz, each equipped with a single changeover relay rated at 16A. These time switches feature an LCD display and buttons, including CLOCK, TIMER, DAY, HOUR, MIN, and MANUAL, as shown in Fig. 3, allowing users to set a real-time clock and program multiple time durations. With a built-in real-time clock, the programmable time switch can schedule up to eight time durations for specific days, alternate days, Monday to Friday, Monday to Saturday, or Monday to Sunday.

Fig. 6a: Front of the time switch

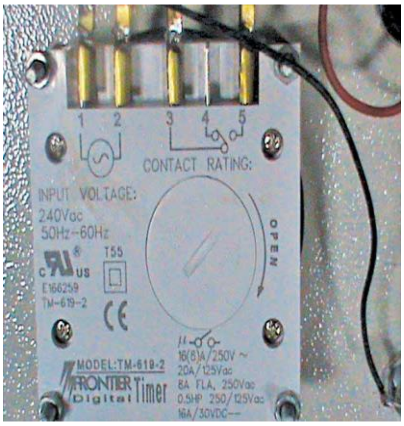


Fig. 6b: Rear of the time switch

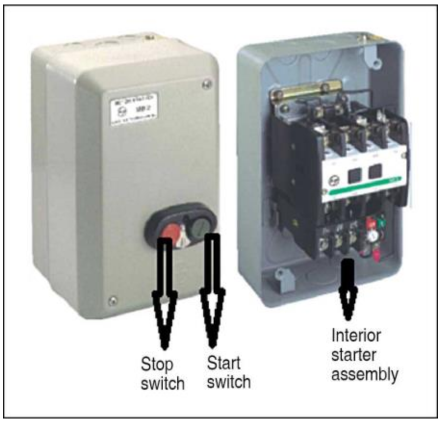


Fig. 6c: A typical starter for a 3 phase motor

To set the real-time clock, the CLOCK button is pressed while the HOUR, MIN, and DAY buttons adjust the time. Programming time durations is accomplished using the TIMER, HOUR, MIN, and DAY buttons. The time switch operates in three modes—ON, AUTO, and OFF—displayed beneath the screen. After setting the time durations, the MANUAL button moves a black horizontal line segment from OFF to AUTO mode. The time switch includes five

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external pins (labelled 1 to 5), as shown in Fig. 6a. A 230V AC supply is connected across pins 1 and 2 of connectors CON1 and CON2 for both the start and stop switches, with pin 1 acting as neutral. Live pins 2 are wired to pins 3, and the output voltage is drawn from pins 1 and 5. A CR2032 button cell preserves the clock and programmed times during power outages, allowing uninterrupted operation for 60 to 90 days. The cell recharges when mains power is available.

The control circuit employs two monostable multivibrators that provide a five-second delay. The first multivibrator, built around IC1, is connected to the start time switch, as shown in Fig. 3. For instance, to program a time duration from 8:00 AM to 9:00 AM in weekly mode, 8:00 AM is set as the 1 ON mode, and 8:01 AM as the 1 OFF mode in the first time switch. The motor is powered down via the second multivibrator circuit, also shown in Fig. 3, where the normally closed (N/C) and common terminals of relay RL2 are connected in series with the motor starters off switch. The second time switch's real-time clock is configured similarly by holding the CLOCK button and using the HOUR, MIN, and DAY buttons to adjust the time.

At 9:00 AM, the second time switch supplies 230V AC to the primary of transformer X2. The full-wave rectifier then delivers 12V DC to the second monostable multivibrator circuit, as illustrated in Fig. 3. In addition, Fig. 6c provides a visual of a typical 3-phase motor starter and its internal components. Two push-buttons are visible on the right: a green button starts the motor, while a red button stops it. The system also includes a relay coil. When the start button is pressed briefly, current flows through the coil, causing the relay strip to engage with the coil’s iron core and apply 3-phase voltage to the motor.

4. RESULTS AND DISCUSSION

The experimental results demonstrate the effectiveness of using a PLC-based control system for improving the performance of three-phase induction motors. Key findings include:

i. Speed Regulation Accuracy:

The PLC-controlled system achieved high accuracy in speed regulation, maintaining constant speed under variable load conditions up to 96% of the synchronous speed. This represents a significant improvement over conventional V/f control methods.

ii. Efficiency Improvements:

The PLC-controlled system showed increased efficiency compared to both open-loop inverter-fed and standard mains-supplied configurations. Efficiency improvements of 10-12% were observed at higher speeds and loads. This can be attributed to the PLC's ability to maintain very low slip values across operating conditions.

iii. Optimized PWM Pulses:

Varying the number of PWM pulses per half cycle affected motor efficiency. The results indicate that 7 pulses per half cycle provided optimal efficiency, with performance decreasing at higher pulse counts likely due to increased switching losses. This highlights the importance of proper PWM optimization.

