DESIGN AND CONSTRUCTION OF A SMART BLUETOOTH BASED AUTOMATIC TRANSFER SWITCH CHANGEOVER FOR SMALL HOUSEHOLD GENERATORS

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ABSTRACT

The necessity to develop a cost-effective, smooth, and secure method to automate switching between different power sources resulted in this study. The paper proposes the use of an automatic transfer switch, which automatically switches between the utility power supply and a backup generator, to ensure uninterrupted power supply. The study aims to develop a cost-effective and secure system that utilizes an android device for remote control and monitoring of the power-generating unit. By employing Bluetooth technology, the study eliminates the delays and errors associated with manual source switching. The research specifically focuses on creating an automatic transfer switch compatible with 5 KVA key starter power generators and developing an android application for remote control within a 10-meter Bluetooth range. The system uses electromechanical and solid-state relays for the generator's start/stop sequence and power transmission, respectively.

Keywords: *Automatic transfer switches, power supply, generator, Bluetooth, switching*

1.0 INTRODUCTION

Due to Nigeria's unstable and intermittent power supply, portable generators have become backup power sources for homes and businesses (Somefun, 2015; Sambo et al., 2010). Based on research by a solar energy company in 2017, about 70 million generators of different sizes and capacities, were imported into Nigeria in a few years (Ajibade, 2017). These generators, which range in capacity from a few kilowatts to several hundred kilowatts, are primarily diesel or gasoline powered. The goal of the Nigerian Electricity Supply Commission (NERC) is to offer its consumers a steady supply of electricity (EPSR Act, 2005.). However, the disparity between energy supply and demand is getting wider as the population of Nigeria continues to grow. As a result, the utility power supply is overloaded, leading to frequent power outages. In the meantime, most appliances or processes that fit and comfort life in any society require electricity (Oyedepo, 2012). Hence, Nigerians choose smaller power generators because they can offer a dependable and effective power supply. A steady power supply is also necessary for the majority of industrial and commercial environments, consequently, the lack of a constant power supply impedes the growth of both public and private trade (Agbetuyi, et al., 2015). As a result of Nigeria's excessive reliance on other energy sources, there is a need to automatically switch between the phases to an alternate power source (a generator), then

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back to the primary supply when restored to support the utility supply. The development of automated transfer switches (ATS) was for these purposes. An electrical or electronic device known as an automatic transfer switch can monitor, manage, and switch between two or more power sources (Lionel, 2000).

One of the electrical devices that can help with a seamless transition from a public supply to a generator and vice versa is an automatic changeover switch with a generator cut-off and starter (Bu, et al., 2020; Feofanov & Feofanova, 2021; Hiremath & Moger, 2020). It automatically changes between different power sources. When there is a public power outage, the generator starts and the supply is switched to the generator, and vice versa. In most homes and businesses in Nigeria today, the mechanisms for starting generators and switching to an alternative power source are still manually operated (Okolobah & Ismail, 2013). With the manual processes of switching between these power supply sources, risks like human error during the switchover likely result in machine damage, fire accidents, electric shock/electrocution, as well as increased downtime resulting in the introduction of massive losses, are practically inevitable. Smart automatic transfer switches are needed as they offer several benefits, such as improved safety, increased reliability, increased energy efficiency, improved load management, and enhanced protection.

