PROGRESS IN ENGINEERING APPLICATION AND TECHNOLOGY
e-ISSN: 2773-5303

PEAT

Vol. 5 No. 1 (2024) 103-113
https://publisher.uthm.edu.my/periodicals/index.php/peat

Development of a Smart Charging and Switching System for a Low-Voltage Air Circuit Breaker

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DOI: https://doi.org/10.30880/peat.2024.05.01.011

Article Info

Received: 28 December 2023
Accepted: 17 January 2024
Available online: 15 June 2024

Keywords

Air circuit breaker, DC motor, Solenoid, Blynk, Pushbutton, NodeMCU, Two-channel relay

Abstract

Air circuit breakers (ACB) interrupt electric current in electrical circuits. It protects electrical equipment from overcurrent and short circuits. Different applications require different ACB sizes and grades. A competent electrician manually pumps and switches the ACB for troubleshooting and maintenance. The ACB may explode, making the operation risky. Typically, an electrician will manually pump and switch the air circuit breaker by touching the ACB directly. For the ACB to be charged ultimately, it needs to be pumped twelve to thirteen times, and the maximum weight the pump can produce is 27.5 kg. An electrician must use two hands to hold the charging handle to pump the charging handle of the ACB. This project presents an application using a solenoid and a mechanical mechanism consisting of a DC motor to replace this manual scope work automatically. The DC motor is used to pump the charging handle of the ACB until the indicator shows "charged." After that, the solenoid turns the ACB on and off. This system comprises components such as the NodeMCU, DC motor, two-channel relay, pushbuttons, Cytron md25hv motor driver, and solenoids. The NodeMCU is the project's central processing unit and manages input and output. Blynk and pushbuttons can control this operation. Next, a camera is attached to monitor the operation from a distance. The goal of this system is to assist workers in the electrical field, which requires constant attention to safety because it can endanger life and even cause death. This project results in a much easier and more reliable working environment.

1.0 Introduction

A three-phase low-voltage switchboard is a crucial component in efficient and secure electricity distribution within Malaysian factories, plants, and commercial buildings [1]. Tailored to ensure optimal efficiency of equipment, these switchboards consist of various elements such as incoming and outgoing cables, busbars, changeover switches, circuit breakers, contactors, fuses, overload relays, and metering equipment, forming low-voltage distribution control panels[2]. Functionally divided, the switchboard provides dual protection mechanisms, safeguarding components and human life against electric shock. The selection of a particular distribution switchboard hinges on the system's load requirements and application type, aiming to address potential short circuits and abnormalities through overcurrent protection, employing a range of hardware and electrical components[3].

Air circuit breakers are used to interrupt electric current in electrical circuits. It safeguards electrical equipment against overcurrent and short circuits[4]. ACBs work by using air as a medium to extinguish the arc that occurs when a circuit is interrupted. The trip mechanism of the ACB activates in the event of an overcurrent or short-circuit fault, forcing the contacts to open and the arc to terminate in the surrounding air[4]. ACBs are available in various sizes and ratings to accommodate multiple applications. A qualified electrician handles the manual pumping and switching of the ACB. The activity is considered hazardous because there is a significant chance of the ACB exploding. However, manual ACB operation remains a challenge. Trained electricians meticulously handle these circuit breakers, pumping and switching them for maintenance. The looming threats of explosions and potential hazards to personnel highlight the pressing need for a safer approach. This project proposes an alternative to the potential dangers of manual ACB handling. The DC motor is used to pump the charging handle of the ACB until the indicator shows "charged." After that, the solenoid turns the ACB on and off. This system comprises components such as the NodeMCU, DC motor, two-channel relay, pushbuttons, Cytron md25hv motor driver, and solenoid. Next, a camera is attached to monitor the operation from a distance. The goal of replacing manual methods with an automated system is to raise electrical safety standards, ensuring a more dependable and secure working environment for electrical professionals. This introduction outlines the details of an automated system that revolutionizes standard ACB operations, leading them towards a safer, more efficient approach.

Workers in the electrical industry frequently experience life-threatening accidents and even lose their lives. Three types of electrical accidents exist: electrical shock, burns, and fires [5]. This system aims to assist workers in the electrical field, which requires constant attention to safety because it can endanger life and even cause death. This project results in a much easier and more reliable working environment. The ACB requires testing and maintenance work. A competent electrician was needed to turn an ACB on and off to do maintenance and testing on the ACB. The technician needs to pump the lever to charge. The ACB manually, then turn on the ACB and discharge it by pressing the off button. The pumping action is done roughly 11–13 times for the ACB to charge. This is hazardous and may ultimately result in electrical fires and the possibility of electric shock. Changes in air leakage can result in decreased air pressure. Any failure in the mechanism that stops the contact from opening or closing could result in life-threatening damage, such as sparking and causing an explosion. There are many reasons for incidents related to ACB. According to a report, more than 90 percent of circuit breaker failures are due to mechanical causes [6].

This project sets out with specific objectives in mind. Firstly, it aims to create a wireless system capable of managing the switching mechanism of a low-voltage air circuit breaker (ACB). Secondly, the goal is to construct a prototype that integrates wireless charging and switching functionalities for this ACB. Lastly, the project seeks to assess and validate the prototype's operational capabilities, determining its ability to charge the ACB wirelessly and effectively control its power state.

