DEVELOPMENT OF SMART ELECTRICITY DISTRIBUTION ALGORITHM FOR MULTI-SOURCE AND SEGMENTED LOADS IN BUILDINGS

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FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA

JULY, 2023

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A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF ENGINEERING IN COMMUNICATION ENGINEERING

JULY, 2023

DECLARATION

I hereby declare that this thesis titled “Development of Smart Electricity Distribution Algorithm for Multi-source and Segmented Loads in Buildings” is a collection of my original research work and it has not been presented for any other qualification anywhere. Information from other sources (published or unpublished) has been duly acknowledged.

ABDUL-AZEEZ, Dauda ……………………….
M.ENG/SEET/2019/9522 SIGNATURE/DATE
FEDERAL UNIVERSITY OF TECHNOLOGY
MINNA, NIGERIA

CERTIFICATION

The thesis titled "Development of Smart Electricity Distribution Algorithm for Multi-source and Segmented Loads in Buildings" by: ABDUL-AZEEZ, Dauda (M.Eng/SEET/2019/9522) meets the regulations governing the award of the degree of M.ENG of the Federal University of Technology, Minna and it is approved for its contribution to scientific knowledge and literary presentation.

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ABSTRACT

Nigeria has encountered numerous power issues in recent years, including limited and irregular power supply, high power costs, and underdeveloped power facilities, all of which have had major negative consequences on the country's socio-economic development. To improve power availability in buildings and ensure adequate usage efficiency, this project presents the development of a smart electric power distribution algorithm for multi-source and segmented loads, for implementation on distribution boards. The developed algorithm supports the current building wiring infrastructure in Nigeria, allowing for 24/7 reliable power supply and effective management of limited power supply in buildings. It employs a multi-source and segmented load system to provide reliability and energy efficiency measures to balance power supply and demand in buildings. Data from offices in the engineering complex of Niger State Polytechnic Zungeru, Nigeria, was used to simulate the developed system in MATLAB Simulink. Results showed that the developed smart distribution algorithm with a total energy consumption 8,910.38 kW conserved energy by 51.09% when compared to the conventional distribution board with 15,978.08kW energy consumption.

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LIST OF ABBREVATION

A	Ideality factor
AC	Alternating Current
AMI	Advanced Metering Infrastructure
BSS	Battery Storage System
BT	Battery Backup
CDB	Conventional distribution board
CO	Carbon II Oxide
CO_2	Carbon IV Oxide
CH_4	Methane
DC	Direct Current
DG	Diesel Generator
DL	Dump Load
E_{CBD}	Energy consumed by conventional distribution board
E_{go}	Band gap for silicon
E_{SDB}	Energy consumed by smart distribution board
EMS	Energy Management System
FC	Fuel Cell
FEMS	Fuzzy logic-based Energy Management System

FIS	Fuzzy Inference System
FLC	Fuzzy Logic Control
FLCBEM	Fuzzy Logic Controller-Based Energy Management
G	PV module illumination
HESS	Hybrid Energy Storage System
HEMS	Home Energy Management System
HRE	Hybrid Renewable Energy
HRES	Hybrid Renewable Energy System
I	Current
I_d	Current flow through the diode
IoT	Internet of Things
I_0	Saturation current of PV module
I_{PV}	PV cell current
I_{sc}	Short circuit current
I_{sh}	Shunt resistor current
K	Kelvin
K	Boltzmann constant

L	Load
MG	Micro Grid
MIMO	Multiple input multiple output
MISO	Multiple input single output
n	Linearity factor
N_p	Number of parallel cell
N_s	Number of series cell
PV	Photo Voltaic
q	Electron
RES	Renewable Energy Source
RESs	Renewable Energy Sources
R_{sh}	Shunt resistance
S	Source
SC	Super Capacitor
SDA	Smart Distribution Algorithm
SDB	Smart Distribution Board
SEMS	Smart Energy Management Solution

SG	Smart Grid
SHEMS	Smart Home Energy Management System
SOC	State of Charge
T_r	Reference temperature
V	Voltage
V_{oc}	Open circuit voltage
V_{sh}	Short circuit voltage
V_T	Thermal voltage
W	Watts

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Energy is an essential resource to life and all living organisms. Currently, electrical energy plays a vital role in the human lifestyle, powering key infrastructures and services (Leitao *et al*., 2020). The energy demand is increasing and may anytime exceed the implementation of conventional energy systems significantly (Mahapatra and Nayyar, 2019). Energy Management System (EMS) has been applied to the process of monitoring, controlling, and conserving energy in an organization/ building. The primary aim of the smart home is to increase home automation, facilitate energy management, and reduce environmental emissions (Saad *et al*., 2014).