Accordingly, this study intends to articulate and establish the need for automatic transfer switches especially integrated IoT to enable real-time monitoring and control of the switch operation. Previous Studies have been carried out on the design and development of an automatic transfer and controller system for a standby power generator. This system is capable of monitoring fuel level, oil level, battery strength, next maintenance schedule. The device starts and stops the generator from a computer located in the comfort of homes or offices. The system was able to switch on/ off a 5 KVA generator. Agbetuyi *et al.*, (2011) designed and constructed an automatic phase change over switch for a single-phase power generator that switches electrical power from public utility supply to generator supply in the event of a power outage or insufficient voltage. He incorporated in the ATS a digital multi-meter (DMM) made up of a 12V D.C and a 5V D.C power supply unit, precision rectifier unit, current transformer, and microcontroller (PIC16F877) to convert the measured analog A.C voltage to digital quantities. Piyare and Tazil (2011) designed a ZigBee-based home automation system and based their design on a standalone Arduino and Bluetooth module, and the communication between the cell phone and the Arduino BT board is wireless. This system is secured for access from any user or intruder. The users are expected to acquire a pairing password for the Arduino BT and the cell phone to access home appliances. This adds protection from unauthorized users. Ezema *et al*. (2012) designed an automatic change-over switch with a generator control mechanism. This system uses a 3 phase and neutral (4 poles) 250V, 50Hz contactor, and delay switches, also used a phase failure detector, a 250V, 50 Hz A.C relay generator starter mechanism, 250V, push and hold switches. The system worked according to design but he recommended that for future development, an overload protection system be included in the project. Olufadi (2014) designed and developed a low-cost ATS with over-voltage protection. The ATS with a single-phase key-operated generating set, used contactors, transformer, relays, 555 timer, and voltage regulators. His device cuts out power whenever an overvoltage occurs. Maraneetharan *et al*. (2015) implemented a GSM-based automatic change-over system for electric generators. This change-over switch uses an SMS from a mobile phone to switch ON/OFF the generator remotely. They developed this system using a PIC microcontroller at the heart of the central computing with a GSM module interface to make communications with the mobile phone; they also developed a power failure detector circuit that checks for the availability/failure of utility power. When a power failure occurs, the system sends one SMS to a particular person "Power is off" when power is restored; another SMS is sent "Power is on". The approach by Maraneetharan *et al.* (2015) involved the use of a mobile phone in the remote control of the ATS but this comes with a continuous Operational cost as SMS attracts charges from mobile communication service providers. Autade (2015) designed an ATS for 1/3phase automatic transfer switch with intelligent energy management. This system uses a combination of relay switches which serve as sensors used to determine the availability or non-availability of voltage supply from either power sources (utility or generator source) before triggering the control sections of the ATS. He also designed a phase detection circuit using transformers and rectifiers. The ATS was found to be reliable and relatively affordable as he even designed a level sensing circuit for checking the fuel level. Addo, (2015) designed a microcontroller-based automatic transfer switching system for a standby electric generator, their design had

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a voltage sensing unit, a hall effect current sensor, relays LEDs, LCD, etc. which were all coordinated by a PIC16F877A microcontroller. The generator starts within 10sec of the utility power outage and switching is done within another 10 secs, a total of 20 secs was expected to elapse during the interruption of power supply to the load. The device also included an overvoltage/over-current protection unit. Arshad *et al.* (2016) designed and implemented a cost-effective Automatic Transfer Switch (ATS). Arshad *et al.* (2016) used bridge rectifiers and filters for sensing the main voltage supply and relays used to open the circuit or short circuit the generator starting mechanism to put the generator on/off. Ayinde *et al*. (2018) designed and constructed a single-phase automatic change-over switch, their design made use of a step-down transformer, an atmega8 microcontroller, etc. the device switches from auxiliary power supply to the mains with a delay of 10 secs in starting and switching off the generator and without human intervention. Ehiabhili *et al.* (2018) designed and constructed a single-phase microcontroller-based automatic change-over switch, it can automatically switch power from national grid to generator and vice versa, once there's a power failure in any of the two power supplies. They achieved this with the use of resistors, capacitors, diodes, etc. the maximum power the circuit can withstand on an A.C voltage of 240V is 12KVA.

2.0 MATERIALS AND METHODOLOGY

The Figure below gives a brief introduction to the processes involved in the achievement of this study.

