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Original Research Article

Smart Three-Phase Electrical Panel Based on IoT Integration and Intelligent Lighting Control

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Abstract: In the quest for efficient power distribution, this article explores the design and implementation of a smart three-phase electrical panel that seamlessly integrates Internet of Things (IoT) technology. The core of this innovation lies in the utilization of NodeMCU, coupled with Blynk platform connectivity, providing users with unprecedented control and monitoring capabilities. Alongside IoT functionality, the panel incorporates a manual push button for localized control and a photocell sensor, linked to a contactor for intelligent lighting management based on ambient conditions. The article delves into the intricacies of the design, outlining the components, implementation steps, and the dual modes of operation – online mode for remote control and offline mode for local functionality. The presented smart panel not only marks a significant advancement in power distribution but also serves as an example for the future of intelligent electrical systems.

Keywords: Three-phase panel, Internet of Things, NodeMCU microcontroller.

1. INTRODUCTION

In the ever-evolving realm of power distribution, the search for heightened efficiency and intelligent control has been a persistent challenge [1]. According to recent studies [2, 3] traditional three- phase electrical panels, while robust, often lack the adaptability required for the modern landscape. These systems fall short in providing a unified solution that seamlessly integrates Internet of Things (IoT) capabilities [4]. Furthermore, the demand for enhanced energy efficiency and real-time control in industrial and commercial settings has surged, urging the exploration of novel solutions [5, 6].

The emergence and rapid development of IoT technologies have significantly transformed the way we approach power distribution, ushering in an era of unprecedented connectivity and intelligence [4, 5]. As electrical systems become increasingly complex and interconnected, the integration of IoT solutions has become a pivotal avenue for optimizing efficiency, ensuring real-time monitoring, and enabling remote control. The deployment of smart sensors, microcontrollers, and communication platforms has empowered electrical systems to transcend traditional boundaries, offering dynamic adaptability to changing demands and conditions. This study positions itself within this dynamic context, seeking to contribute to the ongoing evolution of IoT applications in electrical distribution by presenting a tangible and innovative solution in the form of a smart three-phase electrical panel.

Yet, amidst these known facts lies a critical unknown – the absence of a comprehensive and versatile three-phase electrical panel that not only caters to the foundational principles of power distribution but also addresses the increasing need for real-time monitoring, manual intervention, and intelligent responsiveness to environmental conditions. This research gap represents a substantial barrier to the seamless integration of IoT technology into power distribution systems, leaving a void in the current state of the field. Moreover, the current landscape lacks an affordable solution that can be easily scaled up to meet the diverse needs of different industries. This brings forth another unknown, highlighting the scarcity of low-cost components that allow for scalability without compromising efficiency and functionality.

This article aims to bridge this identified research gap by presenting a groundbreaking design and implementation of a smart three-phase electrical panel that not only provides advanced functionalities but does so with low-cost components [7]. Our proposed solution strategically integrates NodeMCU, a Wi-Fi- enabled microcontroller, with the Blynk platform, offering a transformative yet cost-effective approach. The use of readily available and affordable components not only addresses the known challenges but also positions our solution as easily scalable, providing a tangible and impactful solution to the identified research gap in the field. Through real-world case studies and practical applications, we strive to contribute not only to the theoretical advancements but to provide an accessible and scalable solution to the challenges posed by traditional power distribution systems.

2. MATERIALS AND METHODS

Schematic diagram of the smart three-phase electrical panel was shown in Figure 1. The proposed smart three-phase electrical panel integrates a selection of key hardware components to achieve comprehensive control and monitoring capabilities. The heart of the system lies in the utilization of a NodeMCU, a versatile Wi-Fi-enabled microcontroller, programmed using the Arduino IDE [8]. The NodeMCU acts as the central processing unit, facilitating communication and coordination among various components. A relay is incorporated into the system to control a contactor, serving as the interface between the digital commands generated by the NodeMCU and the physical switching of the electrical loads. Additionally, a manual push button is integrated to provide localized control, allowing manual intervention when necessary. The system is further augmented by the inclusion of a photocell sensor, functioning as an input device to detect ambient light levels. This information is then utilized to intelligently control the lighting loads through the contactor. The entire system is connected and coordinated through the Blynk platform, a powerful IoT software solution [8]. Blynk enables remote monitoring and control, providing users with real-time insights into the electrical panel's status and allowing seamless interaction with the system via a user-friendly mobile application. This integrated approach ensures a robust and flexible solution that combines hardware components with sophisticated software interfaces for optimal performance and adaptability.

