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Descriptive IoT Based Design and Implementation of a 3-Input Automatic Transfer Switch with Data Logging Features

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Abstract

Electricity is crucial for critical sectors such as banking, healthcare, education, and business. However, in developing nations like Cameroon, persistent power fluctuations and outages present significant challenges, leading to communication disruptions, food spoilage, water supply interruptions, and financial losses. This study proposes a novel solution: a three-input automatic transfer switch integrated with Internet of Things (IoT) and data logging capabilities. The system automatically switches between three independent power sources based on priority and availability, employing electromechanical contactors, relays, and timers for seamless switching. It incorporates ATMEGA328P microcontrollers, a GSM module for communication, and an SD card module for efficient data logging. Safety measures, such as miniature circuit breakers, voltage monitoring relays, and proper grounding, ensure user protection and system integrity. A user-friendly mobile application enables remote manual switching and real-time system information requests, while SMS notifications inform consumers about power source changes. The system has a power rating of 4.752 kW, accommodating a maximum continuous load of the same value. Voltage dividers provide a reliable 3.37 VDC output from a 12 VDC input, and data logging operates effectively by storing system data onto an SD card every 1.5 seconds. Comprehensive testing validates the system's performance, with an average percentage error of 2.31% compared to actual values, falling within an acceptable range. This solution distinguishes itself by incorporating modern technologies like data logging and IoT, addressing the limitations of existing alternatives.

Keywords

Automatic Transfer Switch, GSM Module, Solar, Microcontroller, Power, Relay, Sensor

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1. Introduction

Many developing countries still suffer setbacks arising from incessant power failures though, the era of fluctuation and failure in the supply of electricity is long forgotten in many industrialized nations of the world [1]. These countries suffer from slow processes of development in both the public and private sectors of their economy, because investors from foreign lands do not feel safe to come and set up businesses and industries, despite the large markets available in these populated countries, due to frequent power cuts [2]. To mitigate this problem, alternative power sources, such as backup generators are often used to ensure constant power supply. The introduction of these alternative sources of supply brings forth the challenge of switching smoothly and timely between the mains supply and the alternative sources whenever there is a power failure [3]. Initially, these switches were designed for manual operations, but with the technological advancement in electrical power control and automation, automatic transfer switches (ATS) were created. It eliminates the element of manpower interaction in starting a generator and changing the power supply from one source to another [4].

Multiple research endeavors have been undertaken in this domain, showcasing impressive innovation and rigorous methodology in each solution. Basoene *et al.* in 2022 [5], developed a three-phase automatic transfer switch with relays for phase failure protection. This ATS transfers load between a primary source (public utility) and secondary power supplies (two generators), eliminating manual switching during outages. It starts the generators when the public utility fails, monitors supply restoration, transfers power back to the public utility, and safeguards three-phase equipment from phase faults. In 2021, Abdulkareem *et al.* [6], developed an automatic three-phase power changeover circuit with an alarm. This circuit swiftly switches power supply from power holding company of Nigeria (PHCN) to a power generator in the event of an interruption or outage from PHCN. The circuit includes logic control circuits, three-phase sequence monitors, phase failure monitors, overload relays, and contacting relays for efficient switching. It also incorporates a signal to notify the user when PHCN supply is restored and performs the switch automatically. Olatomiwa & Olufadi [7] designed and developed a cost-effective automatic transfer switch capable of transferring power between two sources for the load. The primary source is the public utility supply, while the secondary source is a key-operated ignition generator. The ATS effectively switches power from the utility to the generator during utility line failures and switches back to the primary source when it is restored, shutting down the secondary source. Furthermore, the design includes protection against over-voltages to prevent damage to the load. All materials and components used in this project were sourced locally, making them affordable and readily available. Islam *et al.* [8], presented an automatic electrical mains changeover system (EMCS) using a PIC microcontroller (μC). The system incorporates a PIC16F84A microcontroller with an 18-pin DIP package and enhanced flash, operating at 4 MHz as the main processor. It also includes two switching transistors, two relays, and a low voltage power supply (LVPS). The EMCS efficiently manages the switching between electrical mains sources, providing seamless transfer of power. John *et al.* [9], developed a single-phase microcontroller-based automatic power changeover system that switches power between the national grid and a generator during power failures. The design incorporates electrical components such as resistors, capacitors, diodes, transistors, opto-isolators, integrated circuits, and relays for efficient switching.

It is evident that the integration of IoT and data logging technologies has been largely overlooked in these innovative approaches. This oversight becomes worrisome considering the rapid growth of these technologies in today's era. Significantly, Wilen *et al.* [10], showcased an implementation of IoT technologies, even though it lacks the inclusion of data logging capabilities. Despite the importance of a reliable power supply, the ability to remotely access current system status, remotely select and activate a desired power source, and store data for future analysis are critical factors that must not be overlooked. Unfortunately, existing systems lack these features. Hence, the primary aim of this paper is to provide a comprehensive design and implementation of a three-input ATS that incorporates advanced IoT and data logging features.

2. Design Theories and Principles

2.1. ATS Circuit Design

An automatic transfer switch is an assembly of various electrical components capable of transferring electrical load from one source of power to another [5]. Most ATS systems utilize cables, contactors, circuit breakers, relays, and timers as essential components. These components play a critical role in the transmission of power from the source to the load. Thus, the actual size of the designed ATS system is primarily determined by the sizes of the contactors, circuit breakers, and power cables since the main power flows through them. Consequently, adjusting the system size is as simple as replacing the respective components with those of the required capacity. From [5], the formula employed for calculating the system size is expressed as in (1) and (2):

For single phase systems:

$$P = I_P \times V_P \times \cos\theta \tag{1}$$

For 3-phase systems:

$$P = 3 \times I_P \times V_P \times \cos\theta \tag{2}$$

where P = Active Power, V_P = Phase Voltage, I_P = Phase Current, and $\cos\theta$ = Power Factor.

2.2. IoT and Data Logger Circuit Design

The internet of things (IoT) refers to a type of network to connect anything with the Internet based on stipulated protocols through information sensing equipment's to conduct information exchange and communications in order to achieve smart recognitions, positioning, tracing, monitoring, and administration [11]. On the other hand, a data logger (also data logger or data recorder) is an electronic device that records data over time or in relation to location either with a built in instrument or sensor or via external instruments and sensors [12]. By integrating IoT and data logging capabilities into a system, its performance and usability can be significantly improved while also generating valuable data for analysis and research. In the context of an Automatic Transfer Switch (ATS) system, the supply voltage emerges as a crucial parameter that holds great importance for both IoT operations and data logging. With this integration, operators gain the ability to remotely monitor the voltage continuously, while simultaneously logging the voltage data for future analysis.

It is vital to continuously measure the output voltage in order to safeguard the load from any voltage irregularities. To achieve this, the supply voltage is initially tapped and then converted to DC voltage through rectification. Subsequently, a voltage divider is employed to further drop the voltage to a safe level for the microcontroller. The output voltage from the voltage divider (**Figure 1**) can be determined using the equation provided below:

Where V_{in} = DC voltage from the rectifier, and V_{out} = Output from the voltage divider, is expressed as in (3);

$$V_{out} = \left(\frac{R_2}{R_1 + R_2}\right) V_{in} \tag{3}$$

2.3. Calculating Percentage Error

The percentage error in a measurement is the difference between the measured value and the true value, expressed as a percentage of the true value. It can be used to evaluate the accuracy of a measurement. From [13], the percentage error can be calculated using the following Equation (4):

$$\%\ \text{Error} = \left|\frac{\text{Measured Value} - \text{Actual Value}}{\text{Actual Value}}\right| \times 100 \tag{4}$$

where |Measured Value − Actual Value| = Error

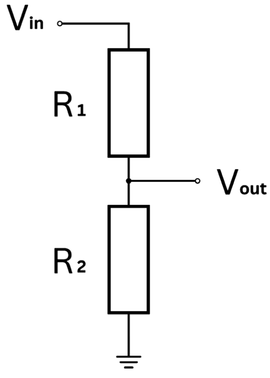


Figure 1. Voltage divider circuit.

3. Proposed Methodology

3.1. Design Concept and Criteria

The design and implementation of the 3-input automatic transfer switch with IoT and data logging features involved analyzing and organizing the various circuit blocks comprising the system. The switching process encompasses power source selection based on availability and priority, relay switching, timer relay switching, and contactor switching. Signal lamps indicate the active power source, while contactor NO auxiliary contacts inform the microcontrollers about the active source. Voltage measurement is implemented through power taps, and current sensors enable current measurement before reaching the load. Two microcontrollers are employed: one for IoT operations and the other for data logging. The IoT microcontroller interfaces with the temperature sensor, 3-phase voltage measurement circuit, contactor NO contacts, GSM module, cooling fan, power source relays, and LCD display. The data logger microcontroller connects to the temperature sensor, real-time clock module, SD card module, contactor NO contacts, 3-phase voltage measurement circuit, and current sensors. The resulting block diagram can be seen in Figure 2.