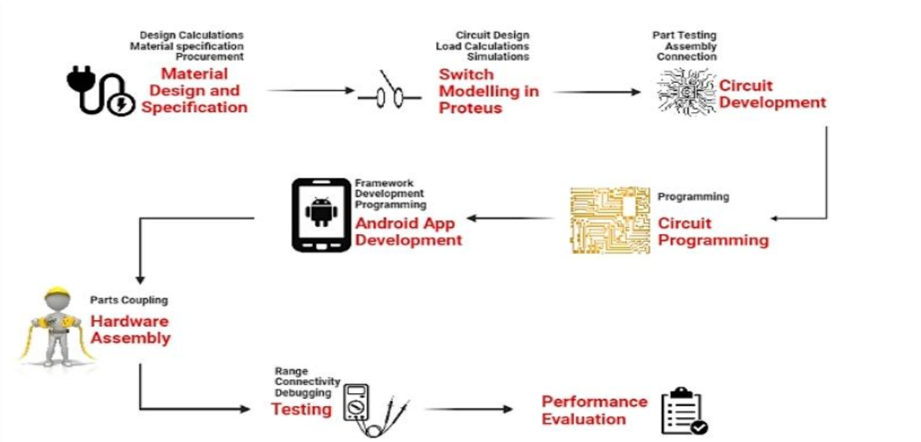

Figure 2.1: Flow chart of the sequence of execution

2.1 Design theories

The A.C voltage monitoring and control circuit are designed and constructed. This was achieved by using voltage monitoring relay (VMR) as a primary component of the power sensing and control circuit; which is used for measuring and comparing the voltage level of the utility supply with a set voltage tolerance range (185-250V A.C) while a 12A miniature circuit breaker will act as a switch to the power supply from the public utility end of the ATS The breadboard configuration can be seen in Figure 2.2

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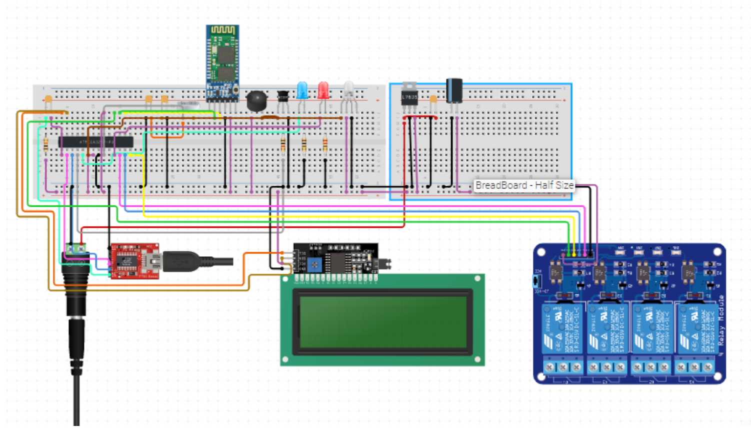

Figure 2.2: Breadboard representations of ATS

The power switching circuit was designed. Solid-state power relays rated 30A, 220V A.C, timer relays to provide some delays (10 seconds) during the starting of the generator and transfer of the connected load vice versa from both power sources depending on the side with steady electrical power at any point in time are used.

The switching mechanism of the generator is done with a 12V D.C supply battery and auxiliary contacts of the timer relays and the Electromagnetic Relay. The automatic ignition and stopping of the generator depend on whether the relays are energized and de-energized. The display unit was also designed. The LCD displaying the status and the condition of the generator has a 5V D.C power supply unit (PSU)
The Power Supply Unit (PSU): This stage consists of a limiting resistor (440 Ω) resistor connected in series with the half-wave rectifying diode (IN4007), then the 220µF capacitor helps to filter the rectified AC voltage. Connected across this is two 12V Zener diode which gives 24V supply to the MOSFET (IRF460 FET Buffer). The MOSFET provides a high input impedance, high current, and voltage for the voltage regulator. An unregulated input voltage (Vin) is filtered by the 2200µF capacitor and connected to the IC's (7805 and 7812) IN terminal. The IC's OUT terminal provides a regulated 12 V (7812) and 5V (7805), which is filtered by the 470µF capacitor. Figure 2.3 shows the circuit diagram of the 12 V and 5V D.C supply unit.