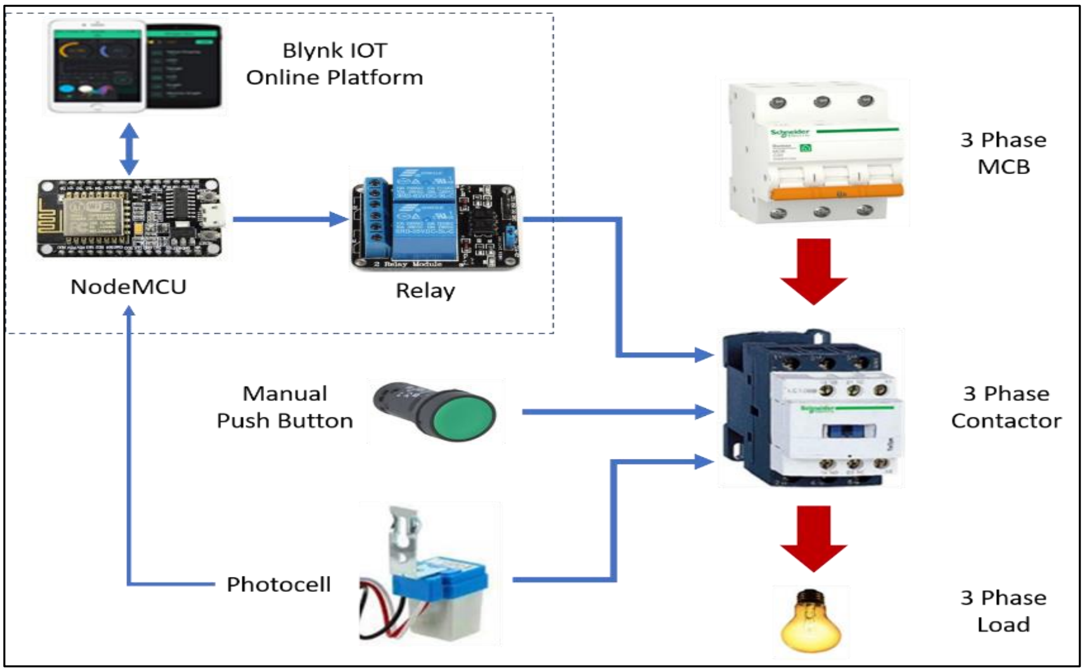

Figure 1: Schematic diagram of the smart three-phase electrical panel

The intricacies of the smart three-phase electrical panel's control system are visually encapsulated in a comprehensive wiring diagram as shown in Figure 2(a). The NodeMCU serves as the central hub, connecting to both the Blynk platform and the Arduino IDE for programming. The relay, a pivotal component, establishes a crucial link between the NodeMCU and the contactor, enabling the digital signals from the microcontroller to effectively control the electrical loads. The manual push button is integrated into the system, offering a localized control interface that communicates directly with the NodeMCU for immediate intervention. Furthermore, the wiring diagram illustrates the connection of the photocell sensor, strategically positioned to capture ambient light levels. This sensor's input is then fed into the NodeMCU, influencing the control of the contactor based on real-time environmental conditions. The synergy of these hardware components, as depicted in the wiring diagram, ensures a coherent and interconnected control system. It not only emphasizes the seamless communication between each element but also underscores the versatility of the design, allowing for both manual and automated control through a unified and intuitive hardware configuration.

Complementing the intricate control system wiring, the single-line diagram offers a holistic view of the three-phase electrical connections within the smart electrical panel as shown in Figure 2(b). Originating from the power source, the three-phase electrical lines are meticulously illustrated, depicting their journey through protective devices like Miniature Circuit Breakers (MCBs) for enhanced safety. The diagram then intricately delineates the distribution of power to various components within the panel, illustrating the controlled path through the contactor to the lighting loads. The inclusion of MCB protection at strategic points emphasizes the commitment to electrical safety, preventing potential overloads or faults. This single-line representation serves not only as a comprehensive guide to the electrical pathways but also as a visual aid to understand the systematic and protected flow of power within the panel. It underscores the integration of intelligent control components into a conventional power distribution network, offering a complete and visually accessible depiction of the three-phase electrical connections and safety measures in place.