3.2. Design Criteria Circuits

The integration of the ATS electrical (Figure 3) and electronic (Figure 4) circuits gives rise to the complete system. The ATS operates on a prioritized power

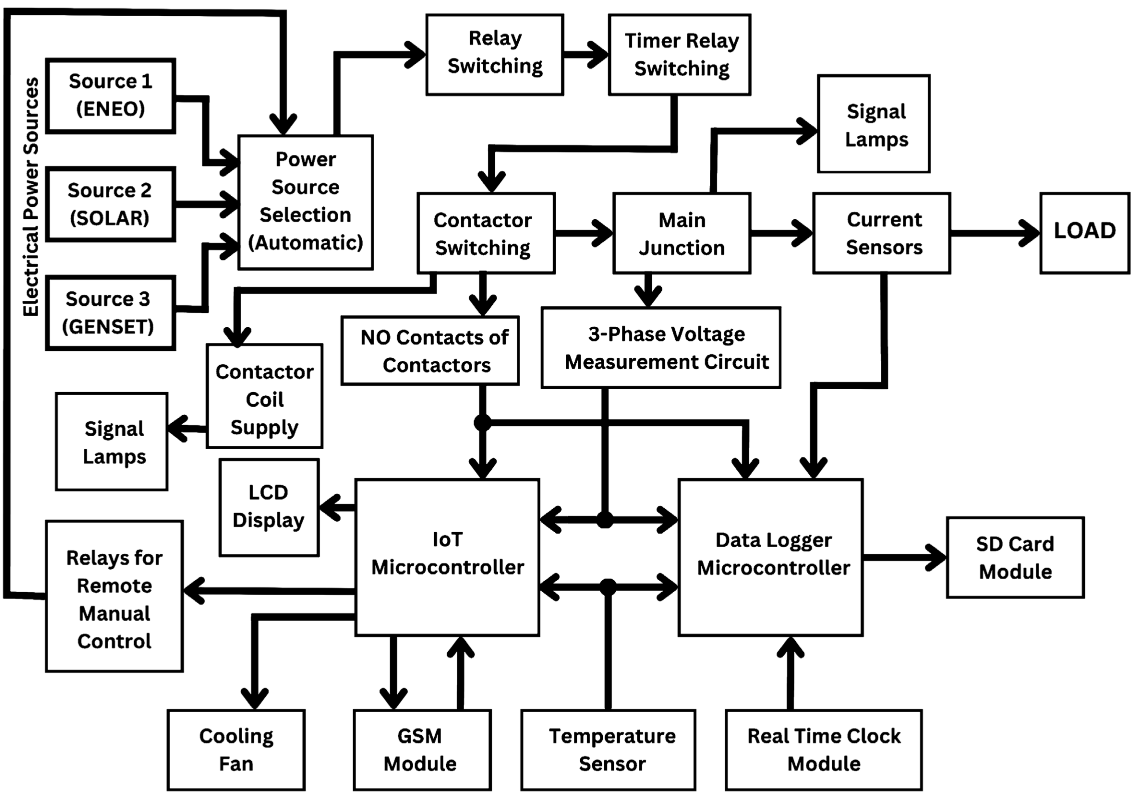


Figure 2. Block diagram of proposed ATS system.

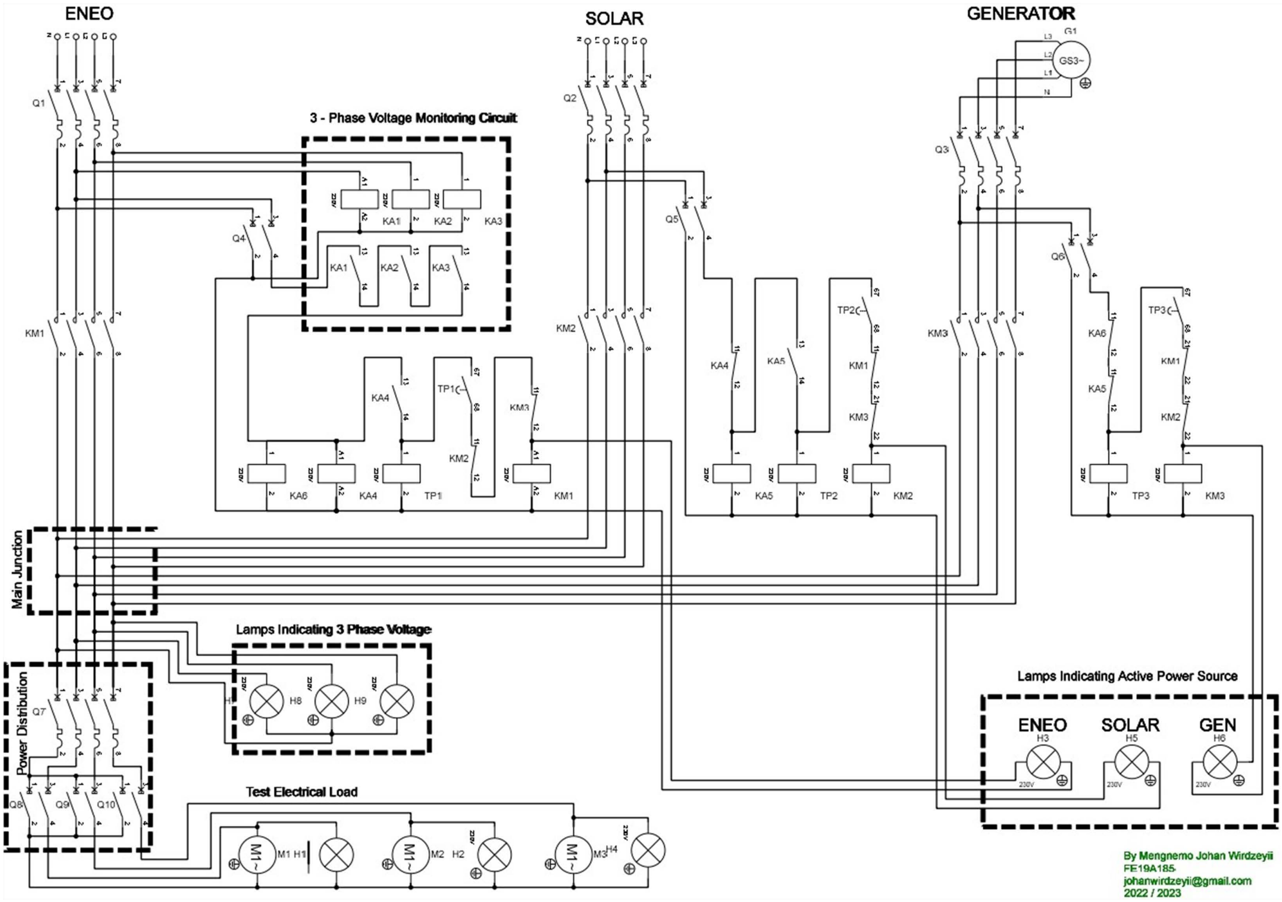


Figure 3. ATS electrical circuit.

source scheme, with ENEO (Energy of Cameroon S.A.) as the primary source, followed by solar and generator as secondary sources. The electrical circuit diagram uses specific symbols to represent each component, with KA denoting relays, TP representing timers, KM representing contactors, Q representing circuit breakers, H denoting lamps, and M representing motors. There is also an electrical interlock between all three contactors so as to ensure that only one contactor coil is energized at any moment, implying that only one power source is allowed to supply power at any instant.

For the electronic circuit (IoT and data logger circuits), two Atmega328p microcontrollers were employed, with one serving the purpose of managing IoT operations, and the other dedicated to data logging operations. The connections between the modules and the microcontrollers were established according to the block diagram (Figure 2) of the system, with each module connected to specific pins on the corresponding microcontroller. These connections were consistently maintained throughout the subsequent phases of the project, ensuring that the system functioned optimally.

In the designed system, various connections are established between the ATS electrical circuit and the electronic circuit (IoT and data logger circuits). These connections include: routing the ATS control power through 5 V relays in the

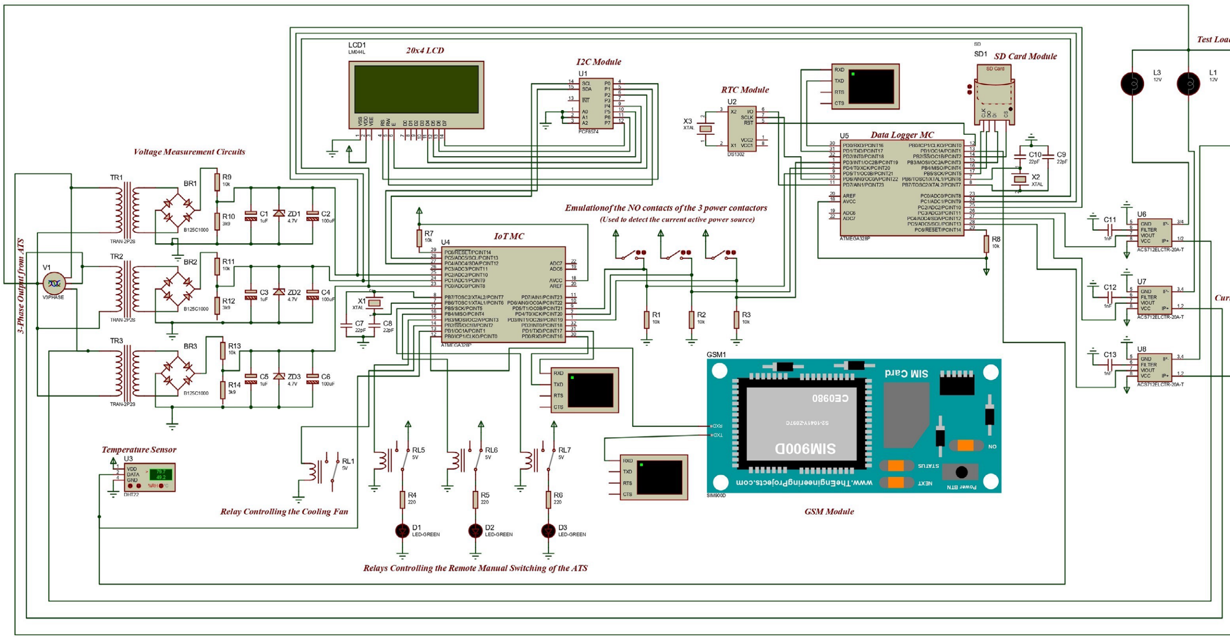


Figure 4. Electronic circuit (IoT and data logger circuits).

electronic circuit to enable manual switching via the microcontroller, linking one of the NO contacts of each contactor auxiliary contacts with a pull-down resistor for convenient monitoring of the contactor state using the microcontroller, and extracting the output voltage from each phase, stepping it down through a transformer for measurement by the microcontroller. The 3 phase voltage measurement circuit comprises three 220/12 VAC step down transformers, each stepping down the voltage from one of the 3 phases output. Each output is then passed through a bridge rectifier, and then through a voltage divider made up of a 10 kΩ and a 3.9 kΩ resistor so as to further drop the voltage to a voltage tolerable by the microcontrollers. Considering that there is a maximum output voltage of 12 V from the transformer and rectifier, the final voltage leaving the voltage divider through rest of the circuit to the microcontroller is given as follows:

From Equation (3), for an input voltage (V_{in}) = 12V, R_1 = 10 kΩ, R_2 = 3.9 kΩ, V_{out} is calculated as in (5):

$$V_{out} = \frac{3.9}{10+3.9} \times 12 = 3.37 \text{ V} \tag{5}$$

This voltage level is deemed safe to transmit to the microcontroller input. It is worth noting that the practical measurement may differ slightly from the calculated value. However, it is anticipated that the deviation from the calculated value would be negligible. Also, capacitors are used for filtering, and a 4.7 V zener diode used for voltage regulation. In **Figure 4**, the NO contacts of the 3 contactors are emulated by the use of pushbuttons, and pull-down resistors are incorporated to enable the NO contacts to function similarly to pushbuttons. This configuration enables the microcontroller to track which contactor coil is currently energized, and consequently, which power source is active at any given moment. To enable remote manual switching, 5VDC single-pole, double-throw (SPDT) relays are utilized, which are connected to the IoT microcontroller. When a specific command is received from the GSM, the system executes the defined actions. In cases where a change of power source is requested, the relay connected to the preferred source remains de-energized, while the coils of the other two relays are energized, preventing them from transporting control power. This arrangement ensures that only the selected source can supply power. This control mechanism is achievable because the electrical control power, which is tapped from one of the main phases, passes through the normally closed (NC) contact of each 5VDC relay on the electronic circuit before reaching the other components on the electrical control circuit for each of the three sources. The current sensors are connected on the current path of the output and the data pin sends the measurement data to the data logger microcontroller. The current sensors measure the current for each phase and once all the data is sent, further computations are made and the data is registered to an SD card via the SD card module. The temperature sensor is employed to continuously measure the temperature of the system, and another 5VDC relay is utilized to activate the cooling fan, via the microcontroller, when the measured temperature surpasses a predetermined maximum value. Additionally, the system's LCD display continuously provides information based on recent updates.

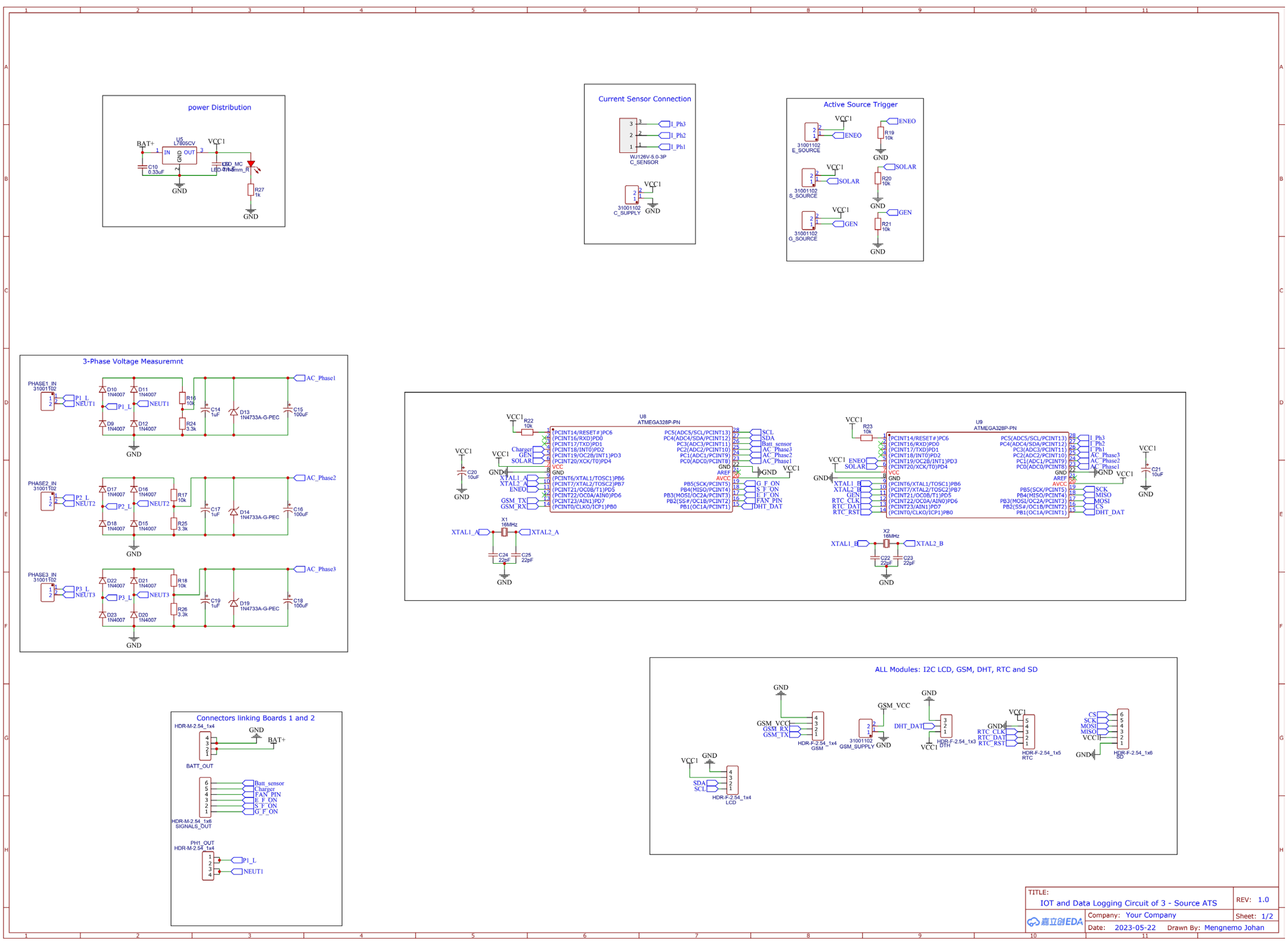
The ATS electrical circuit was designed on Schemaplic software, while the electronic circuit (IoT and data logger circuits) was designed on Proteus. To establish connections between the ATS and electronic circuits, a printed circuit board (PCB) was designed using EasyEDA software. The PCB was divided into two boards: one dedicated to hosting microcontrollers and a section of the circuitry, while the other board accommodated all the 5 V relays and remaining circuit components. Furthermore, a specialized battery charger circuit was integrated to facilitate convenient recharging of the electronic circuit's battery once it reaches a predetermined level of discharge. The PCB designs can be seen in **Figure 5(a)**, **Figure 5(b)**, **Figure 6(a)** and **Figure 6(b)**.

3.3. ATS Flow Chart

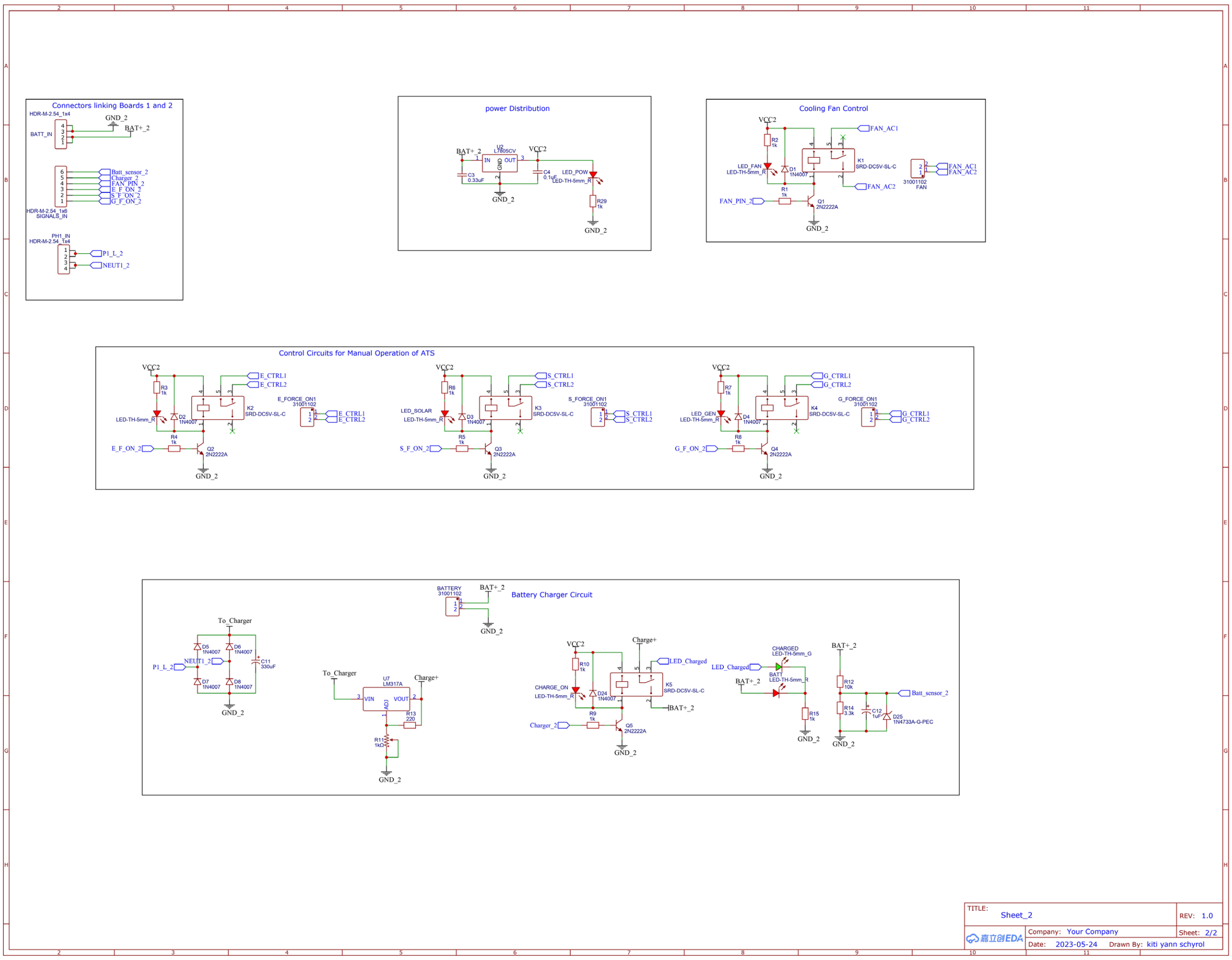
The flow chart in **Figure 7** illustrates the sequence of operations of the ATS system. The system begins by initializing and preparing all modules, sensors, and the entire electronic circuit. It then displays a welcome message on the LCD before transitioning to the default screen. Temperature, 3-phase voltage, and current are continuously measured, with the cooling fan activated if the temperature exceeds 27˚C. The system checks the availability of the first power source (ENEO) and switches to the second power source (Solar) if the first is unavailable or if voltage irregularities or phase issues are detected. Signal lamps indicate the active power source and available phases, while data is logged, information is displayed on the LCD, and SMS notifications are sent to the operator. If the second power source is also unavailable, the system switches to the third power source (generator) following the same procedures. The operator can send commands via the app to request system information, manual switching between power sources, or restoration to automatic mode, with corresponding actions, notifications, data logging, and LCD updates performed accordingly.