Regarding the project's scope, it is essential to note that the focus is exclusively on the Terasaki Temp2Power Ar208s ACB within the LVSB laboratory at UTHM. The project emphasizes using appropriate equipment to develop a system specifically for charging and switching the ACB. Furthermore, the system will be mounted to the ACB's panel, ensuring seamless integration. The operation is controlled using Blynk or physical pushbuttons and monitored from a distance by a camera.

2.0 Materials and methods

2.1 Materials

This project integrates a diverse range of materials to achieve its sophisticated functionality. The Terasaki Temp2Power Ar208s is the ACB model that is used in the execution of this project. The Terasaki ACB was selected for this project because it is the ACB that is currently available in the laboratory at UTHM. This will make it simpler to test the project. NodeMCU is the project's central processing unit, handling input and output functions. The NodeMCU is connected to two-channel relays used to control the solenoid. Additionally, the NodeMCU is connected to a Cytron MD25HV motor driver to control the DC motor. For this project, a brush DC motor was chosen for its simplicity, cost-effectiveness, ease of control, and ability to be speed-controlled by varying the voltage using pulse width modulation (PWM). The pulley system is used in this project as a mechanism to pull the charging handle of the ACB. The solenoid is used to turn the ACB on and off. This project will use a camera with Wi-Fi functionality to monitor from a distance using a phone. This helps monitor the operation of that project. Doing this will lessen the possibility of the operation failing due to a malfunction or an error. Pushbuttons and Blynk control the process of pumping the charging handle of the ACB using a DC motor consisting of a mechanical mechanism and turning the ACB on and off using a solenoid.

2.2 Project block diagram

In this project, two solenoid and mechanical mechanisms consisting of a DC motor will be attached to the output of the ACB to pump the charging handle until it shows "CHARGED." A full-stroke pumping action, usually performed 10–13 times, is required to charge the closing springs. The air circuit breakers, wireless charging process, and switching mechanisms can be managed via the Blynk and push buttons. The NodeMCU is where the signal will be processed. The solenoids will respond to commands for opening and closing, either through the app's button press or manually by triggering the physical pushbutton. A two-channel relay facilitates the control of solenoid actions. Next, the app and push button can switch off the DC motor after the charging handle has been sufficiently pumped. There will be two different power supplies; one is used to power the NodeMCU, and the other is used to power the DC motor. The motor requires a higher voltage. Meanwhile, the NodeMCU only requires 5 volts to operate. Next, a camera is attached to monitor the operation from a distance. The monitor can be done using a phone from afar using the dedicated software that came with the camera. In summary, the NodeMCU is a medium for managing outputs through the Blynk and push buttons. At the same time, the camera serves the purpose of monitoring the operation from a distance.