Smart home energy can be managed through a selection of efficient appliances, improvement in customers' knowledge and experience with residential energy management, participation in demand-side management (DSM) programs, and the deployment of EMS.

In addition to saving money on electricity, smart homes also offer some other advantages, including security, increased comfort, better home automation, and better energy management. Smart technologies for home energy management systems (HEMS) integrate storage and renewable resources with energy consumption as one of their key characteristics (Shareef *et al*., 2018) .

Some of the justification for energy management are: -

i. EMS enables the consumer to monitor and control the amount of energy consumed or to consume it more efficiently. Consumers should know how the energy is being used in their homes, which can only be computed when energy throughout the home is monitored (Krishnan, 2020).

ii. Energy management is the key to saving energy in our homes and organizations. Much of the importance of energy saving stems from the global need to save energy. This global need affects energy prices, emission targets, and legislation, all of which lead to several compelling reasons why energy has to be saved in our homes and organizations (Etedadi *et al.*, 2021).

iii. Reduce carbon emissions and the environmental damage that they cause. This effect can be reduced by promoting a green, sustainable image. Moreover, 38% of the world's total electricity is produced via coal power plants. The burning of coal and other fossil fuels releases Greenhouse gases like Carbon IV Oxide (CO_2), Methane (CH_4), and Carbon II Oxide (CO), which poses the threat of global warming and induce climate change (Nasir, 2021).

HEMS is a technology platform that combines hardware and software to allow users to track energy usage and generation, as well as manually control and/or automate energy usage in homes. Advanced metering infrastructure (AMI) devices have triggered a trustworthy communication method connecting both power utilities and residential users under the canopy of grid design. This communication channel clears the door for the inclusion of economic incentives conceived for a smart home for managing demand-side resources by switching to and from energy consumption during peak-load hours of the day as a type of load shedding for lower power billings (Krishnan, 2020). The basic elements of a smart home are shown in Figure 1.1.

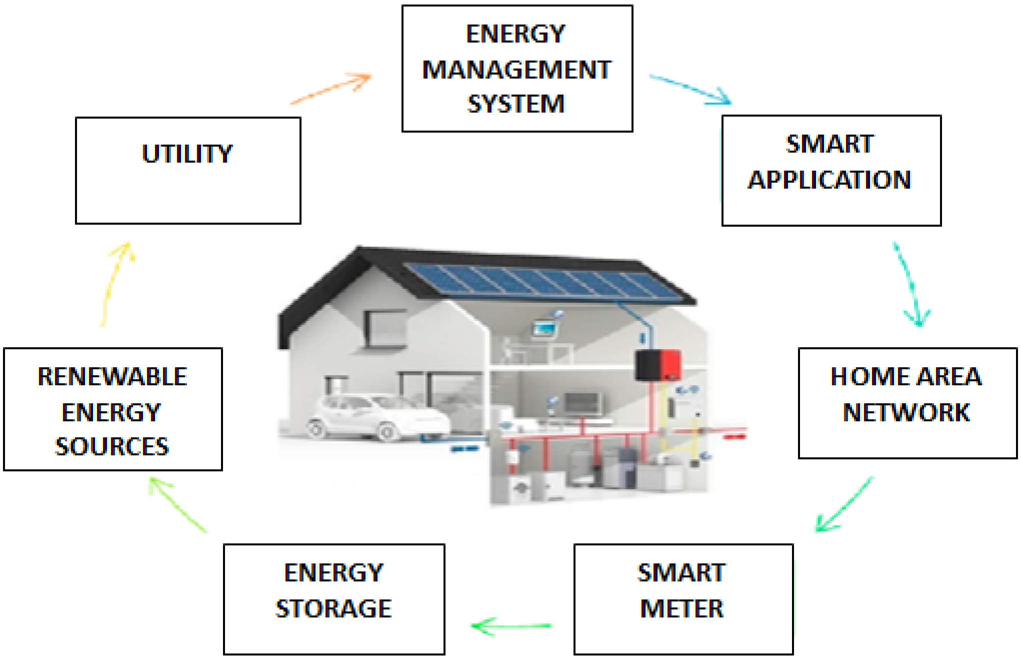


Figure 1.1: Elements of a Smart Home.