The interior and exterior layout of the smart three-phase electrical panel is meticulously designed to optimize functionality, accessibility, and safety as shown in Figure 2(c). Internally, the components are arranged systematically within the enclosure, emphasizing efficient use of space and ease of maintenance. The NodeMCU, relay, and other control elements are positioned strategically, ensuring convenient access for programming, monitoring, and troubleshooting. Wiring pathways are organized methodically, minimizing the risk of interference or accidental damage. The contactor and MCBs are positioned logically, promoting straightforward connections to the power source and lighting loads.

Externally, the panel enclosure is designed with user convenience and safety in mind. The exterior features a user-friendly interface with clearly labeled sections for manual controls, such as the push button, and an indicator for the status of the system. The enclosure is constructed from durable and weather- resistant materials to withstand environmental conditions, making it suitable for both indoor and outdoor installations. Additionally, the exterior design includes proper ventilation to dissipate heat generated by the components, ensuring optimal operating conditions and longevity. The layout for both the interior and exterior is a result of a careful balance between functionality, safety, and user accessibility. This thoughtful design ensures that the smart three-phase electrical panel not only meets the technical requirements of the control system but also provides a user-friendly and durable solution for diverse applications.

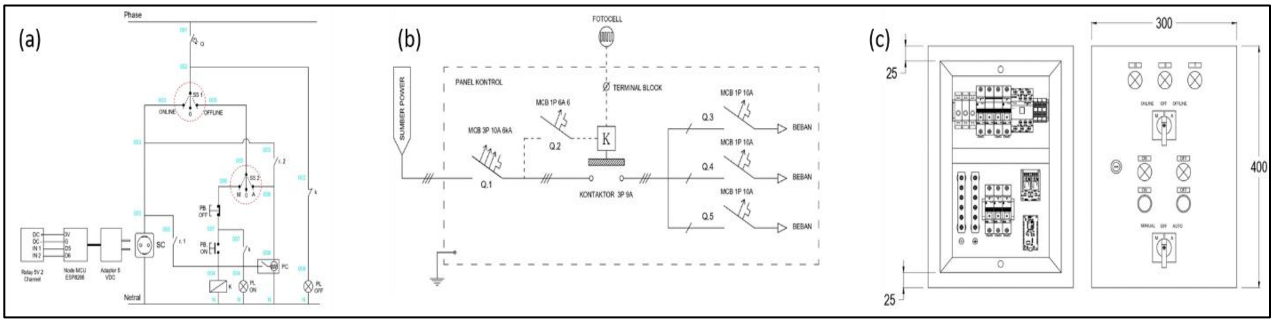

Figure 2: (a) Wiring diagram of the control, (b) Single line diagram of the three-phase, (c) layout diagram for the box panel design

3. RESULTS AND DISCUSSIONS

This section of the study provides a visual insight into the realized implementation of the proposed smart three-phase electrical panel. The actual installed components within the box panel reflect the meticulously designed control system as shown in Figure 3. Within the enclosure, the NodeMCU stands as the core processing unit, intricately connected to a relay that facilitates the digital control of the contactor. The placement of the manual push button is clearly evident, offering users a localized control interface. Additionally, the photocell sensor, strategically positioned for ambient light detection, is visibly integrated into the system.

Externally, the panel showcases a user-friendly interface with appropriately labeled sections for manual controls, ensuring ease of operation. The inclusion of MCBs for protective measures is visibly apparent, underscoring the commitment to safety. The carefully organized wiring pathways contribute to the tidy and accessible interior layout. Through this visual representation of the installed components, the results section provides a tangible illustration of the successfully implemented smart three-phase electrical panel, highlighting its practicality and applicability in real-world scenarios.