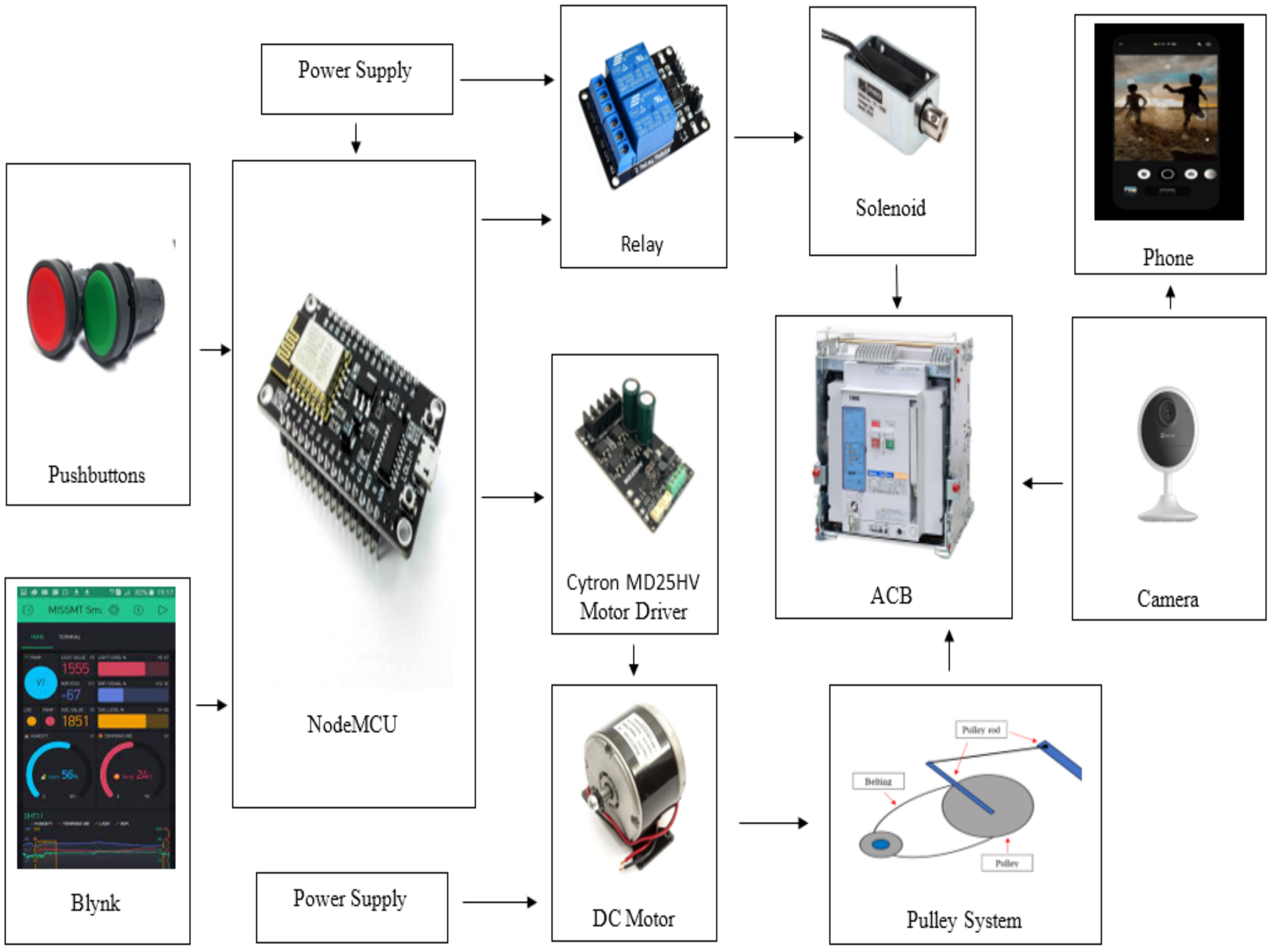


Fig. 1 *Project block diagram*

2.2 Flowchart of the project

The project initialization phase involves configuring and setting up essential components such as the NodeMCU, LED pilot lamp, pushbuttons, Blynk, and motor driver. To establish a connection between Blynk and NodeMCU, begin by setting up a project on the Blynk app and obtaining the authentication token provided in the Arduino IDE after the Blynk app is connected to the NodeMCU. The NodeMCU will process the input from the Blynk app and the physical push button. The data will be processed in NodeMCU, and the output will be controlled by commanding the 2-channel relay connected to the solenoid to turn it on and off. The motor driver will control the DC motor for speed control and direction. In this project, a solenoid and mechanical mechanism consisting of a DC motor will be attached to the output of the ACB so that it can pump the charging handle until the charge indicator shows "CHARGED." Pumping the handle with the full stroke 10–13 times will fully charge the closing springs. Moving on, the solenoid is used to click the turn-on and turn-off buttons.