4. ATS Circuit Simulation Results

The results obtained after simulating the 3—input ATS circuit on Schemaplic is illustrated in Figures 8-11. All circuit breakers are initially turned on with priority given to ENEO, while solar power is only allowed when ENEO power is unavailable. The generator is activated only when both ENEO and solar power are unavailable. The ENEO line is monitored by a voltage monitoring relay that checks the incoming voltage for abnormalities such as over-voltage, under-voltage, phase failure, and phase reversal before allowing control power to flow. If any irregularities are detected, the relay restricts control power, preventing ENEO from supplying power and initiating an automatic switch to the second source (solar). Control power flows to the ENEO DPDT relays (KA4 and KA6), after being properly checked, energizing their coils. This allows control power to flow to the ENEO DPDT timer relay (TP1), while preventing solar and

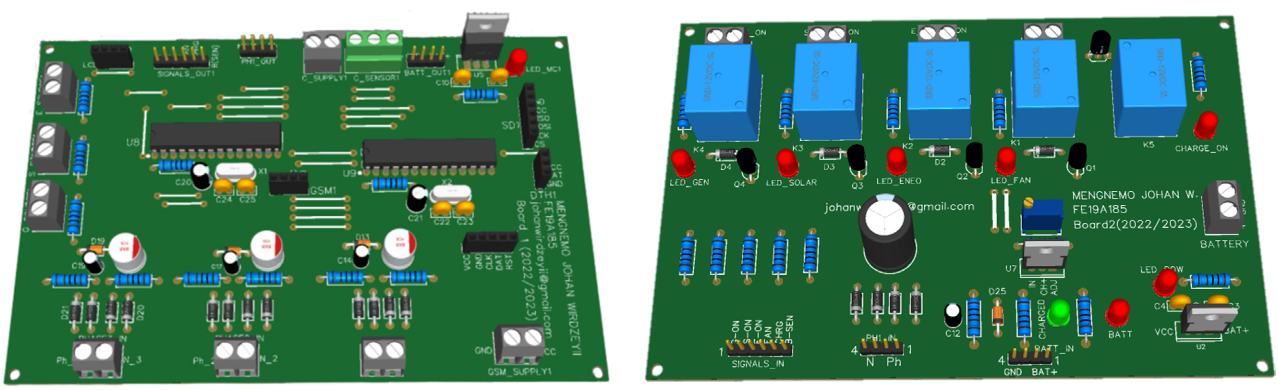


(a)



(b)

Figure 5. (a) PCB 1 schematic diagram; (b) PCB 2 schematic diagram.



(a) (b)

Figure 6. (a) 3D view of PCB 1; (b) 3D view of PCB 2.

generator control powers from flowing. TP1's coil is energized, initiating a safety time delay before control power is allowed to flow to the ENEO contactor (KM1) coil, enabling ENEO to supply power. In the event that ENEO power becomes unavailable, switching to solar power is initiated. The solar DPDT relay (KA5)

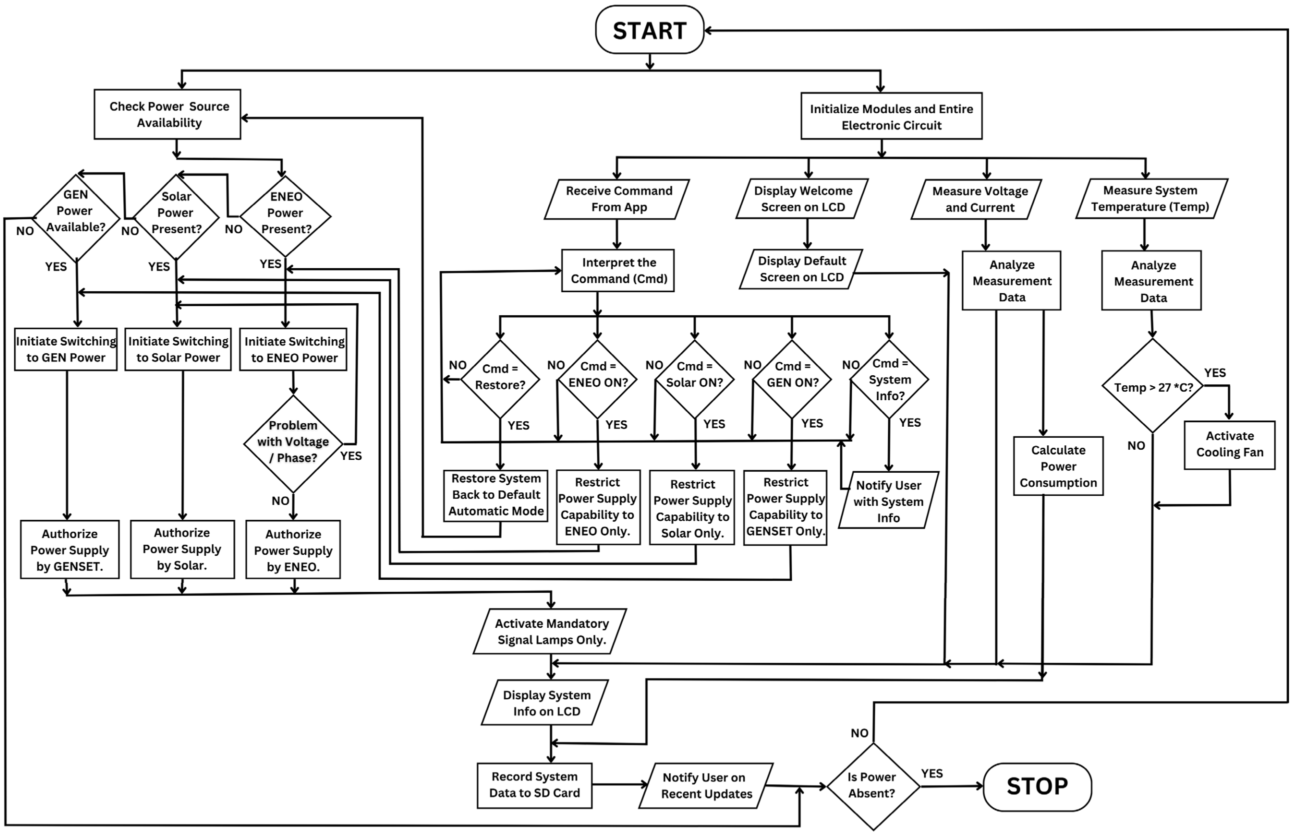


Figure 7. Flow chart of the ATS system.

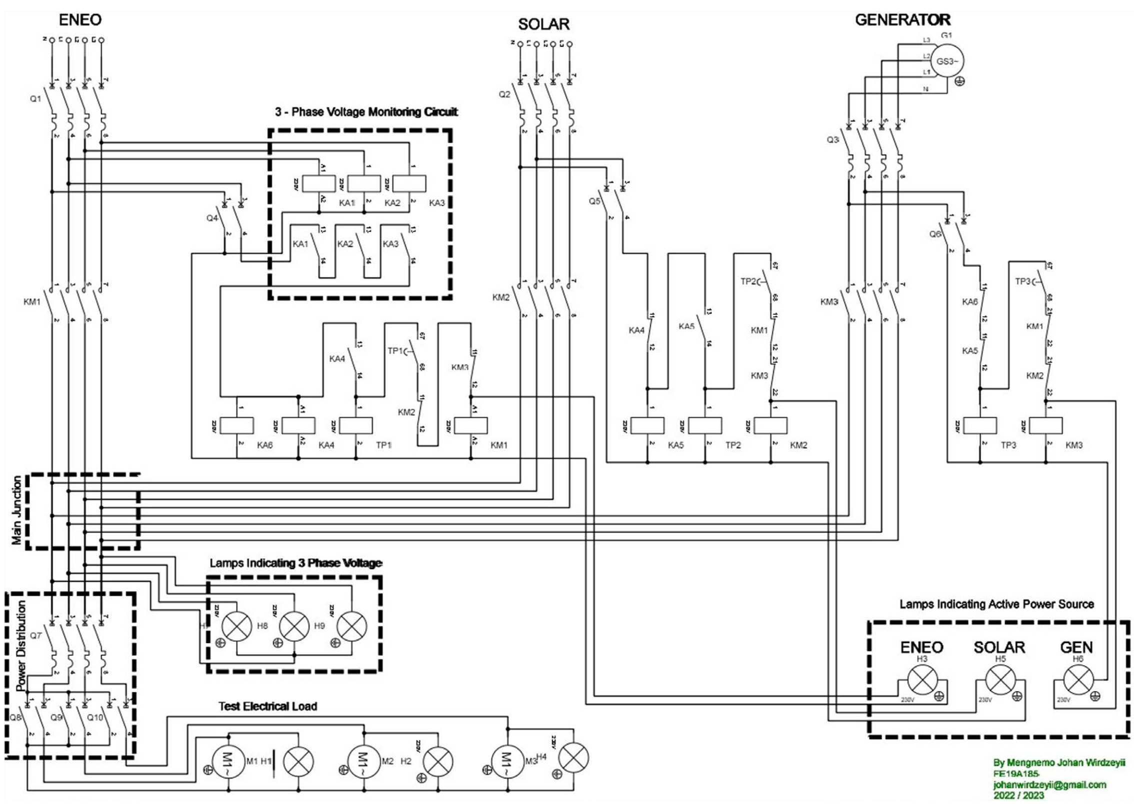


Figure 8. ATS in OFF state.