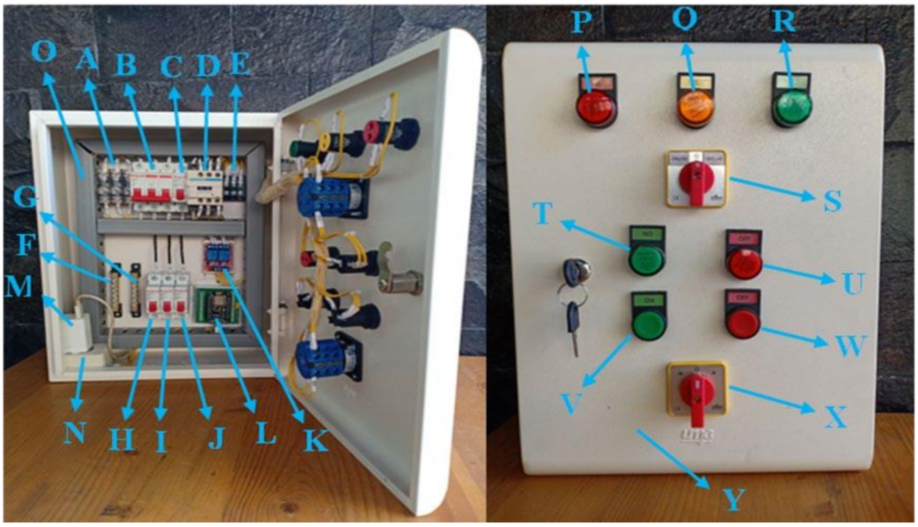

Figure 3: Box panel implementation

Furthermore, the components were explained according to the labels shown in Figure 3. The interior design was labeled as alphabet A to O with description as:

- A is the fuse to protect the pilot lamp.
- B, namely MCB 3P 6A as the main barrier and safety in load installations.
- C, namely MCB 1P 6A as protection for the control circuit.
- D, namely the contactor as a connector and breaker for the electric current that goes to the load.
- E is the Terminal block as a place to connect the cables that go to the photocell.
- F is the neutral busbar as a neutral cable termination location.
- G, namely the ground busbar as the termination place for the ground cable.
- H, namely MCB 1P 6A as a limiter and load protector for lamp 1.
- I, namely MCB 1P 6A as a limiter and lamp load protector 2.
- J, namely MCB 1P 6A as a limiter and load protector for lamp 3.
- K is a 5VDC 2 Channel relay as a tool that transmits commands to the ON or OFF contactor commanded by the NodeMCU.
- L is the NodeMCU as a tool that can receive online commands from the Blynk IoT application which will be sent to the 5VDC Relay.
- M, namely the power supply adapter as a means of changing the voltage from 220 VAC to 3 VDC which will be supplied to the NodeMCU.
- N is a socket as a 220VAC voltage terminal that connects to the power supply adapter.
- O, namely the cable duct hole as a cable house so that the wiring panel looks neat.

On the exterior or door panel there are components labeled as alphabet P to Y. The components descriptions are:

- P is the red pilot lamp as an indicator of the L1 or R voltage, where if it is on then the L1 or R voltage has been entered and vice versa if it goes off then the L1 or R voltage is cut off.
- Q, namely the yellow pilot lamp, is an L2 or S voltage indicator, where if it is on then the L2 or S voltage has been entered and vice versa if it goes off then the L2 or S voltage is cut off.
- R, namely the green pilot lamp, is an L3 or T voltage indicator, where if it is on then the L3 or T voltage has been entered and vice versa if it goes off then the L2 or S voltage is cut off.
- S, namely the selector switch, is a lever for selecting modes including Online, Off and Offline.
- T is the green pilot lamp as an indicator that the panel is working.
- U is the red pilot lamp as an indicator that the panel is not working.
- V, namely the green push button, is the button to turn on the panel to work.
- W, namely the red push button, is the button to turn off so that the panel stops working.
- X is the selector switch as a lever to select modes including Manual, Off and Automatic.
- Y is a box panel with dimensions of 30 cm long, 15 cm wide and 40 cm high as a casing for the components mentioned above.

The testing phase of the smart three-phase electrical panel was conducted with a comprehensive approach to ensure the robustness and reliability of the integrated system. Functionality testing involved validating the proper operation of the NodeMCU, relay, and contactor synchronization, ensuring that digital commands from both the Blynk platform and the manual push button were accurately translated into control signals for the contactor. This phase also included the assessment of the photocell sensor's responsiveness to ambient light conditions, confirming its ability to influence the intelligent lighting control mechanism. The testing phase encompassed four distinct scenarios, each evaluating the smart three-phase electrical panel's performance under varying conditions.

1. Online Mode with Application Button

In this scenario, the system's responsiveness to digital commands from the Blynk application was scrutinized. Users employed the Blynk platform to remotely activate the contactor through the application button. This test assessed the real-time communication between the application and the NodeMCU, ensuring the seamless execution of commands in the online mode. The test result was shown in Figure 4.