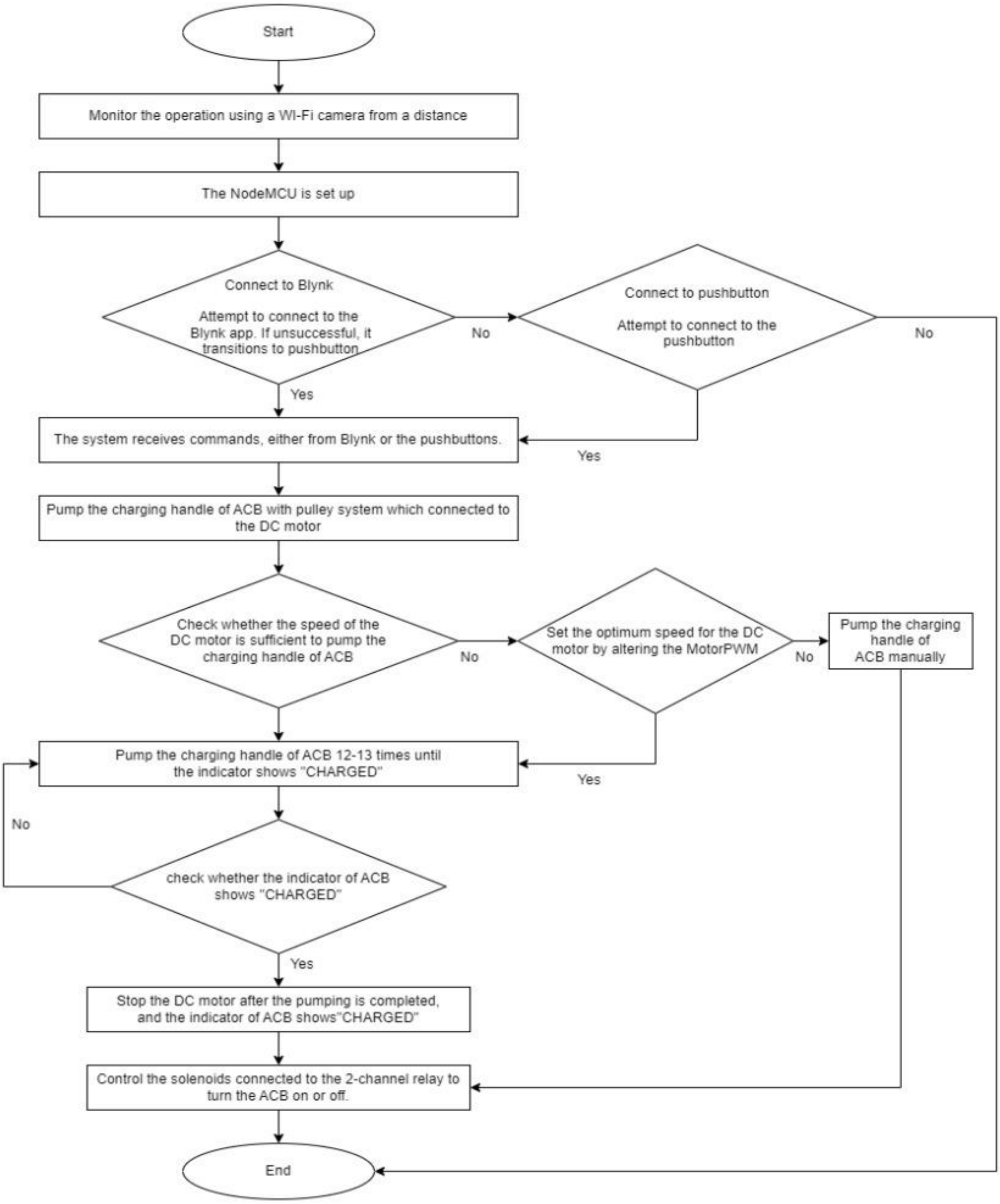


Fig. 2 *Flowchart of the project*

2.3 Limitations of the project

Integrating Blynk with NodeMCU presents various advantages but also comes with specific limitations. First, the accessible version of Blynk might impose constraints on available widgets and functionalities, potentially limiting the scope of interactions and visual elements between the NodeMCU and the Blynk app. Next, the project's reliance on Blynk's cloud infrastructure introduces a dependency on a stable and consistent internet connection. Any disruptions in connectivity can directly impact the real-time responsiveness and reliability of NodeMCU interaction with the Blynk. This can be countered by implementing Bluetooth and the IR remote. The scalability issue is that this project is used for Terasaki Temp2Power Ar208s ACB. The system's scalability might be limited. Adapting it to different types or models of circuit breakers might require significant reengineering. Ensuring scalability and compatibility involves designing a flexible architecture that can adapt to various ACB models and integrating standard communication protocols for seamless interactions between components. Limited visualization for the motor direction and speed of the DC motor as it only uses an LED pilot lamp. To overcome this, Integrating an LCD panel can offer visibility into the motor's directional rotation (forward or reverse) and provide voltage output readings when adjusting the PWM.

3.0 Results and discussion

The results will be divided into two sections: the mechanical and the electrical parts. The mechanical component is constructed to be mounted on the front panel of the ACB. The analysis and discussion are done on the hardware and software. The prototype is tested in the lab to measure its performance in pumping action and turning the ACB off or on using the Blynk and pushbuttons. Additionally, a wireless camera was connected to allow safer monitoring from a distance. I have carried out four different tests: the Blynk activation test, the Push button activation test, the Analysis of motor PWM and output voltage, and the weight of the prototype.

3.1 Design of the prototype

The electrical design was carefully executed, ensuring the functionality of each purchased component before integration. The length of the wire is measured for optimal circuit connections, prioritizing future upgrades and ensuring seamless operation. The circuit was securely enclosed within a protective box to enhance safety and prevent exposure. The prototype's frame was crafted by welding metal pieces together, incorporating trays to house the circuit box, DC motor, and push button. A customized L bracket was also designed to attach the prototype to the ACB panel. A wireless camera was integrated to monitor the output.