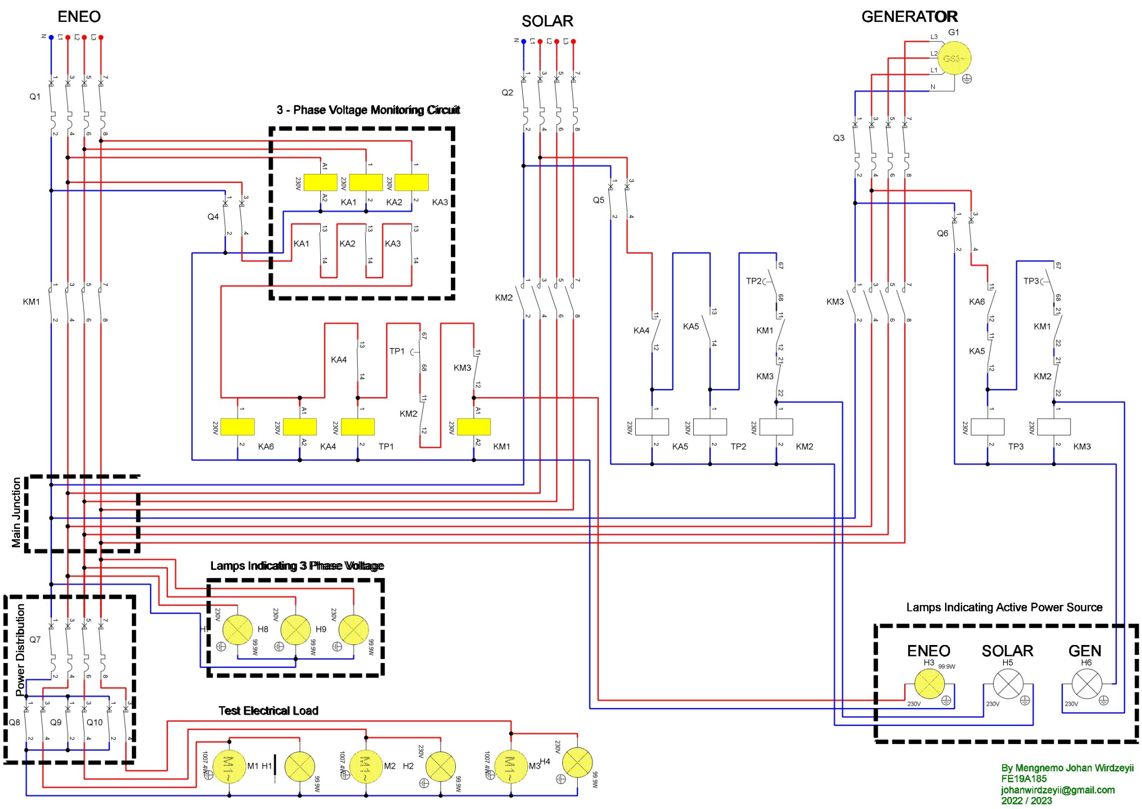


Figure 9. ENEO supplying power.

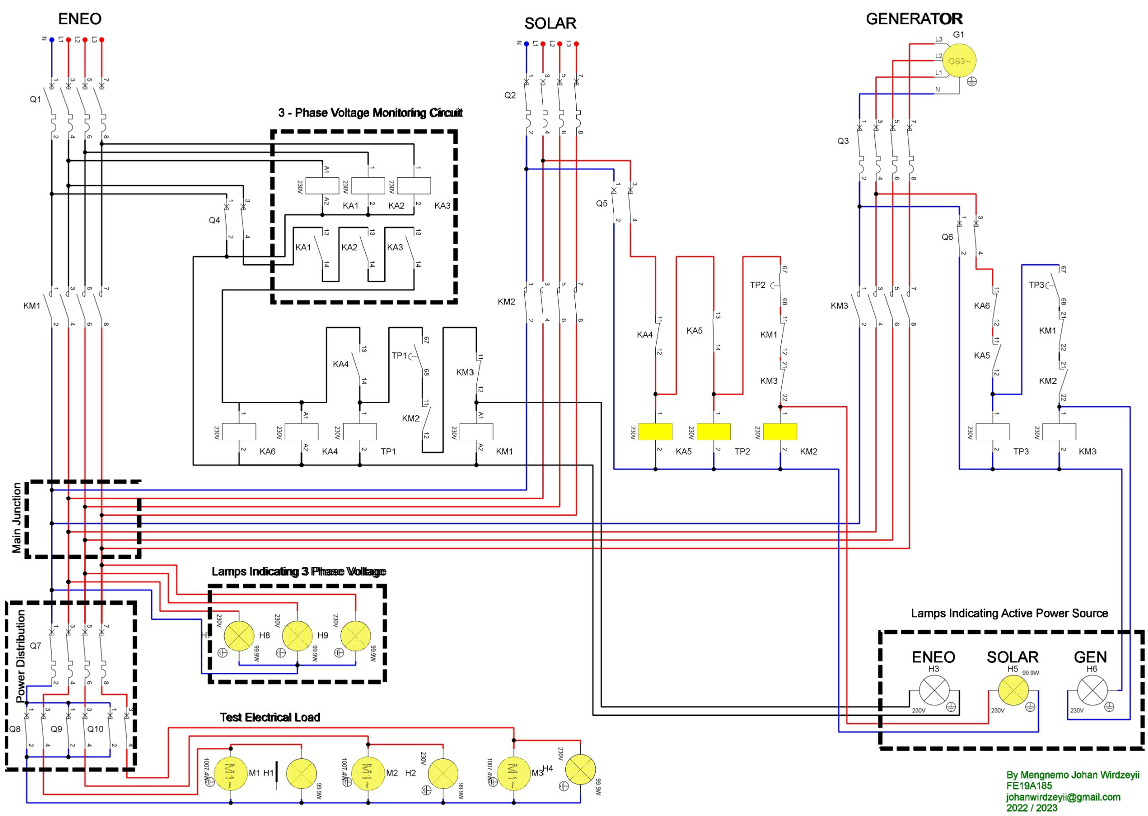


Figure 10. Solar supplying power.

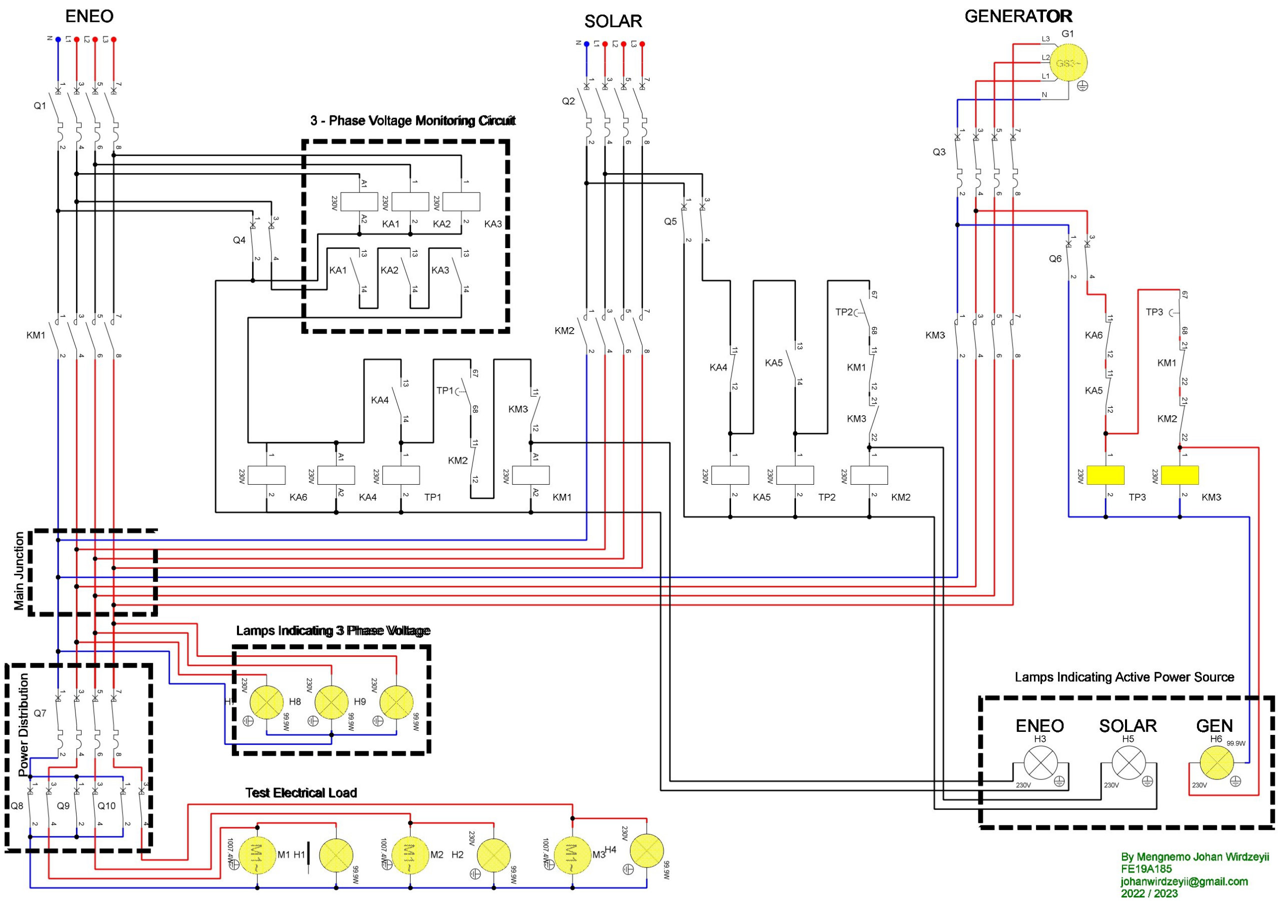


Figure 11. Generator supplying power.

coil is energized, and control power flows to the solar timer relay (TP2), while preventing generator control power from flowing. Once the safety time delay offered by TP2 runs out, control power reaches the solar contactor (KM2) and energizes its coil, allowing solar power to be supplied. If both ENEO and solar powers are unavailable, switching to generator power is initiated, and control power reaches the generator timer (TP3). Once its coil is energized, a safety time delay is initiated, after which the control power reaches the generator contactor (KM3) coil, allowing the generator to supply power. When ENEO or solar power becomes available again, generator control power is cut and ENEO or solar takes over the supply of electrical power. ENEO is always prioritized over all other sources, followed by solar, and then the generator. Also, the signal lamps indicate the type of source supplying, as well as the available phases.