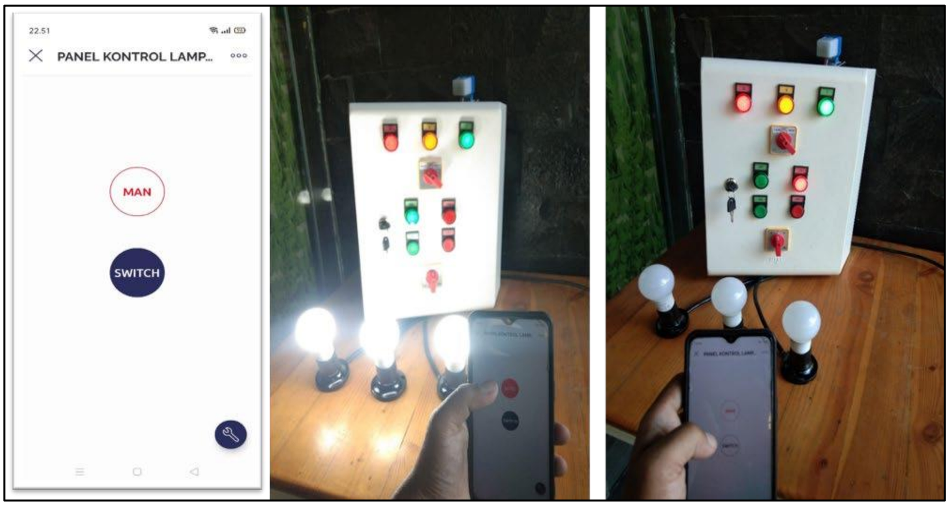

Figure 4: Operation mode ONLINE with control from application button, (left) Blynk App interface, (center) ON condition, (right) OFF condition

2. Online Mode with Photocell

Testing in online mode continued by assessing the integration of the photocell sensor into the system. The Blynk application was utilized to remotely monitor and control the lighting loads based on ambient light conditions detected by the photocell. This scenario aimed to validate the system's adaptability to dynamic environmental factors through the IoT platform. The test result was shown in Figure 5.

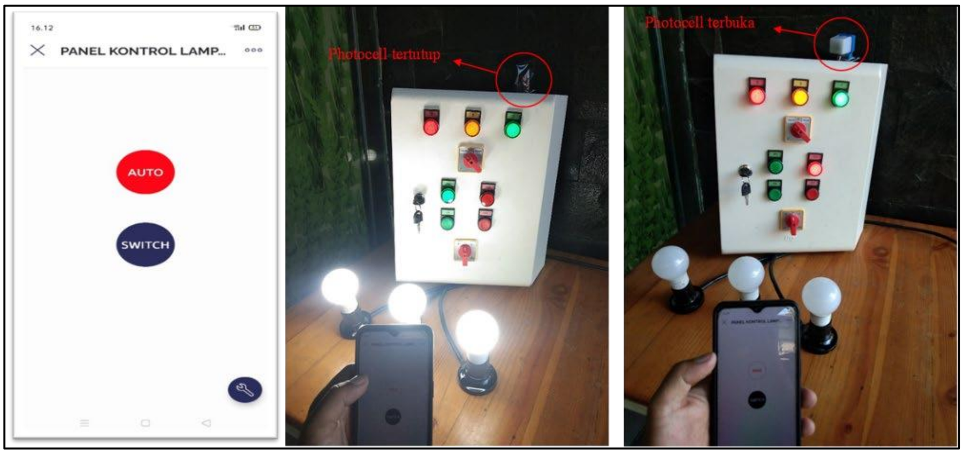

Figure 5: Operation mode ONLINE with control from photocell, (left) Blynk App interface, (center) ON condition, (right) OFF condition

3. Offline Mode with Push Button

Transitioning to offline scenarios, the focus shifted to localized control. In this case, the manual push button was utilized to activate the contactor independently of the Blynk platform. This test verified the effectiveness of the manual override in the absence of an internet connection, ensuring the system's reliability in offline conditions. The test result was shown in Figure 6.