(Krishnan, 2020)

Home Energy Management provides a smooth, continuous electrification operation in housing developments with demand rationalization that facilitates the reductions in energy products prices. Thus, a practical and intelligent supervisory approach may be used to preserve, on the one side, an equilibrium between demand and output, thereby regulating the allocation of household electricity to change the system's stability (Zafar *et al.*, 2020).

1.2 Statement of the Research Problem

There is poor electric power management in Nigerian buildings, despite the lot of money being spent on electric power consumption by consumers. This poor energy management from consumers has added to the high level of power outages in Nigeria due to poor electric power management from the distribution stations (Elinwa *et al.*, 2021).

Multiple sources with dynamic energy capabilities provide electrical energy to a constantly changing load in modern microgrid (MG) systems. To ensure that load demand is met optimally, that is, by prioritizing the use of renewable, clean, and affordable sources, a central controller is needed. Constraints on supply and demand are also satisfied without sacrificing user comfort (Ghaffar *et al*., 2019). As a result, an intelligent control system is needed that can effectively manage the energy sources and load so that energy consumption, the peak–to-average ratio, and costs are kept to a minimum (Okae *et al*., 2017;Ngwenya and Bokoro, 2018).

1.3 Aim and Objective of the Research

The aim of this research is to develop a smart electricity distribution algorithm for multiple-source and segmented loads in buildings.

The objectives of the research are: -

i. To measure the power consumption of offices in the engineering complex of Niger State Polytechnic, Zungeru.
ii. To develop an algorithm for the smart electricity distribution system using fuzzy logic.
iii. To simulate the developed algorithm in Matlab environment.
iv. To evaluate the performance of the developed algorithm for energy-saving against the conventional electric distribution system for the case study in objective one.

1.4 Justification of the Research

The research will provide a cost-effective way of conserving electrical energy in Nigeria. This is because installing electronic components like a microcontroller unit, which the algorithm runs on, and a system of relays for switching allows for the deployment of the algorithm on CDB.

Also, this will increase the availability of electrical energy in Nigeria by cutting down wastage.

In addition, the cost spent on power, especially by corporate organizations and institutions will be reduced.

1.5 Scope of the Research

The scope of this research is to ensure efficient power management in buildings. The research is limited to using the engineering complex building of Niger State Polytechnic, Zungeru as a case study.

1.6 Thesis Outline

This research work is divided into five chapters, chapter one consists of the background, problem statement, aim and objectives, justification, and scope of the research. Chapter two deals with the review of relevant literature influencing the research work which includes the the theoretical frame and related works. Chapter three presents the research system model, and methodology. The fourth chapter contains the result and discussion of the result obtained in course of the research. And finally, chapter five contains the conclusion and recommendation.

CHAPTER TWO

2.0 LITERATURE REVIEW

This chapter presents a review of relevant literatures influencing this research. It dwells on the theoretical framework, review of existing energy management system as well as the strengths and limitations of each of the methods discussed.

2.1 Solar Panel

The photovoltaic (PV) effect is the primary factor in the conversion of solar radiation into electric power. The semiconductor component of a PV module is what turns light into electricity. PV cells have three basic characteristics to function: they must absorb light, produce electron-hollow pairs, and produce exactions. A current source, a series resistance, a shunt resistance, and a diode make up an equivalent circuit to a PV cell, (Uddin and Islam, 2018) as shown in Figure 2.1.