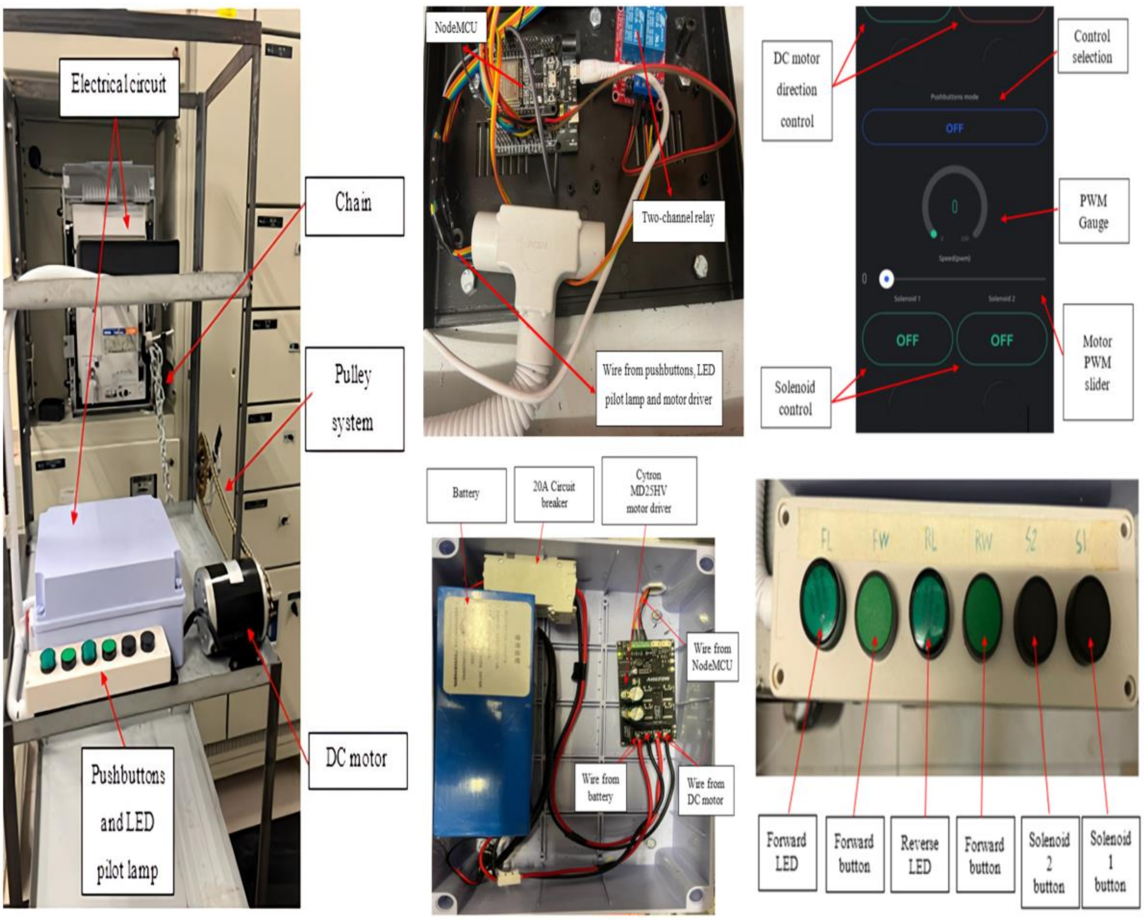


Fig. 3 *Design of the prototype*

3.2 Result of the prototype

The project's successful execution showcased effective wireless control of the air circuit breaker (ACB) through Blynk and physical pushbuttons, ensuring remote monitoring via a WI-FI camera for enhanced safety measures. With the device's display providing real-time feedback, the system integrates four pushbuttons—two managing the solenoid through a 2-channel relay and the remaining two directing the DC motor's forward and reverse movements. The DC motor operates upon button activation, rotating to engage the ACB's charging handle and ceasing movement upon reaching a designated angle. Reversing this action resets the handle. Achieving 10–13 strokes results in a fully charged state, denoted by the "CHARGED" indicator. Solenoid actions, triggered by Blynk or push-button signals, correspond to ACB controls—the first solenoid enabling ACB activation ("ON") and the second, ACB deactivation ("OFF"), with corresponding indicator displays. This robust control system provides seamless and precise ACB function management through intuitive interfaces and automated actions.

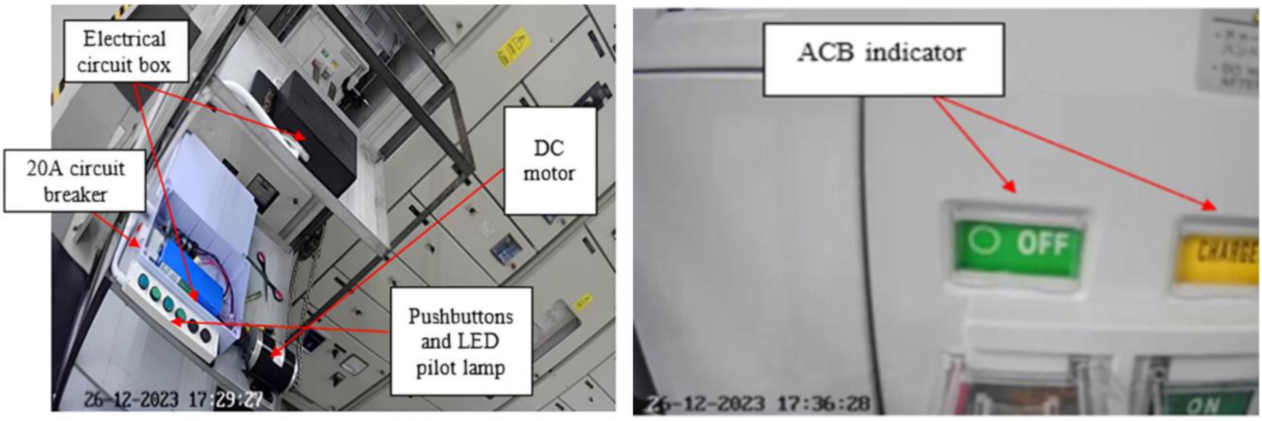


Fig. 4 *Live view of the prototype from the WI-FI camera*

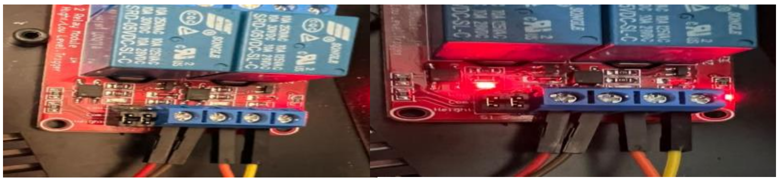
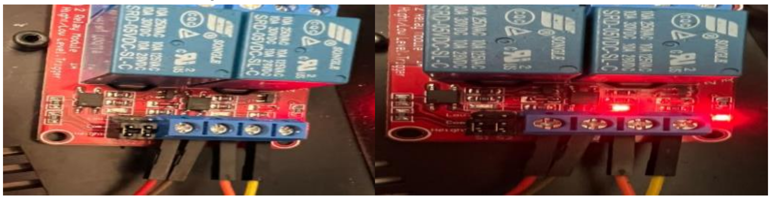
3.3 Blynk activation test