5. Hardware Implementation

The hardware implementation process involved acquiring the required components and tools. Initially, the metallic control box and rails were cut and drilled using an electrical drill, hand saw, and electrical drill saw. The rails were then mounted, creating a structure for component mounting. Electrical components were mounted, and connections were made on the electrical circuit, with tests conducted to ensure the proper functioning of the automatic transfer switch (ATS). Electronic components were soldered onto the PCB, followed by further tests to ensure functionality. Microcontrollers were programmed, and connections were established between the electrical and electronic circuits, with additional tests performed for smooth operation. Finally, the necessary circuitry was mounted on printed 3D structures, and a comprehensive testing of the entire setup was conducted. This can be seen in Figures 12-17.

The ATS makes use of 2.5mm2 single core copper cables, 16A MCBs, and LC1-D09 10 contactors that can support a maximum current load of 9 A. The size of the contactor is the primary determinant of the system's capacity from the components provided, as it has the smallest rating. Therefore, the maximum current carrying capacity that the system can handle continuously is restricted to 9A.

From Equation (2), Let $I_P = 9\text{A}$, $V_P = 220\text{V}$, and $\cos\theta = 0.8$, we had the numerical application as in (6)

$$P = 3 \times 9 \times 220 \times 0.8 = 4752\ \text{W} = 4.752\ \text{kW} \tag{6}$$

Hence, the system is rated at 4.752 kW, which represents its ability to accommodate a maximum continuous load of the same value.

Figure 12. Drilling and cutting.

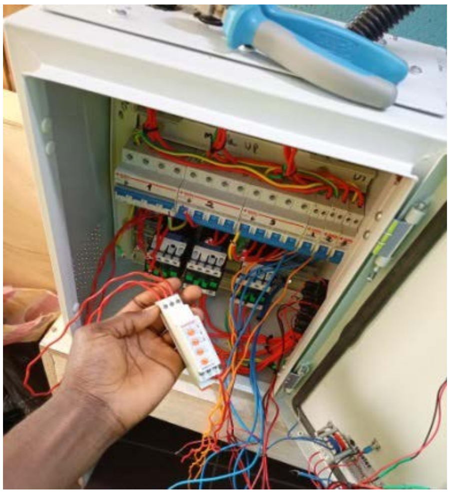


Figure 13. Mounting of electrical circuit.

Figure 14. Soldering of components on PCBs.

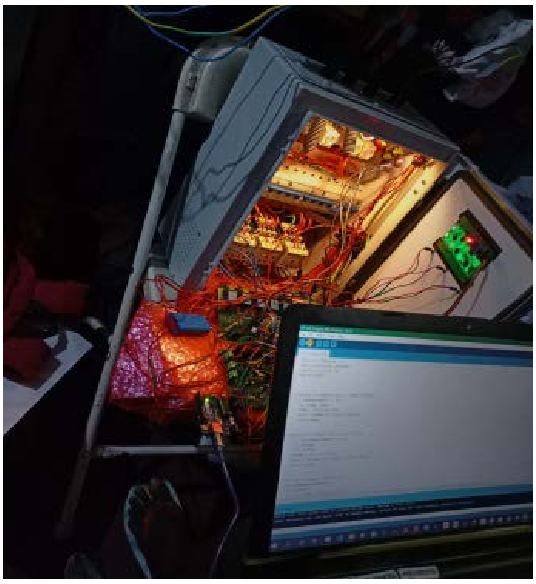


Figure 15. Programming of MCUs.

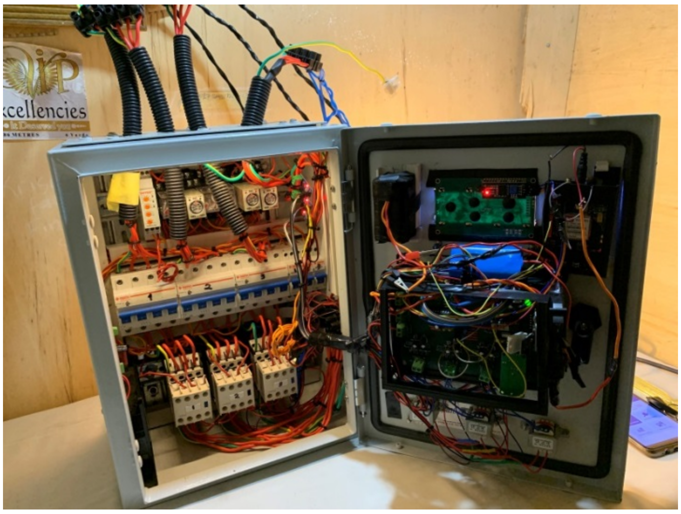


Figure 16. Interior view of complete ATS system.

Figure 17. Exterior view of complete ATS system.

6. Mobile App Development

The app was built using MIT App Inventor and uses SMS as a means of communication. Specific messages are assigned to specific buttons, and these messages are interpreted and a set of instructions are run by the microcontroller when the command reaches it via the GSM. With the mobile app, one can request for current system information, switch to any power source, and restore system back to default automatic mode as can be seen in Figure 18. The following Table 1 further explains the functions of each button in the app.

7. Results and Discussion

The implemented ATS performed as expected. Also, the IoT component provided constant updates through SMS and allowed for manual control via a mobile app. Real-time updates were displayed on the LCD, and the cooling fan was automatically activated to prevent overheating. The data logger functioned exceptionally well, logging various data such as date, time, voltages, current draw, power consumption, system temperature, and power source type onto an SD card every 1.5 seconds. The results obtained are highlighted by Figures 19-21.

For reference, Table 2 depicts the measured values for 3-phase voltage and battery voltage, as compared to the actual values obtained through a digital multi-meter. Although the measured values exhibited some inaccuracies, they remained in close proximity to the actual values.

From Equation (4), the percentage errors in the measurement values can be gotten as follows:

For Phase 1 Voltage (Ph1): $\% \text{Error}_{(ph1)} = |(223 - 218.5)/218.5| \times 100 = 2.06\%$

For Phase 2 Voltage (Ph2): $\% \text{Error}_{(ph2)} = |(224 - 219.7)/219.7| \times 100 = 1.96\%$

For Phase 3 Voltage (Ph3): $\% \text{Error}_{(ph3)} = |(222 - 217)/217| \times 100 = 2.30\%$

For Battery Voltage (Batt): $\% \text{Error}_{(batt)} = |(7.35 - 7.57)/7.57| \times 100 = 2.91\%$

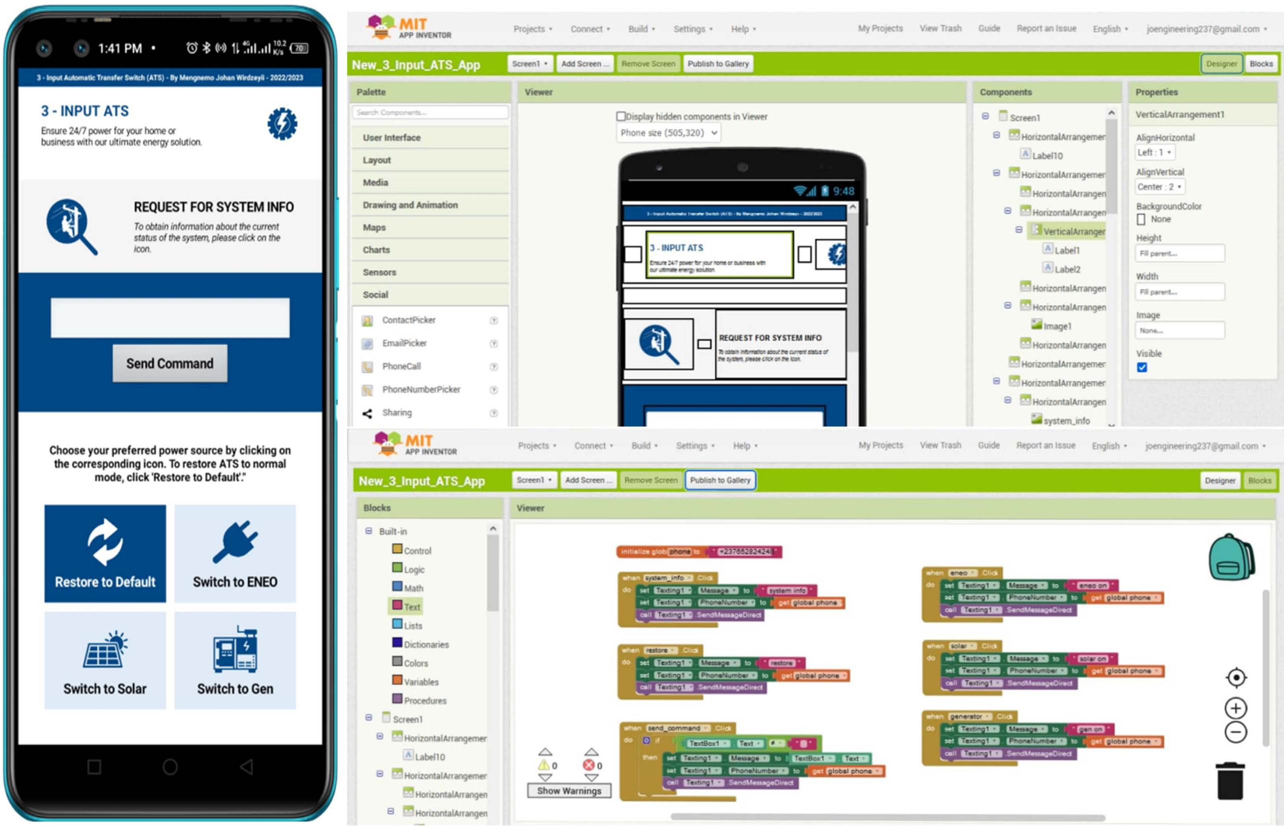


Figure 18. Mobile app development on MIT app inventor.