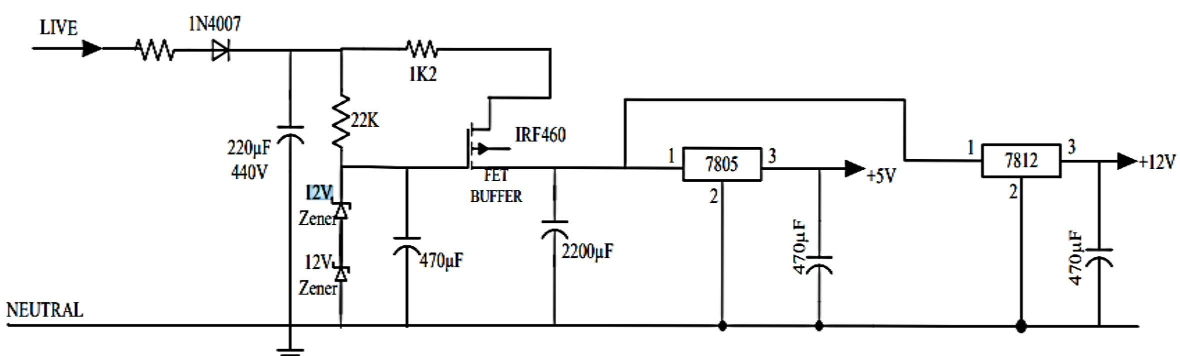

Figure 2.3: Circuit diagram of the 12V and 5V DC supply unit

As shown in Figure 2.3, the input supply to the solid-state relay is 220Vac. The half-wave rectification of the A.C voltage is done by the rectifier diodes D1 (1N4007) which converts only the positive half cycle of the 220vac to D.C. This diode has a forward bias voltage of 0.7volts Thus, the output DC voltage level from the half-wave rectifier circuit can be calculated as shown in Equation 0.1

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$$V_{dc} = 0.318V_m \qquad 0.1$$

Where V_m = Maximum Voltage after rectification
V_{dc} = rectified D.C voltage
V_m Measured by a digital multi-meter is 15.97V = 16V
V_{dc} = 16 ẋ 0.318 = 5.088V
The selection of the 22K̇Ω was achieved using five 110K̇Ω resistors in parallel

$$R_T = \frac{110K\Omega}{5} = 22K\Omega$$

Design of power source / back-up power system

As part of the problem statement, power is a key factor in the efficiency and functionality of the device in terms of reliability. The device will get its power source from AC 220V which will be converted and step down to 5V DC at 2A with the aid of a DC power adapter. This voltage is supplied as input to the battery charger which is connected to the rechargeable battery bank. The replaceable and rechargeable lithium batteries (6) will be connected in parallel to increase the total capacity of the bank (ampere-hour) at the same voltage of 3.7V base on the rating. The rechargeable battery bank is connected to the DC-DC converter which serves as a step-up unit to achieve the required output voltage (5V) for the microcontroller. Base on this design, when the power source is out, the battery automatically continues the power supply to the device. The DC adapter setup is shown in Figure 2.4