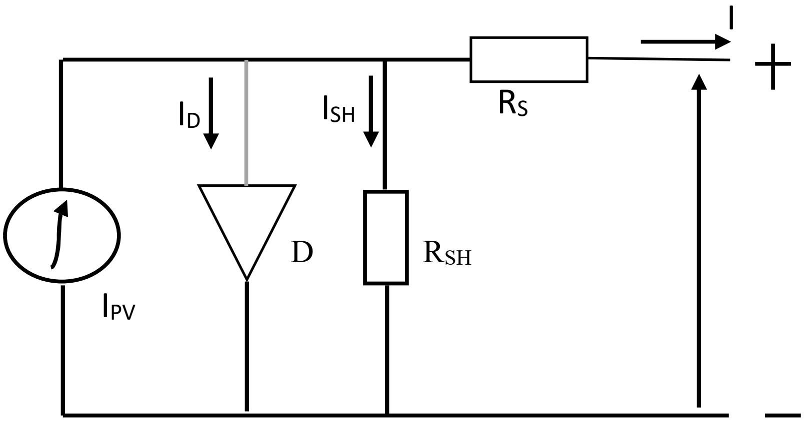


Figure 2.1: Equivalent circuit diagram of PV cell

The PV cell's equivalent circuit allows us to express the current flow through the load as;

$$I = I_{PV} - I_d - I_{sh} \tag{2.1}$$

Where, I_d – diode current in amp, I_{PV} -PV cell in amp, I_{sh}-shunt resistor in amp.

The shunt resistor's voltage is

$$V_{sh} = V + IR_s \tag{2.2}$$

where *Rs* is the series resistance in ohms and V is the voltage across the load in volts.

The shunt resistor's current flow is

$$I_{sh} = \frac{V_{sh}}{R_{sh}} = \frac{(V + R_s I)}{R_{sh}} \tag{2.3}$$

R_{sh} – shunt resistance in Ω.

The diode's current flow is

$$I_d = I_0 \left[e^{\frac{V_{sh}}{nV_T}} - 1 \right] \tag{2.4}$$

where,

$$V_T = \frac{KT}{q} \tag{2.5}$$

V_T – Thermal voltage in volt, n-linearity factor, q-Electron charge = 1.6 $*10^{-19}$C.

The following equation can be used to express light generated current.

$$I_{PV} = [I_{sh} + K(T - 298) * G/1000] \tag{2.6}$$

Where *T* is the working temperature of the solar module in Kelvin, *K* is the short-circuit current temperature co-efficient, *G* is the PV module illumination in W/m^2, and I_{sh} is the short circuit current in amps at 25 ^{0}C temperature and 1000W/m^2 solar radiation.

An expression for a module's reverse saturation current is:

$$I_{rs} = \frac{I_{sc}}{\left(exp^{\frac{qV_{OC}}{N_s KAT}} - 1\right)} \tag{2.7}$$

Open-circuit voltage $\left(V_{oc}\right)$ in volts, number of series-connected cells (N_s), Boltzmann constant (K) of 1.3805*10-23 J/K, and ideality factor (A) of 1.6 are all present.

The PV module's saturation current I_0 is dependent on the temperature of the cell, which is

$$I_0 = I_{rs}\left[\frac{T}{T_r}\right]^3 exp\left[\frac{qE_{go}}{BK}\left[\frac{1}{T_r} - \frac{1}{T}\right]\right] \tag{2.8}$$

Where T_r is the reference temperature in kelvin which is 298K, PV module saturation is I_0 in amp, E_{go} is the band gap for silicon which is 1.1eV.

The overall current flow across the load is

$$I = N_p * I_{Pv} - N_p * I_0\left(e^{\frac{q(V + R_S I)}{N_S AKT}} - 1\right) - \frac{(V + R_S I)}{R_{sh}} \tag{2.9}$$

Np is the number of parallel cells in this equation. I_{pv}, R_s, and R_{sh} as well as some environmental factors like temperature and solar radiation affect how physically the PV cell behaves.

With the aid of DC-AC inverters, solar PV can directly transmit power to a load without the use of batteries. DC-DC converters can also be used by solar PV to charge batteries.

2.2 Grid

The electrical grid, also known as the power grid, is a complex, interconnected system used to transport electricity from generators to consumers, who then use it for their daily needs. These developed from modest local plants to the thousands of kilometers-long networks that connect millions of homes and businesses today. Although there are countless complex interconnections in the grid system, there are three main sections. That is the generation, transmission, and distribution of electricity (Krishnan, 2020)

2.3 Battery

The PV system uses a variety of battery types, including lithium-ion, lead-acid, nickel-cadmium, and nickel-metal hydride. Density and electrical capacity are the two chemical characteristics of batteries that matter most. The amount of energy produced inside a battery increases with its energy density. Additionally, less energy is produced inside batteries with lower energy densities. Therefore, it is thought that batteries with higher energy density and lower weight are best suited for use in simple systems.