This project uses buttons, LED, gauge, and slider widgets, each assigned to specific virtual pins for control. A total of seven virtual pins are used. The virtual pin (V1) manages the forward direction of the motor, while (V2) controls the reverse direction. The virtual pin (V3) synchronizes the pushbuttons with Blynk. The virtual pin (V4) regulates the motor's PWM, facilitating speed adjustments. The virtual pin (V5) turns off Blynk control, allowing manual circuit control via physical push buttons. Virtual pins (V6) and (V7) also control the solenoid operation after uploading the code to the NodeMCU; the Blynk app is accessed on a smartphone connected to the same Wi-Fi network as the NodeMCU. The widgets are activated, and I observe if the programmed action responds accordingly when the button state changes in the app. The output is then tabulated in Table 1.

Table 1 *Functionality of the Blynk*

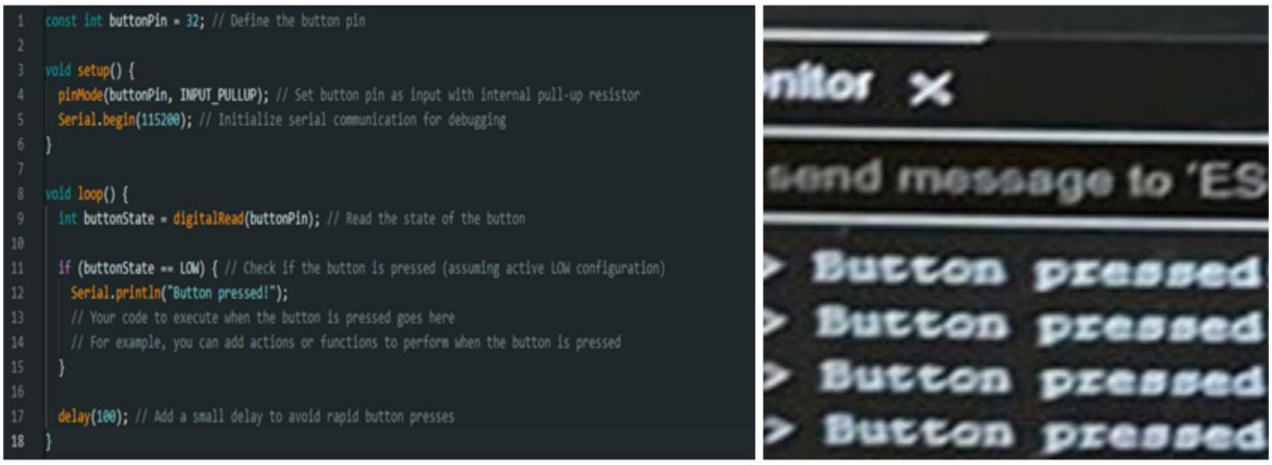
Virtual pins	Functionality of the prototype
Forward virtual pin (V1) 	When the forward button is pressed, the motor will rotate forward, as indicated by the lighting up of the MA LED on the motor driver.  

Table 1 *Continue*

Reverse virtual pin (V2) 	When the reverse button is pressed, the motor will rotate in reverse, as indicated by the lighting up of the MB LED on the motor driver. 
Motor PWM virtual pin (V4) 	When the motor PWM slider is adjusted, the motor speed changes based on the PWM input, as indicated by the lighting up of the MA LED and MB LED, which will change from dimmer to brighter on the motor driver. This shows that the voltage differs as PWM is adjusted and controls the speed of the motor. 
solenoid 1 virtual pin (V6) 	When the solenoid1 button is pressed, the solenoid will turn on, as indicated by the lighting up of the INT1 LED on the 2-channel relay. 
solenoid 2 virtual pin (V7) 	When the solenoid1 button is pressed, the solenoid will turn on, as indicated by the lighting up of the INT2 LED on the 2-channel relay. 