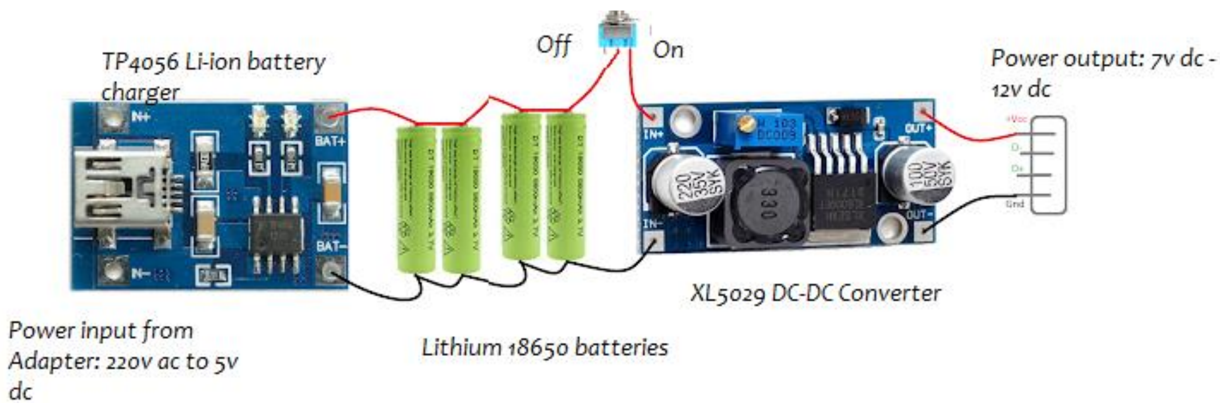

Figure 2.4: Circuitry Setup for power source 3D diagram

The battery output voltage obtained through the OCV and voltage drop caused by the battery equivalent internal impedance, as

$$U_{bat} = \mathrm{E} - R_b i_{bat} \qquad 0.2$$

$$= E_0 - \mathrm{K}\frac{Q}{Q - it} \,\mathrm{x}\, \mathrm{it} + A_b \exp(-\mathrm{B.it}) - Pol_{res} \,\mathrm{x}\, i^* - R_b i_{bat} \qquad 0.3$$

Where U_{bat} is the battery output, E is the OCV, E_0 is the battery internal equivalent voltage, K is the polarization constant, Q is the maximum battery capacity, it is the extracted capacity, R_b is the internal impedance, i_{bat} is the battery current and i_* is the filtered battery current. Pol_{res} is polarized resistance which is different when charging or discharging.

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Design Calculations for Electronic Components

Table 0.1: Design Calculations for Solid State Relay

Input Values	Equation/Formula	Result
1. Solid State Relay (Power requirement of the solid-state relay) From Specification, V_s =12v R = 150Ω,	R = 150 P = I * V_s	R = 10k Ω I = 30A

Table 0.2: Design Calculations for Microcontroller

2. PIC16F877A (Power requirement of the microcontroller) From Specification, V_s = 5v Imax = 25mA	R = V_s/I 3.12 R = 5/0.025 P = Imax * V_s	R= 200 Ω P = 0.125W

Table 0.3: Design Calculations for LCD Screen

3. LCD Screen (Power requirement of the LCD) From Specification, V_s = 5v, Imax = 1.1mA	P = I * V_s = 0.0011* 5	P = 0.0055W

Table 0.4: Design Calculations for Passive Buzzer

4. Passive buzzer (Power requirement of the passive buzzer) From Specification, V_s = 5v I = 10mA to 30mA	Iav = (10 +30)/2 P = Iav * V = 0.020 * 5	Iav = 20mA P = 0.1W

Load

To run the entire load in case of a power outage, and if the house has a large enough generator, a transfer switch that has the same rating as the main breaker panel is required.

Power consumed by components

i. Power is consumed by electrical components as they interface with the microcontroller.

$$\text{Power} = \text{Current used x Voltage required (rated)} \quad 0.4$$

ii. Resistor Required

$$Resistance = \frac{Voltage\ rated}{Required\ current\ input} \quad 0.5$$

iii. Capacitor Required

$$Capacitance = \frac{Voltage\ rated}{Required\ current\ input} \quad 0.6$$

iv. Current Amplification

This is achieved with the use of a transistor with a required amplification ratio