The use of lead- acid batteries is being considered for the smart home storage system. The potential difference between metallic lead on the negative side and PbO_2 on the positive side stores the chemical energy of the battery during the charge state.

There are three modes of battery charging at this location: disconnected from the system after charging; charging and discharging due to supply. The battery shouldn't be overcharged or completely discharged (Roshan *et al.*, 2019)

2.4 Generator

Generators produce electric power from mechanical energy for use in an external circuit. The electromagnetic induction theory underlies the operation of an electric generator. The necessary mechanical energy can be produced by an engine running on diesel fuel. Natural gas, gasoline, or energy from renewable sources. The magnetic field that exists between the magnet's two poles is cut when the coil rotates. The conductor's electrons will interact with the magnetic field, causing an electric current to flow through it.

2.5 Inverter

Inverter systems are typically used to convert DC voltages from solar panel and battery output into AC voltage. The power is produced by the DC source, so the device never produces any kind of power (Zafar *et al.*, 2020).

2.6 Fuzzy Logic Concept

One artificial intelligence system that is widely used in machine management is fuzzy logic. The idea that expresses not only "true" or "false," but also all values in between, is referred to as "fuzzy." Human operators can recognize some advantages of fuzzy logic, allowing for the use of their expertise in the control's design. An input stage, a process stage, and an output stage are all parts of fuzzy logic (Uddin and Islam, 2018).

2.7 Fuzzification

The interpretation of the input data (crisp value) using fuzzy inference systems (FIS) is known as "fuzzification". To produce an interpretation of the input, the process converts the crisp input values into pertinence or assurance levels. The input data is examined using fuzzy sets, also known as user-defined membership functions. The data is given a value by the functions that range from 0 to 1. The three most prevalent membership function shapes are Gaussian, trapezoidal, and triangular (Peixoto *et al.*, 2018).

2.8 Inference Method

Fuzzy inference is the factual process of using fuzzy to map from a specific input to an output. Membership, fuzzy logic operators, and if-then rules make up this system (Roshan *et al.*, 2019).

2.9 Defuzzification

The process of defuzzification involves the conversion of the results of fuzzy inference into a clear output. In other words, a decision-making algorithm that chooses the best crisp value based on a fuzzy set achieves defuzzification. Crisp variables are created during the defuzzification process from output in the form of fuzzy variables. A function is provided by the inference method and produces a fuzzy membership variable (Roshan *et al.*, 2019).

2.10 Review of related works

Mubdir *et al.* (2016) designed a smart home energy management system (SHEMS) to lower energy consumption by detecting residential activity and classifying it as either active, away, or asleep. The system can save up to 18% on energy. The system is missing a feature that would allow it to identify security problems when the residents are away from home.

(Okae *et al.*, 2017) developed and executed a building-based smart energy management solution (SEMS) for meeting electrical demand with a distributed and heterogeneous source of power supply to ensure reliable power supply and energy efficiency in buildings. The energy management strategy is done at the distribution board side to provide a balance between supply from distributed sources and demand in the building. No monitoring and control software architecture for the energy management system was used.

A system to implement internet of thing (IoT) for monitoring home appliances was created by (Joshi and Khan, 2017). It enables the user to have flexible control mechanism remotely through a secured internet web connection. It helps the users to control the electric appliances automatically, manually, and remotely using a smartphone or personal computer. This system could be liable to Cyber attacked.

A fuzzy logic control (FLC) algorithm was developed by (Hettiarachchi *et al*., 2017) that aided in the voltage control scheme for the AC busbar and a sequential operating method for DC busbar control under various conditions. It determines the constraints and identifies the necessary scenario in the AC and DC bus bar control to apply fuzzy logic. There was no frequency control for the AC bus bar.

Gamage *et al*. (2018) develop algorithms for the hybrid energy storage system (HESS) based on batteries and supercapacitors to run as efficiently as possible. It determines the ideal HESS charging and discharging rate based on the battery's state of constraint. The supercapacitors primarily handle transient power, while the battery was used to balance the energy requirement over long periods. It lessens the strain on the battery storage system, extending the battery's life cycle. Continuously powering the load with batteries and supercapacitors can harm them.