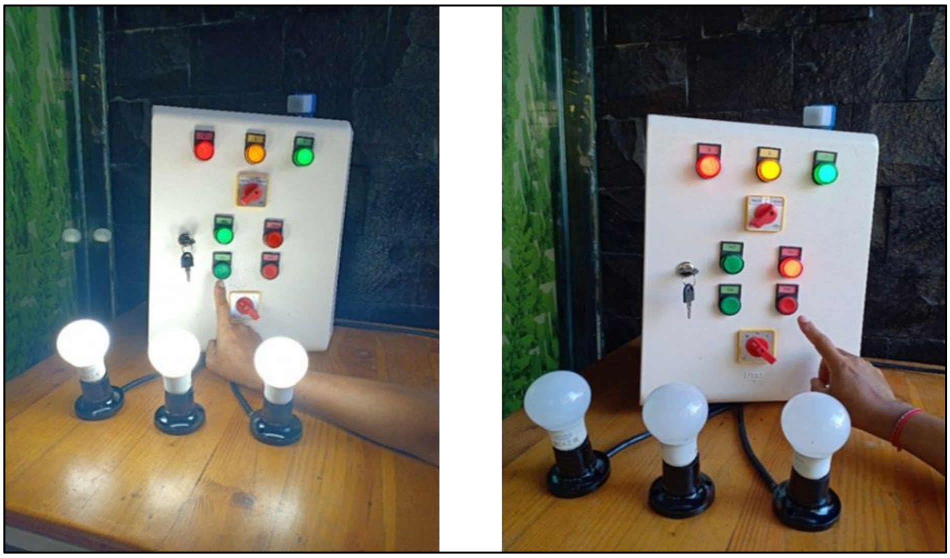

Figure 6: Operation mode OFFLINE with control from push button, (left) ON condition, (right) OFF condition

4. Offline Mode with Photocell

The final scenario combined localized control and environmental responsiveness. The manual push button and the photocell sensor were employed together to control the lighting loads without relying on online connectivity. This dual-input scenario evaluated the system's versatility in offline conditions, showcasing its adaptability to both user intervention and ambient light cues. The test result was shown in Figure 7.

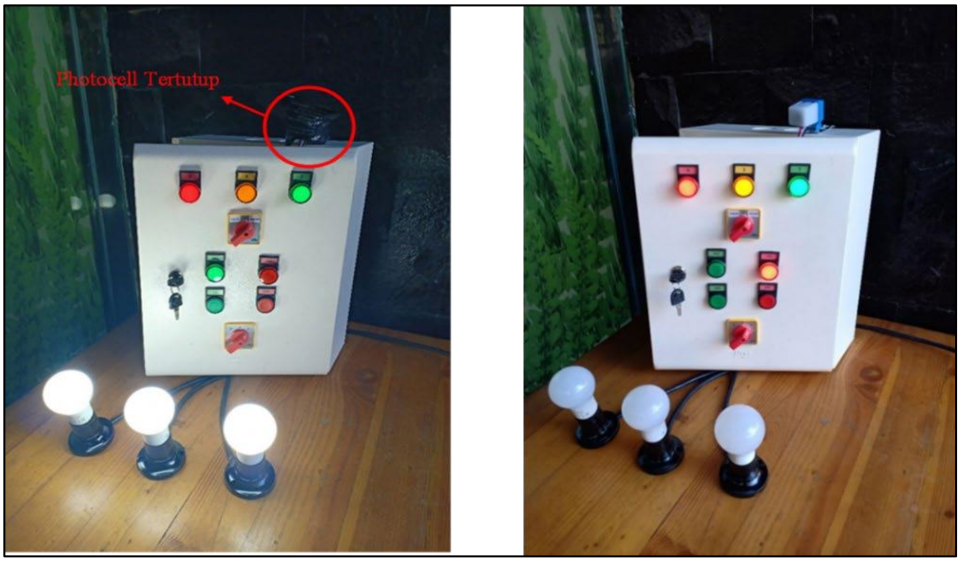

Figure 7: Operation mode OFFLINE with control from photocell, (left) ON condition, (right) OFF condition

Throughout these testing scenarios, real-world conditions were simulated to validate the system's functionality, responsiveness, and adaptability. The outcomes of these tests contribute valuable insights into the diverse operational modes of the smart three-phase electrical panel, ensuring its reliability in various practical applications.

4. CONCLUSION

In conclusion, this study presents a comprehensive exploration and implementation of a smart three-phase electrical panel, integrating advanced control mechanisms with Internet of Things (IoT) technology. The systematic design, which includes components such as NodeMCU, relay, manual push button, and photocell, demonstrates a harmonious blend of hardware elements for seamless control and monitoring. The Blynk platform acts as a robust IoT software solution, facilitating remote access and control. The implementation of four distinct testing scenarios validated the system's versatility, showcasing its ability to operate efficiently in both online and offline modes while responding intelligently to user inputs and ambient environmental conditions. The real-world installation of components within the panel, as illustrated through wiring diagrams and single-line diagrams, emphasizes the practicality of the proposed system. Overall, this study marks a significant step forward in the integration of smart technologies into conventional power distribution, paving the way for enhanced efficiency, real-time control, and intelligent adaptability in electrical systems.

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