iv. Speed-Efficiency Relationship:

Motor efficiency increased with speed up to around 1150 RPM, after which it began to decrease. This aligns with expectations, as efficiency typically peaks near rated speed before declining due to increased losses at higher speeds.

v. Flexibility and Programmability:

The use of a microcontroller-based system allowed for easy adjustment of control parameters and PWM strategies through software changes, without requiring hardware modifications. This flexibility is valuable for optimizing performance across different operating conditions.

vi. Protection and Monitoring:

The implemented control software provided overload protection and continuous monitoring of key parameters like speed and stator current. This enhances the overall reliability and safety of the motor drive system.

vii. Transient Performance:

While not explicitly quantified, the authors note that the system exhibited oscillations in torque during transients, limiting its suitability for applications requiring rapid speed changes. This suggests room for further optimization of the control algorithms.

4.1. Operation Dynamics

The PLC-controlled three-phase induction motor system operates like a coordinated team. The PLC acts as the brain, making decisions about when and how the motor should run. Power electronics serve as the muscles, controlling the electricity flow based on the PLC's instructions. The induction motor itself is the workhorse, converting electrical energy into mechanical motion. These components interact constantly, adjusting to each other's needs and responses. Running this system smoothly requires careful synchronization of all parts, much like conducting an orchestra to create a harmonious performance.

a) Speed Control:

The core of the system's operation dynamics lies in its ability to maintain constant speed under varying load conditions. This is achieved through a closed-loop control system where the PLC continuously monitors the actual motor speed via a speed sensor (typically a tachometer or encoder) and compares it to the desired setpoint. Any deviation triggers a correction in the control output.

The system employs a Proportional-Integral (PI) control algorithm. The error signal (difference between setpoint and actual speed) is multiplied by a proportional gain (Kp) and integrated over time. This combined signal is then used to adjust the voltage-to-frequency (V/f) ratio of the inverter output. The PI control ensures both rapid response to changes (proportional term) and elimination of steady-state errors (integral term).

b) PWM Generation:

A key aspect of the operation dynamics is the generation of Pulse Width Modulation (PWM) signals. The PLC generates these signals based on the required V/f ratio. The number of pulses per half cycle significantly impacts the motor's performance. The research showed that 7 pulses per half cycle provided optimal efficiency, likely due to a balance between waveform quality and switching losses.

c) Load Response:

Under varying load conditions, the system dynamics come into play. As load increases, the motor tends to slow down. The PLC detects this speed drop and responds by increasing the V/f ratio, effectively increasing the voltage supplied to the motor to maintain constant speed. This dynamic adjustment occurs continuously, allowing the motor to maintain its set speed across a wide range of loads.

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d) Efficiency Optimization:

The system's operation dynamics include continuous optimization for efficiency. By maintaining very low slip (difference between synchronous and rotor speed), the PLC minimizes rotor losses. The control algorithm adjusts the V/f ratio not just for speed control, but also to keep the motor operating in its most efficient region.

e) Transient Behaviour:

During sudden changes in load or speed setpoint, the system exhibits transient behaviour. The research noted some oscillations in torque during these transients. This indicates a complex interplay between the motor's inertia, the control system's response time, and the electrical characteristics of the motor and inverter.

f) Protection Dynamics:

The operation dynamics also encompass protective functions. The PLC continuously monitors parameters like stator current. If these exceed predefined thresholds (e.g., during an overload condition), the system rapidly responds by either reducing power or shutting down to prevent damage.

4.2. Construction

The construction of the PLC-based control system for three-phase induction motors involves several key components, each playing a crucial role in the overall functionality:

a) Power Circuit:

i. Rectifier: Typically, a bridge rectifier (e.g., KBPC3510) converts single-phase AC input to DC.
ii. DC Link: Large capacitors smooth the rectified DC, creating a stable DC bus.
iii. Inverter: A three-phase inverter using six MOSFET switches (arranged in three legs) converts DC back to variable frequency AC.

b) Control Circuit:

i. PLC/Microcontroller: The heart of the system, typically a device like PIC16F877A, which handles all control logic, PWM generation, and I/O processing.
ii. Speed Sensor: Usually an encoder or tachometer, providing speed feedback to the PLC.
iii. Current Sensors: Monitor stator currents for protection and control purposes.
iv. Voltage Sensors: May be used to monitor DC link and output voltages.

c) Interface Circuits:

i. Gate Drivers: Circuits to properly drive the MOSFET gates, often including opto-isolators for electrical isolation between control and power circuits.
ii. Signal Conditioning: Circuits to adapt sensor outputs to PLC input ranges.
iii. User Interface: Often includes switches for control inputs and an LCD for displaying system status.

d) Cooling System:

i. Heat sinks and possibly fans for cooling power electronic components, especially the inverter MOSFETs.

e) Protections:

i. Fuses or circuit breakers for overcurrent protection.
ii. Thermal protection devices integrated with or near the motor.

f) Enclosure:

i. A cabinet or enclosure to house all components, with appropriate IP rating for the intended environment.

g) Wiring and Connections:

i. Power wiring capable of handling motor currents.
ii. Shielded cables for sensitive control signals to minimize electromagnetic interference.