A revolutionary EMS for a home MG application to ascertain the MG components' efficiency performance, projected energy generation and demand, energy cost, and system constraints was introduced by (Jafari *et al*., 2020). Both the current situation and long-term projections of energy production and consumption have been taken into consideration. There was an increase in the cost per day when using only grid energy.

An EMS was created by (Prajwal and Gupta, 2018) to build a control system which will maintain a continuous power supply for the user and also reduce the electricity cost by using an alternate form of electrical energy during peak time. The system recognizes peak hours or periods of power shortage and takes the appropriate action to ensure that consumers are not inconvenienced.

Uddin and Islam (2018) offered a fuzzy logic-based intelligent management controller that will be able to supply any excess power to the grid that is available after meeting consumer load demands and maintaining an appropriate state of charge (SOC) for the battery. The system can exchange power with the local grid and can be used as a universal system. The variations in their output may not match the time distribution of the load demand, resulting in reduced system energy performance. The intermittent nature of solar and wind, is dependent on weather and climate changes.

Krishna *et al.* (2018) presented a smart energy management system to automatically switch over light and medium loads to nearby renewable energy storage according to the latter's availability. The grid's midday energy consumption was reduced by more than 50%, resulting in a domestic consumer's daily energy consumption falling to 35%. Every hour, SHEMS sends to the cloud the information it has collected about energy consumption from the grid and the battery. It lags in accuracy and has been perceived slow.

EMS to keep the battery state of charge within a safe range while minimizing changes in the grid profile was developed by (Arcos-Aviles *et al.*, 2018). The battery SOC is set to 75% of the rated battery capacity so that the EMS can respond quickly to MG energy changes. The battery's available dynamic range can compensate for MG net power fluctuations while keeping the SOC within a safe range. The approach lacks ability to control an electric water heater.

A robust control technique was proposed by (El Zerk *et al.*, 2018) to supply load by guaranteeing the availability of power on demand, enhancing the quality of the generated power and stabilizing the AC/DC Bus to improve the hybrid system's dynamic behavior. The system's regulation of DC voltage, maintenance of the batteries at admirable intervals, and supply even with wind and irradiation fluctuation or load changes are all ensured by using a combination of renewable energy sources PV/Wind and batteries as a storage system. Unpredictable weather changes affect the system's performance.

Ramalingam *et al*. (2019) developed EMS to instantly and continuously monitor electrical data online. It has an embedded system-based communication gateway with a cloud interface that is simple to set up for both domestic and business users. It actively lowers standby power usage and the power outlet at the same time. It offers a greater range of values and expands the data transfer coverage limit. This system is exposed to cyberattacks.

Ashaj and Erçelebi (2019) provided another option to create a smart, low-cost power management system that includes some appliances that can be used for power consumption control. The system runs smoothly and efficiently controls the power switch in real- time and has a relatively quick processing time. It successfully controlled multiple tasks simultaneously without failing. In addition to tracking moving objects other than people, such as animals or flying objects, the system is unable to detect the distribution of foreground objects outside of the connected region.

Prathyush and Jasmin (2018) developed a 25-rule fuzzy logic control (FLC) for use in an EMS for a grid to keep the battery state of charge within a safe range while reducing grid power profile deviations and reduce power variations while maintaining the battery's state of charge within permitted bounds. It reduces the microgrid’s operating costs. It maximizes the use of energy and in the event of a power outage, fuel cells only supply the bare minimum of power. It set the battery SOC at 80% of its rated capacity by allowing the EMS to react quickly to changes in the microgrid's energy supply. The system lacks of energy rate of change approach for controllable loads.

The energy management to integrate solar and wind hybrid renewable sources to meet load power demand was proposed by (Shyni and Ramadevi, 2019). The Luo converter was able to eliminate the high-frequency current harmonics in the wind generator because of the low power and cost dissipation in this system. Weather changes affect the system's performance.