3.4 Pushbuttons activation test

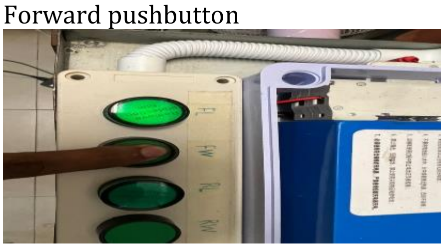
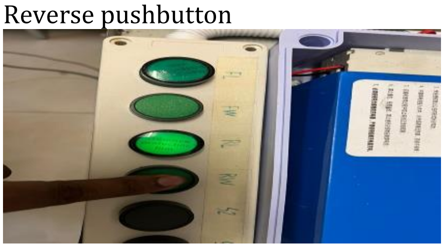
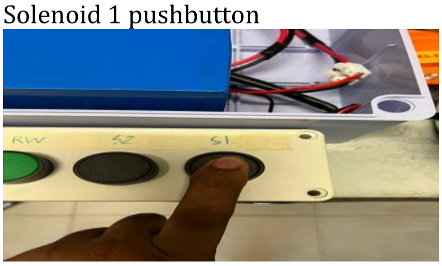
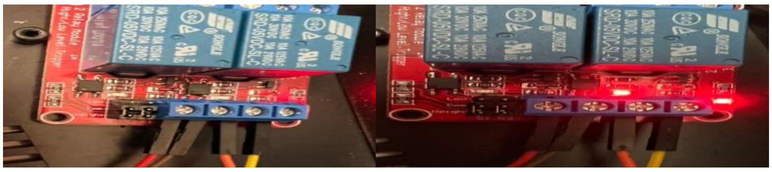
The push button activation test was a crucial step in validating the functionality of input components within the system. Using code from Figure 5, an initial evaluation was conducted by connecting the motor's forward and reverse push buttons to specific pins on the NodeMCU and linking the 2-channel relay to corresponding pins. This test generated outputs in the Arduino IDE's serial monitor, confirming the activation of individual push buttons, as shown in Figure 5. Subsequently, after verifying the push buttons' functionality, they were employed to control the motor's direction and the 2-channel relay. The resulting Table 4.2 showcased the successful rotation of the motor when the respective push buttons were activated, confirming the motor's forward and reverse movements. Additionally, the push buttons demonstrated effective control over the 2-channel relay, as evidenced in Table 2.



```
const int buttonPin = 32; // Define the button pin

void setup() {
  pinMode(buttonPin, INPUT_PULLUP); // Set button pin as input with internal pull-up resistor
  Serial.begin(115200); // Initialize serial communication for debugging
}

void loop() {
  int buttonState = digitalRead(buttonPin); // Read the state of the button

  if (buttonState == LOW) { // Check if the button is pressed (assuming active LOW configuration)
    Serial.println("Button pressed!");
    // Your code to execute when the button is pressed goes here
    // For example, you can add actions or functions to perform when the button is pressed
  }

  delay(100); // Add a small delay to avoid rapid button presses
}
```


Fig. 4 *Testing push button activation and result*

Table 2 *Functionality of the pushbuttons*

Pushbuttons	Functionality of the prototype
Forward pushbutton 	When the forward button is pressed, the motor will rotate forward, as indicated by the lighting up of the MA LED on the motor driver. 
Reverse pushbutton 	When the reverse button is pressed, the motor will rotate in reverse, as indicated by the lighting up of the MB LED on the motor driver. 
Solenoid 1 pushbutton 	When the solenoid1 button is pressed, the solenoid will turn on, as indicated by the lighting up of the INT1 LED on the 2-channel relay. 
Solenoid 2 pushbutton 	When the solenoid1 button is pressed, the solenoid will turn on, as indicated by the lighting up of the INT2 LED on the 2-channel relay. 

3.5 Analysis of motor PWM and voltage

The project's core revolves around utilizing PWM (Pulse Width Modulation) to regulate the motor's speed. Controlled through the Blynk app's slider, PWM alters resistance, varying the voltage output to the motor. The

NodeMCU processes the slider's data to generate a PWM signal, manipulating a square wave's duty cycle to mimic an analog signal's characteristics. This PWM signal is relayed to the Cytron md25hv motor driver, which interprets and modulates the motor's power by adjusting the duty cycle. Higher duty cycles amplify power and accelerate the motor, while lower duty cycles decelerate it. This system achieves precise speed control by manipulating the PWM signal, confirmed via voltage measurement using a multimeter, as evidenced in Table 3.

Table 3 *The output voltage as motor PWM changes*

Motor PWM	Voltage(V)		
	1st Reading(V)	2nd Reading(V)	Average(V)
0	0	0	0
50	7.38	7.39	7.38
100	14.78	14.81	14.79
150	22.25	22.24	22.25
200	29.66	29.65	29.66
250	37.98	37.97	37.98