Table 1. Functions of various buttons on the mobile app.

Button	Function
System Info	Clicking the button triggers a command sent to the microcontroller through GSM, resulting in the user receiving an SMS notification containing system information.
Restore to Default	Clicking the button triggers a confirmation alert for restoring the system to default automatic mode. After confirmation, a command is sent via GSM to the microcontroller, initiating the system restoration and notifying the user through an SMS. If no confirmation is received, the process is aborted, and the system remains unchanged.
Switch to ENEO	Clicking the button triggers a confirmation alert to switch the power source to ENEO. After confirming, a command is sent via GSM to the microcontroller instructing it to exclusively enable power supply from ENEO. The user receives an SMS notification confirming the power source change. If no confirmation is received, the process is aborted, and the power source remains unchanged.
Switch to Solar	Clicking the button prompts a confirmation alert for switching the power source to Solar. Upon confirmation, a command is sent via GSM to the microcontroller, instructing it to enable power supply solely from the Solar source. The user receives an SMS notification regarding the successful power source switch. If no confirmation is received, the process is aborted, and the power source remains unchanged.
Switch to Gen	Clicking the button triggers an alert asking the user to confirm the switch of power source to the generator (Gen). If the user confirms, a command is sent via GSM to the microcontroller, instructing it to activate the generator as the sole power source. The user is then notified of the successful power source switch through an SMS. If the user does not confirm, the process is aborted, and the power source remains unchanged.
Send Command	Clicking the button sends the command entered in the text box to the microcontroller through the GSM module.

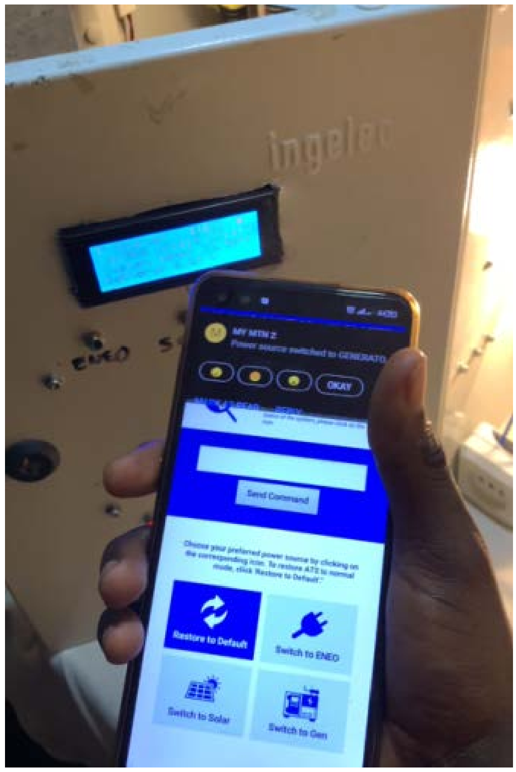
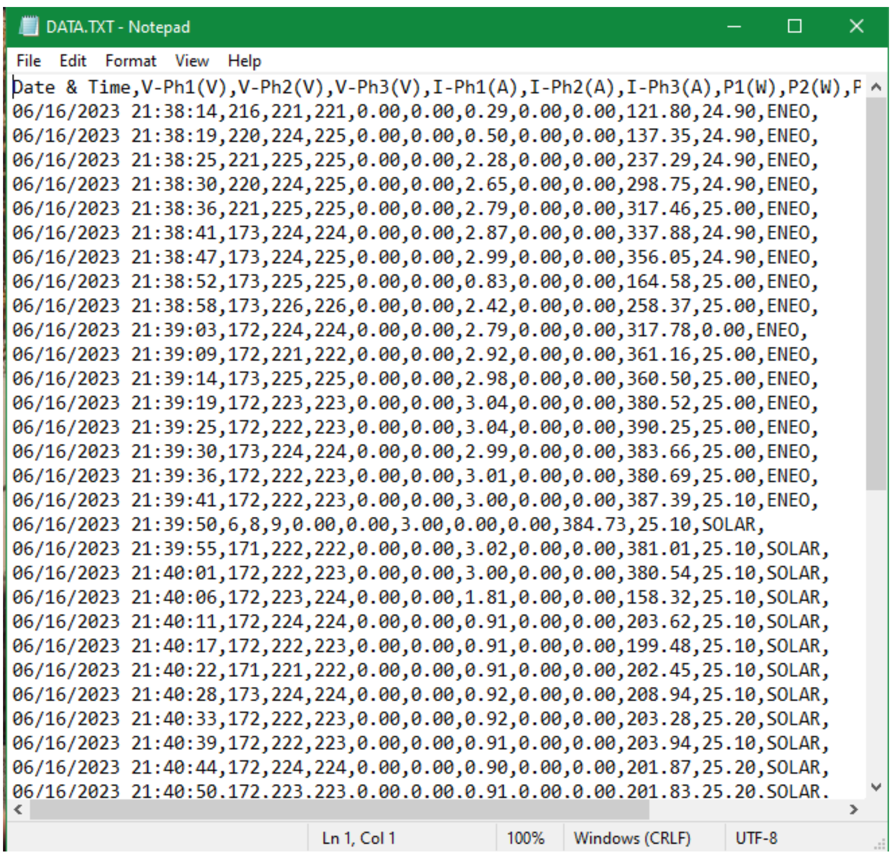


Figure 19. System operational with mobile app.