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$$Final\ Current\ = Amplification\ ratio\ x\ Current \tag{0.7}$$

$$Size\ =\ Cross\ sectional\ area\ x\ Height \tag{0.8}$$

v. Size of Device

vi. Percentage current consumption

$$Percentage\ current\ = \frac{Total\ current\ used}{maximum\ rated\ current\ output\ x\ 100} \tag{0.6}$$

vii. Bank power capacity (watt-hour) at full charge,

$$P\ = I\ x\ V x\ h \tag{0.9}$$

viii. Battery consumption time

$$Lasting\ battery\ time\ = \frac{available\ power (Wh)}{total\ power\ consumption\ (W)} \tag{0.10}$$

List of Materials

The materials and components used in this study are listed are as follows;

1. PIC 16F8877A microcontroller
2. Opto-coupler
3. 16x2 Liquid Crystal Display (LCD) module
4. HC-05 Bluetooth module
5. Piezo speaker (buzzer)
6. Jumper/Connection wires
7. Electronic box
8. UART Module
9. Resistors
10. Battery bank
11. Electromagnetic relays
12. Android developer studio
13. Switches
14. Bridge rectifier

Constructions

The construction process in this study entails hardware construction and software construction. The hardware section consists of the Circuit development, electronics connection, and the component box and test board construction, while the software construction describes all the algorithm and flow chats that were used in this study. The software development of this work was carried out in two broad sections; the firmware development for the microcontroller and the mobile application software development.

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Figure 3.1: Developed ATS with test

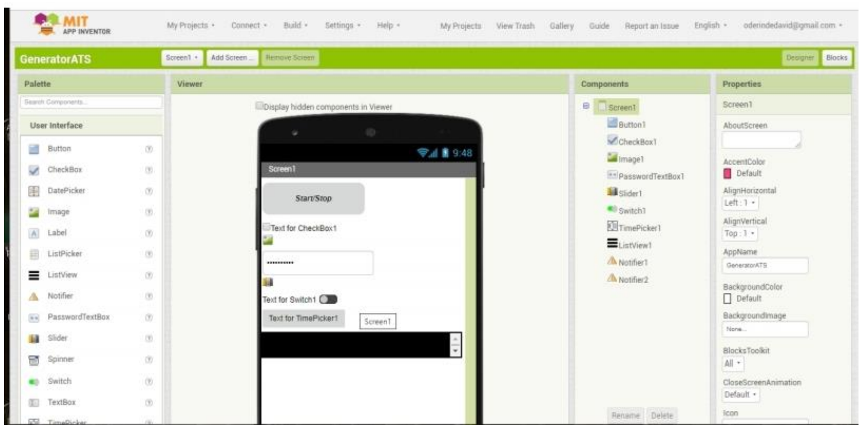

Figure 3.2: Android development interface using PC

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Working procedure of the ATS

The operational Procedure of the developer is shown in Figure 3.3

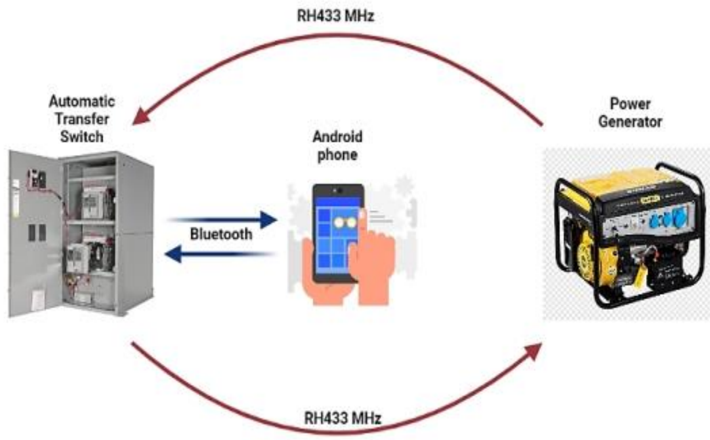

Figure 3.3: Description of the device operation

Manual Mode

i. When there is a power outage on the utility line, if the device is on manual mode, the buzzing alarm on the ATS starts to buzz, indicating a failure in power
ii. The ATS goes on generator standby mode, awaiting a request to start the generator
iii. Upon getting the signal to start the power generator from either the android device or from the generator start button on the ATS, the ATS sends an encoded digital signal over a radio frequency to the generator unit instructing it to energize the generator coil.