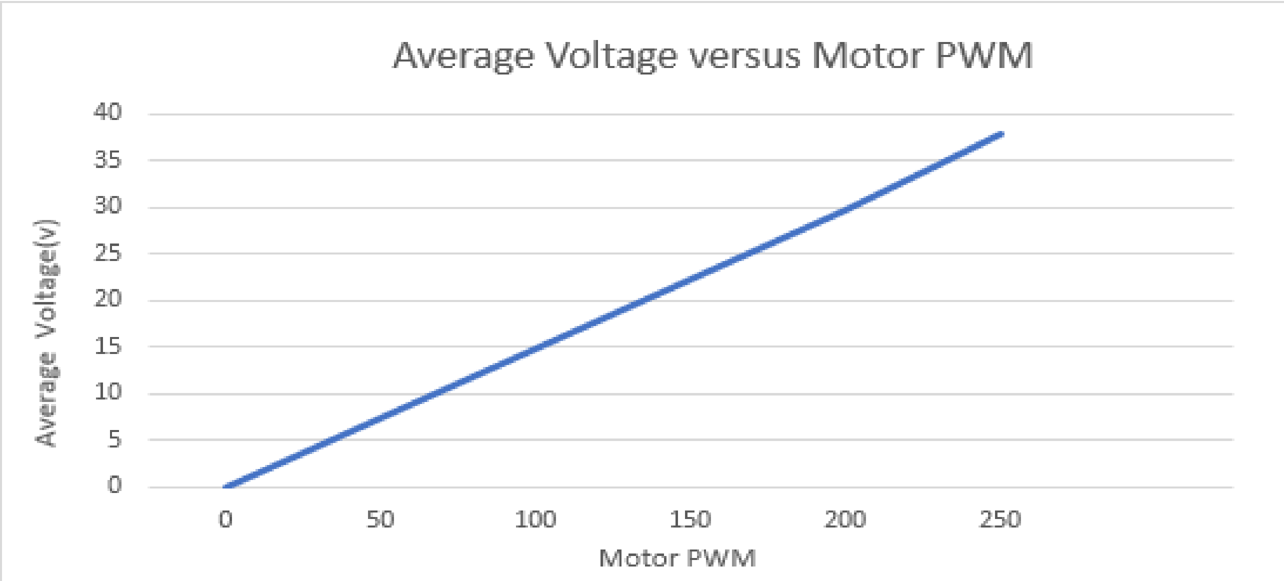


Fig. 5 *Graph of motor PWM versus output voltage from table 3*

3.6 Weight of the prototype

The prototype's weight is measured to determine if it can be held on the ACB panel during charging and switching operations. This test uses an electronic weight mechanism, as shown in Figure 5. The prototype's combined weight and components will be documented in Table 4.

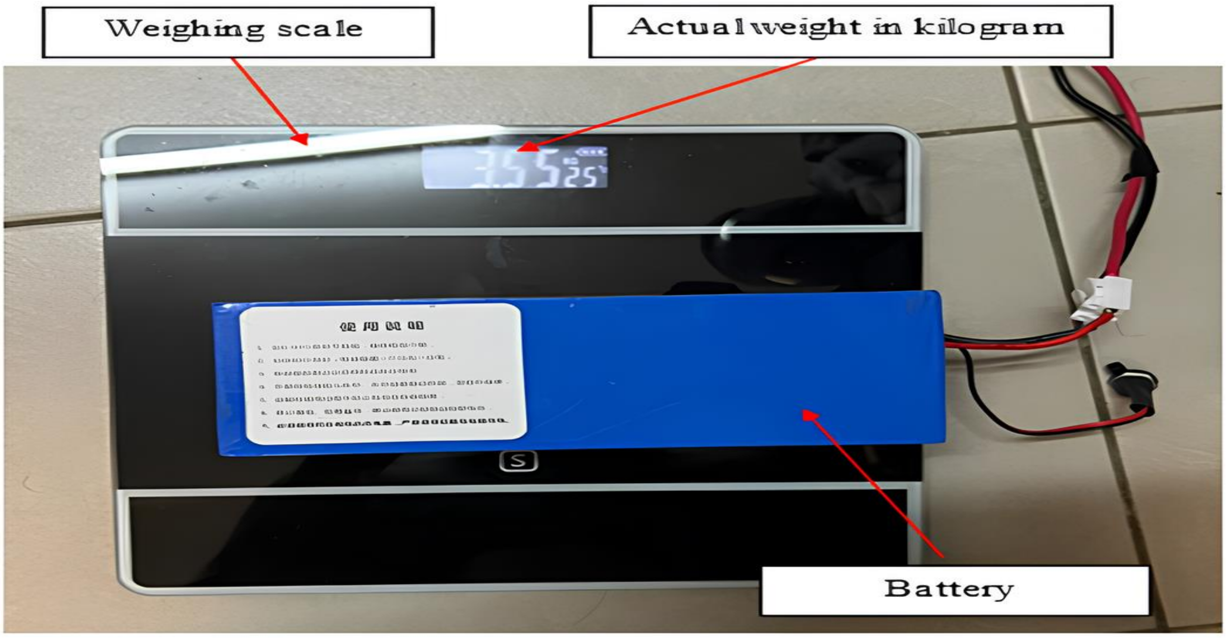


Fig. 6 *Measuring the weight using a weighing scale*

Table 4 *The output voltage as motor PWM changes*

Parameters	Weight(kg)
Solenoid	0.5kg
Dc motor	3kg
Circuit box	0.95kg
Battery	3.55kg

4.0 Conclusion

The successful completion of this project signifies a significant achievement in bolstering workplace safety by reducing human exposure to potential life-threatening tasks, achieved through the replacement of manual operations with cutting-edge autonomous processes. Next, competent electricians who frequently work with higher-voltage electrical systems will likely benefit from this system. A wireless-based interface makes the interaction between humans and machines natural and intuitive. This project aims to pump the lever to charge the ACB, then turn on the ACB and discharge it by pressing the off button automatically. This thesis examined the hardware and software co-design of a mechanism using DC motors and solenoids. This could reduce the labor employed in industry and the danger to human life. This mechanism provides a more intuitive method of Charging and switching systems for low-voltage air circuit breakers.

Acknowledgment

The author extends his sincere gratitude to University Tun Hussein Onn Malaysia, specifically the Faculty of Engineering Technology and the Department of Electrical Engineering Technology, for their unwavering support and provision of invaluable information sources. The collaborative environment and resources offered by the university played a pivotal role in completing this project. Special appreciation is directed towards the supervisor, Professor Madya. Dr. Md. Nor Ramdon Bin, for his continuous support, guidance, and visionary insights throughout the research journey. His expertise and commitment significantly contributed to the success of this project.

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