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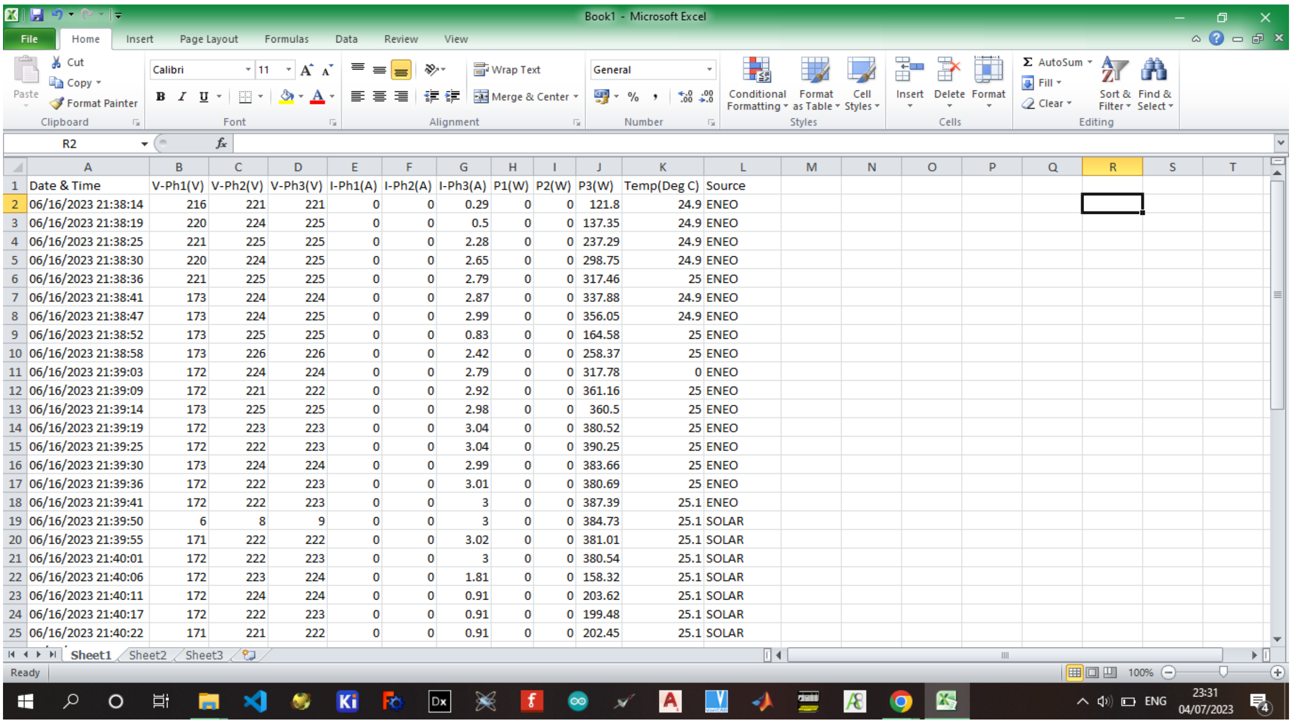
Date & Time,V-Ph1(V),V-Ph2(V),V-Ph3(V),I-Ph1(A),I-Ph2(A),I-Ph3(A),P1(W),P2(W),P
06/16/2023 21:38:14,216,221,221,0.00,0.00,0.29,0.00,0.00,121.80,24.90,ENEO,
06/16/2023 21:38:19,220,224,225,0.00,0.00,0.50,0.00,0.00,137.35,24.90,ENEO,
06/16/2023 21:38:25,221,225,225,0.00,0.00,2.28,0.00,0.00,237.29,24.90,ENEO,
06/16/2023 21:38:30,220,224,225,0.00,0.00,2.65,0.00,0.00,298.75,24.90,ENEO,
06/16/2023 21:38:36,221,225,225,0.00,0.00,2.79,0.00,0.00,317.46,25.00,ENEO,
06/16/2023 21:38:41,173,224,224,0.00,0.00,2.87,0.00,0.00,337.88,24.90,ENEO,
06/16/2023 21:38:47,173,224,225,0.00,0.00,2.99,0.00,0.00,356.05,24.90,ENEO,
06/16/2023 21:38:52,173,225,225,0.00,0.00,0.83,0.00,0.00,164.58,25.00,ENEO,
06/16/2023 21:38:58,173,226,226,0.00,0.00,2.42,0.00,0.00,258.37,25.00,ENEO,
06/16/2023 21:39:03,172,224,224,0.00,0.00,2.79,0.00,0.00,317.78,0.00,ENEO,
06/16/2023 21:39:09,172,221,222,0.00,0.00,2.92,0.00,0.00,361.16,25.00,ENEO,
06/16/2023 21:39:14,173,225,225,0.00,0.00,2.98,0.00,0.00,360.50,25.00,ENEO,
06/16/2023 21:39:19,172,223,223,0.00,0.00,3.04,0.00,0.00,380.52,25.00,ENEO,
06/16/2023 21:39:25,172,222,223,0.00,0.00,3.04,0.00,0.00,390.25,25.00,ENEO,
06/16/2023 21:39:30,173,224,224,0.00,0.00,2.99,0.00,0.00,383.66,25.00,ENEO,
06/16/2023 21:39:36,172,222,223,0.00,0.00,3.01,0.00,0.00,380.69,25.00,ENEO,
06/16/2023 21:39:41,172,222,223,0.00,0.00,3.00,0.00,0.00,387.39,25.10,ENEO,
06/16/2023 21:39:50,6,8,9,0.00,0.00,3.00,0.00,0.00,384.73,25.10,SOLAR,
06/16/2023 21:39:55,171,222,222,0.00,0.00,3.02,0.00,0.00,381.01,25.10,SOLAR,
06/16/2023 21:40:01,172,222,223,0.00,0.00,3.00,0.00,0.00,380.54,25.10,SOLAR,
06/16/2023 21:40:06,172,223,224,0.00,0.00,1.81,0.00,0.00,158.32,25.10,SOLAR,
06/16/2023 21:40:11,172,224,224,0.00,0.00,0.91,0.00,0.00,203.62,25.10,SOLAR,
06/16/2023 21:40:17,172,222,223,0.00,0.00,0.91,0.00,0.00,199.48,25.10,SOLAR,
06/16/2023 21:40:22,171,221,222,0.00,0.00,0.91,0.00,0.00,202.45,25.10,SOLAR,
06/16/2023 21:40:28,173,224,224,0.00,0.00,0.92,0.00,0.00,208.94,25.10,SOLAR,
06/16/2023 21:40:33,172,222,223,0.00,0.00,0.92,0.00,0.00,203.28,25.20,SOLAR,
06/16/2023 21:40:39,172,222,223,0.00,0.00,0.91,0.00,0.00,203.94,25.10,SOLAR,
06/16/2023 21:40:44,172,224,224,0.00,0.00,0.90,0.00,0.00,201.87,25.20,SOLAR,
06/16/2023 21:40:50,172,223,223,0.00,0.00,0.91,0.00,0.00,201.83,25.20,SOLAR,
```

Ln 1, Col 1 100% Windows (CRLF) UTF-8

Figure 20. Logged data onto an SD card.



Date & Time	V-Ph1(V)	V-Ph2(V)	V-Ph3(V)	I-Ph1(A)	I-Ph2(A)	I-Ph3(A)	P1(W)	P2(W)	P3(W)	Temp(Deg C)	Source
06/16/2023 21:38:14	216	221	221	0	0	0.29	0	0	121.8	24.9	ENEO
06/16/2023 21:38:19	220	224	225	0	0	0.5	0	0	137.35	24.9	ENEO
06/16/2023 21:38:25	221	225	225	0	0	2.28	0	0	237.29	24.9	ENEO
06/16/2023 21:38:30	220	224	225	0	0	2.65	0	0	298.75	24.9	ENEO
06/16/2023 21:38:36	221	225	225	0	0	2.79	0	0	317.46	25	ENEO
06/16/2023 21:38:41	173	224	224	0	0	2.87	0	0	337.88	24.9	ENEO
06/16/2023 21:38:47	173	224	225	0	0	2.99	0	0	356.05	24.9	ENEO
06/16/2023 21:38:52	173	225	225	0	0	0.83	0	0	164.58	25	ENEO
06/16/2023 21:38:58	173	226	226	0	0	2.42	0	0	258.37	25	ENEO
06/16/2023 21:39:03	172	224	224	0	0	2.79	0	0	317.78	0	ENEO
06/16/2023 21:39:09	172	221	222	0	0	2.92	0	0	361.16	25	ENEO
06/16/2023 21:39:14	173	225	225	0	0	2.98	0	0	360.5	25	ENEO
06/16/2023 21:39:19	172	223	223	0	0	3.04	0	0	380.52	25	ENEO
06/16/2023 21:39:25	172	222	223	0	0	3.04	0	0	390.25	25	ENEO
06/16/2023 21:39:30	173	224	224	0	0	2.99	0	0	383.66	25	ENEO
06/16/2023 21:39:36	172	222	223	0	0	3.01	0	0	380.69	25	ENEO
06/16/2023 21:39:41	172	222	223	0	0	3	0	0	387.39	25.1	ENEO
06/16/2023 21:39:50	6	8	9	0	0	3	0	0	384.73	25.1	SOLAR
06/16/2023 21:39:55	171	222	222	0	0	3.02	0	0	381.01	25.1	SOLAR
06/16/2023 21:40:01	172	222	223	0	0	3	0	0	380.54	25.1	SOLAR
06/16/2023 21:40:06	172	223	224	0	0	1.81	0	0	158.32	25.1	SOLAR
06/16/2023 21:40:11	172	224	224	0	0	0.91	0	0	203.62	25.1	SOLAR
06/16/2023 21:40:17	172	222	223	0	0	0.91	0	0	199.48	25.1	SOLAR
06/16/2023 21:40:22	171	221	222	0	0	0.91	0	0	202.45	25.1	SOLAR

Figure 21. Logged data imported to MS Excel.

Table 2. Comparing the system voltage measured values to the actual values.

Actual Values				Measured Values (from MCU)			
Ph1 (V)	Ph2 (V)	Ph3 (V)	Batt (V)	Ph1 (V)	Ph2 (V)	Ph3 (V)	Batt (V)
218.5	219.7	217.0	7.57	223.0	224.0	222.0	7.35

The average percentage error in the measurements is around 2.31%, which is statistically acceptable [14] and reflecting a testing accuracy of 97.69%. The data logging achieved can store system data every 1.5 seconds; which is slow with regards to the 0.1 milli-seconds observed by Amadi *et al.* [15], but faster than the observations (20 seconds delay) of Abubakar *et al.* [16] with their multi–source switching system.

Comparing this work further with related literature, the proposed ATS design showcased notable advancements. Firstly, the integration of IoT technology empowered remote monitoring and control of the ATS system, enabling users to access real-time status updates and remotely select power sources. This feature enhances convenience and flexibility, particularly in scenarios where physical access to the ATS may be limited or challenging. Additionally, the data logging functionality offered valuable insights into the system's performance, facilitating proactive maintenance and optimization. These functionalities are absent in existing systems. Amongst so many other research endeavors, in [5], the authors were able to carry out simulations on their designed system made up of 3 power sources (the utility and two generators), which was successful, and there is neither the implementation of IoT nor data logging technologies. In [6], the authors worked on a similar system, but with two power sources and the addition of an alarm system. The system was designed and developed successfully, and several tests were carried out to ensure proper functionality, yet it was still missing IoT and data logging functionalities. In [7], the authors succeeded with the design and implementation of the ATS system making use of locally sourced low-cost equipment, yet, without integrating IoT or data logging. In [8], the authors succeeded in the design and simulation of the PIC microcontroller base electrical mains changeover system. Despite the fact that a microcontroller was used, it just ended at making use of basic components, without integrating either IoT or data logging. In [9], the authors also succeeded in the design and implementation of the microcontroller based ATS capable of handling 12KVA. This work did not still include IoT or data logging features. In [10], the authors succeeded in integrating IoT technologies to their ATS system, yet, it was lacking data logging. Also, no special mobile application was built to be able to control and monitor the system. Rather, an already existing app (Blynk) was used.

It is worth noting how unique this study is, integrating both IoT and data logging technologies to a 3-input ATS system, cemented with the numerous functionalities attached to it. However, it is essential to acknowledge certain limitations of this study. The experiments were conducted in a laboratory environment, and although efforts were made to replicate real-world conditions, the actual operational challenges and environmental factors may differ.

8. Conclusion

This paper reports on a comprehensive design and implementation of a three-input Automatic Transfer Switch (ATS) that integrates advanced Internet of Things (IoT) and data logging features. The motivation behind the research stemmed from the persistent issue of power failures in developing countries like Cameroon, which hinder economic growth and discourage foreign investments. Previous studies had primarily focused on developing innovative ATS solutions with diverse functionalities, but the incorporation of IoT and data logging technologies had been largely overlooked. This work is aimed to bridge this gap by combining the capabilities of an ATS with IoT technology, allowing for remote access to system status, remote selection and activation of power sources, and data logging for future analysis. By incorporating these advanced features, the objective was to enhance the reliability and efficiency of power transfer processes while providing valuable insights for system optimization and performance evaluation. The proposed ATS design represents a significant advancement in the field, offering a more comprehensive and technologically advanced solution for managing power supply during outages. Future research could explore further enhancements and applications of IoT and data logging in power distribution systems to address the evolving needs of industries and communities.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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