Baset *et al*. (2020) presented an energy management strategy to effectively manage the load demand among the various parts of the fuel cell/battery storage/supercapacitors (FC/BS/SC) system. It reduces fuel cell hydrogen consumption and optimally manages load demand among the various FC/BS/SC system sources. Fuel cell power rises gradually, which will impact the efficiency of the energy management system as a whole.

Hosseinnezhad and Shafie-khah (2020) suggested a two-stage model of HEMS to handle the practical challenges brought on by technical limitations and uncertainty. It provides consumers with a high level of comfort. HEMS determines an operational scenario with an acceptable success rule for real-time regulation. Regulate the discrepancies between the forecasted and actual values. The local market and local energy exchange concepts were not covered, and there was no trustworthy management system that could guarantee the smart home's commitments for the day ahead.

A wavelet conversion-based approach was used by (Zand *et al.*, 2020) to managed the power of a hybrid FC, battery, and capacitor. The wavelet conversion can distribute power at various frequencies to pertinent sources in an optimal manner, making it simple to control the optimized power. Batteries and supercapacitors are used as secondary energy sources, with FC serving as the primary source. FC require a continuous source of hydrogen and oxygen as reactants to sustain a chemical reaction to produce electrical energy.

A sophisticated control strategy for managing and regulating the flow of hybrid renewable energy (HRE) in rural applications that uses a diesel generator and a battery as a backup was presented by (Meje *et al.*, 2020). It controls the power flow between the sources while accommodating the demands of various loads and simultaneously storing extra energy in the battery. The battery is charged as soon as each component starts working and discharged whenever there are problems or emergencies with the HRES operation, which results in a lack of smooth and optimal performance.

(Yasin and Alsayed, 2021) proposed an FLC -based power management strategy to address the power converters' switching problems and load dynamic performance problems that the deterministic approach had. It lowers the output signal's total harmonic distortion of voltage (THDV). Less energy is injected to dump load (DL). Zero energy has been added to DL. The entire strategy has a significant impact on the battery storage system's (BSS) and SC charging and discharging modes.

Esmaeel *et al.* (2021) proposed a new model for the scheduling problem based on a HEMS, which reduces the cost of electricity each day. The indoor temperature was maintained within a predetermined margin and the air conditioner system was set using the indoor-outdoor temperature model. The temperature is controlled by the air conditioner using an inverter. There is a tradeoff between reducing the energy bill with relative discomfort.

Busisiwe *et al.* (2021) suggested a fuzzy logic EMS to control the electricity flows in a compact, neighborhood-based distributed generation system. The SC is used to make up for the lack of power experienced when the diesel generator (DG) first starts up and to make up for the BSS's charging and discharging current limitations. It inconvenient the user when the daily electricity cap is lower and allows for low load consumption.

Meliani *et al.* (2021) introduce the use of EMS to effectively balance supply and demand, reduce peak load during the unplanned duration, and increase efficiency. The system lowers the price of electricity by about 20 to 30%. The system lacks of accurate and rapidly modeling of uncertainty. The distributed energy grid system lacks an integrated system configuration and operation management approach.

Arcos-Aviles *et al.* (2021A) proposed FLC based EMS To reduce power peaks and fluctuations in the utility network exchanged profile. It achieves an evolution of the SOC within the permitted ranges and a smooth grid power profile. Reduction in the maximum power derivative of over 40% when being compared with fuzzy-based EMS which uses a heuristic approach. It does not update the forecast variables and fuzzy logic control parameters simultaneously, which could increase EMS efficiency.

Sultan *et al.* (2021) developed SHEMS to provide families with comfortable services and increase uninterrupted electricity production. It offers a smooth, continuous electrification operation in housing developments with demand rationalization, which makes it easier for the cost of energy production to drop. Low power consumption because electricity is frequently unavailable; the charging condition has the biggest impact on the transported active flows.

Tuomela *et al*. (2021) suggested HEMS that can direct energy demand to off-peak hours by using renewable energy. There was a rise in energy efficiency. The electricity used for heating was not metered.

An EMSs to minimize power peak and fluctuation of the power profile exchanged with the utility network through particle swarm optimization and differential evolution was proposed by (Arcos-Aviles *et al*., 2021B). Difficulties getting accurate data on consumption behavior due to changes in pricing and corresponding demand based on

Such price changes.