4.3. Workings

The PLC-based control system operates through a coordinated effort of its key parts. The programmable logic controller (PLC) processes inputs, executes programmed logic, and sends output signals. These signals control power electronics, which regulate electricity to the motor. The motor responds to these electrical inputs, while sensors feedback operational data to the PLC. This continuous loop of communication and adjustment ensures the system runs efficiently and responds to changing conditions or commands.

Start-up Sequence:

i. When powered on, the PLC initializes, setting up I/O configurations and loading control parameters.
ii. The user inputs the desired speed setpoint via the interface.
iii. The PLC checks for any fault conditions before allowing motor start.

Speed Control Process:

i. The PLC generates initial PWM signals based on the speed setpoint.
ii. These PWM signals control the inverter's MOSFETs, producing a three-phase AC output.
iii. The motor starts rotating, and its speed is measured by the speed sensor.
iv. The PLC continuously compares the actual speed to the setpoint, adjusting the PWM output as needed.

PWM Generation:

i. The PLC calculates the required fundamental frequency based on the desired speed.
ii. It then generates PWM pulses, modulating their width to create a sinusoidal average output.
iii. The number of pulses per half cycle is optimized (7 in this case) for best efficiency.

Load Handling:

i. As load changes, the speed sensor detects any speed variations.
ii. The PLC adjusts the V/f ratio by modifying PWM patterns to maintain constant speed.
iii. This process occurs rapidly and continuously, ensuring stable operation.

Protection Mechanisms:

i. The PLC constantly monitors stator current and other parameters.
ii. If an overload is detected, it can rapidly reduce power or initiate a shutdown.
iii. Thermal protections may directly interrupt power if motor temperature exceeds safe limits.

Efficiency Optimization:

i. The control algorithm maintains a low slip condition for optimal efficiency.

ii. It may adjust the V/f ratio slightly from the standard linear relationship to minimize losses at different operating points.

User Interface:

i. The LCD displays current speed, status, and any fault conditions.
ii. User inputs (e.g., speed changes, start/stop commands) are processed by the PLC and integrated into the control logic.

These results demonstrate that PLC and microcontroller-based control systems can significantly enhance the performance of three-phase induction motors, particularly in terms of efficiency and speed regulation accuracy. The ability to easily modify control strategies through software updates provides a flexible platform for ongoing optimization. However, care must be taken in PWM design to balance efficiency gains against potential increases in switching losses. Future work could focus on improving transient response and expanding the operational range for constant-speed performance.

5. RECOMMENDATION AND CONCLUSION

5.1. Recommendation

The following recommendation has been made based on observations and knowledge acquired from the design and construction of this project work.

i. It is advised to implement a level sensor to act as a cut-off mechanism, rather than relying solely on time-based expiration to control operations.
ii. A control system for an alternative power source should be integrated to ensure continuous operation of the pumping machine, even in the event of a power outage.
iii. In cases where there is no power supply, the system should be designed to reschedule any set time that was missed due to the outage, ensuring that operations are not disrupted.
iv. The inclusion of a unit with a power source trip circuit is recommended, capable of detecting both low and high voltage levels, to safeguard the system's functionality and prevent damage.

6. Conclusion

In conclusion, this research has successfully developed a programmable three-phase motor system designed to cater to the versatile needs of both industrial and agricultural sectors. The system's key advantages, including precise scheduling, automation, and programmable control, offer significant enhancements in operational efficiency and adaptability, addressing the specific requirements of these diverse applications. The study's comprehensive structure, encompassing an introductory section, rationale, objectives, literature review, methodology, results, and discussion, has culminated in valuable findings with broad implications. This research's contributions underscore its potential applications for optimizing motor-driven processes in industrial and agricultural contexts, providing a promising solution for evolving motor control needs.

Looking ahead, it is evident that the current industrial landscape is on the brink of a transformative era marked by the adoption of automation and cutting-edge technologies like IoT and AI. Nigeria stands on the brink of a transformative era where emerging technologies are converging with operational technology, encompassing PLCs, SCADA, and DCS. The time switch component of the system holds immense potential for expanded programmable settings, offering greater flexibility to industries. Integrating the UNL2003 MOTOR DRIVER and advanced security measures also ensures broader utility and enhanced safety. The system's future evolution envisions Bluetooth and Wi-Fi capabilities for remote machinery shutdown, bolstering safety protocols, and scalability to accommodate various industrial motor requirements. This forward-looking approach promises to redefine industrial processes and operations, positioning Nigeria at the forefront of industrial automation and efficiency.

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