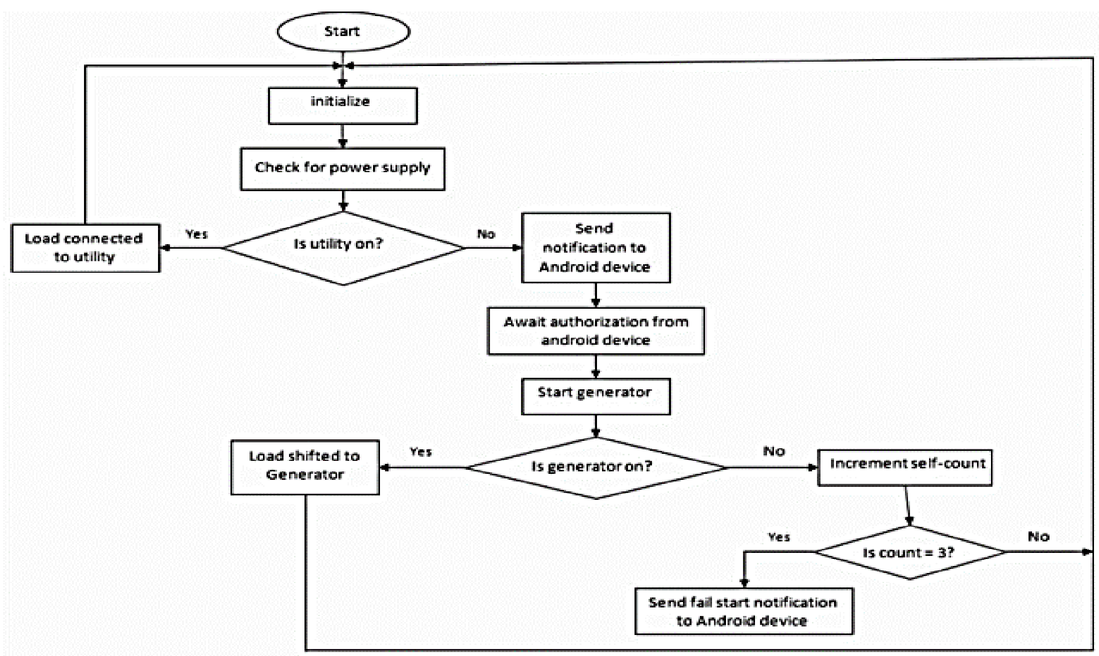

Figure 3.4: Flowchart for manual mode operation

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Automatic Mode

i. When there is a power outage on the utility line, the buzzing alarm on the ATS starts to buzz, indicating a failure in power
ii. It then initiates the generator start process which the microcontroller sends a digital signal over a radio frequency to the generator unit, which in turn energizes the generator coil to start the generator
iii. This process is repeated in reverse when power is restored on the utility line.

Performance Evaluation

Several performance tests were conducted on this device, these evaluations include; testing the Bluetooth functionality, the LCD functionality, power consumption, Bluetooth range, RH433 MHz range, and Bluetooth Receive Signal Strength Indication (RSSI) cooperative motion.

3.0 RESULTS AND DISCUSSION

Blue tooth Module test

During the connectivity and functionality test, all the strings established connection and performed as programmed, with a 100% connection rate as expected and no glitches recorded.

Figure 4.1: Results of Bluetooth

LCD Module character display test result

The LCD Character display was able to display all the feedback text, however, the contrast was adjusted and backlights to fit the displayed characters.

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Figure 4.2 Character Display

Power consumption test results

An open circuit test was carried out on the circuit using a multimeter to determine loss and no-load current in the circuit connection. The connections from the output connector load to the input of the mains (Utility line) contactor and generator contactor are ensured. The short circuit test carried out during energizing and de-energizing of the circuit indicates no variation in the output power. Load and unload diagnosing were also carried out as troubleshooting, and it ensured perfect operation of the circuit. The circuit was powered ON by the power switch. The circuit power supply was re-checked to ensure 5V is supplied to the PIC16 8877A microcontroller and 12V to the relays. All other connections (resistors, transistors, rectifiers, switches, capacitors) were ensured. An LCD attached to the cover of the casing is a feedback display for the mains and the generator as shown in Figure 4.2. A 60W incandescent light bulb was used as the load. The ON/OFF switch is designed with the circuit that put the circuit in operation and set to OFF mode if an alternative source of power supply is not required.

Backup battery lasting capacity test

The power bank used in the study was made up of six batteries of 2600mAh (with a rated voltage of 3.7v) each connected in parallel.
Total battery capacity = 6 * 2600 = 15600mAh
Theoretical calculation estimated the lasting power of the backup battery for 52 hours.
However, the test result showed the device lasting approximately 70 hours after the backup battery was full and left to function.

3.6 Range test result

The device works in a triangular communication pattern when on manual mode, the range test between the android device and the ATS (Bluetooth communication) and the range test between the ATS and the generator unit (Radio Frequency communication 433 MHz)

3.7 ATS Functional Transfer Switch Test Result &Discussion

The ATS was able to crank the kick start of the generator to start in automatic mode after a delay of cycle of 10 seconds
After the generator was turned off, and utility supply simulated, the generator was turned off successfully after a no load run time of 120seconds. (Ahammed *et al.*, 2022)

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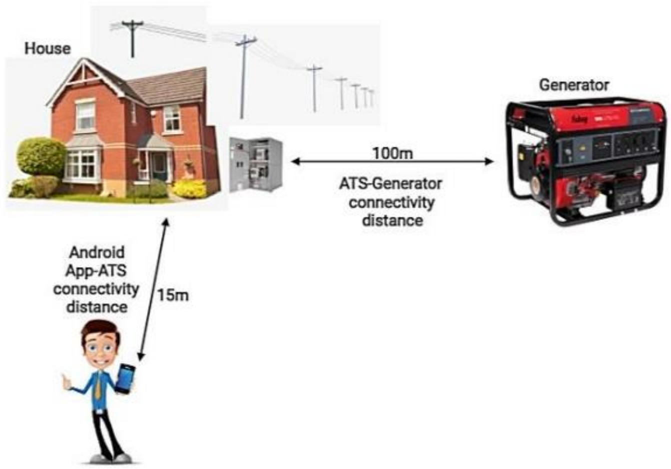

Figure 5.1: Communication of the Android mobile phone to the ATS and then from the ATS to the generator unit

From Figure 5.1 above it can be drawn that the Bluetooth's effective range is 15m and a sharp decline was experienced after 15m during testing. It can be speculated that the device is out of range after 15m. Similarly, it was observed that there is a seamless connection between the ATS and the generator unit at the 50m range. The RF433 was effective for the 50 meters range it was tested and the connection at this range was 100%

4.0 CONCLUSION

The unreliable public utility power supply in Nigeria has individuals and businesses looking for alternative and reliable sources of power. In response to this, an Automatic Transfer Switch (ATS) has been created which can quickly monitor and switch between the power sources within seconds. Additionally, the smart ATS has the added convenience of automatically starting a backup generator in the event of a power failure from the main source, eliminating human involvement and errors. The Blue tooth controlled ATS system has been designed and built to meet specific requirements and has been tested with successful results.
Due to the epileptic nature of our primary power supply and the widespread use of smaller, portable generators by the majority of the population, the incorporation of a smart automated transfer switch into smaller generators is of significant benefit in Nigeria.

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