The summary of related works that have been discussed is shown in Table 2.1

Table 2.1: A summary of the related works

S/N	Author	Aim	Strength	Weakness
1	Mubdir *et al.*, 2016	To lower energy consumption by detecting residential activity and classifying it as either active, away, or asleep.	The system can save up to 18% on energy.	Missing a feature that would allow it to identify security problems when the residents are away from home
2	Okae *et al.*, 2017	To develop of smart energy management system for buildings.	It provides a balance between the supply from distributed source and the demand in the building.	No monitoring and control software architecture for smart energy management system.
3	Joshi and Khan 2017	To implement IoT for monitoring home appliances.	It helps the users to control the electric appliances automatically, manually, and remotely using a smartphone or personal computer.	Liable to Cyber attacked.
4	Hettiarachchi *et al.*, 2017	To creates a voltage control scheme for the AC busbar and a sequential operating method for DC busbar control under various conditions.	It determines the constraints and identifies the necessary scenario in the AC and DC bus bar control to apply fuzzy logic.	There was no frequency control for the AC bus bar.

S/N	Author	Aim	Strength	Weakness
5	Gemage *et al*., 2018	To create algorithms for the hybrid energy storage system (HESS) based on batteries and supercapacitors to run as efficiently as possible.	It lessens the strain on the battery storage system, extending the battery's life cycle.	Continuously powering the load with batteries and supercapacitors can harm them.
6	Prajwal and Gupta 2018	To build a control system which will maintain a continuous power supply for the user and also reduce the electricity cost by using an alternate form of electrical energy during the peak time.	The system recognizes peak hours or periods of power shortage and takes the appropriate action to ensure that consumers are not inconvenienced.	Difficulties getting accurate data on consumption behavior due to changes in pricing and corresponding demand based on such price change.
7	Uddin and Islam 2018	To supply any excess power to the grid that is available after meeting consumer load demands and maintaining an appropriate state of charge (SOC) for the battery.	The system can exchange power with the local grid and can be used as a universal system.	The variations in their output may not match the time distribution of the load demand, resulting in reduced system energy performance.

S/N	Author	Aim	Strength	Weakness
8	Krishna *et al.,* 2018	To automatically switch over light and medium loads to the nearby renewable energy storage according to the latter's availability.	Every hour, SHEMS sends to the cloud the information it has collected about energy consumption from the grid and the battery.	It is inaccurately perceived as being slow.
9	Arcos-Aviles *et al*., 2018	To keep the battery state of charge within a safe range while minimizing changes in the grid profile.	The battery's available dynamic range can compensate for MG net power fluctuations while keeping the SOC within a safe range.	The method is unable to regulate an electric water heater.
10	El Zerk *et al*., 2108	To supply load by guaranteeing the availability of power on demand, and enhance the quality of the generated power.	The system regulates of DC voltage, maintenance of the batteries at admirable intervals, and supply even with wind and PV.	Unpredictable weather changes affect the system's performance
11	Prathyyush and Jasmin, 2018	To reduce power variations while maintaining the battery's state of charge within permitted bounds.	It maximizes the use of energy and in the event of a power outage, fuel cells only supply the bare minimum of power.	Controllable loads lack an energy rate of change approach.
12	Ramalingam *et al*., 2019	To instantly and continuously monitor electrical data online.	It actively lowers standby power usage and the power outlet at the same time.	Subject to cyberattacks.

S/N	**Author**	**Aim**	**Strength**	**Weakness**
13	Shyni and Ramadevi, 2019	To integrate solar and wind hybrid renewable sources to meet load power demand.	The Luo converter able to eliminate the high-frequency current harmonics in the wind generator because of the low power and cost dissipation in this system.	The intermittent nature of solar and wind, which is dependent on weather and climate changes affect system's performance.
14	Ashaj and Ercelebi, 2019	To create a smart, low-cost power management system that includes some appliances that can be used for power consumption control.	It successfully controlled multiple tasks simultaneously without failing.	The system is unable to detect the distribution of foreground objects outside of the connected region.
15	Baset *et al.*, 2020	To effectively manage the load demand among the various parts of the FC/BS/SC system.	It optimally manages load demand among the various fuel cell/battery storage/super-capacitor system sources.	Fuel cell power rises gradually, which will impact the efficiency of the energy management system as a whole.
16	Jafari *et al.*, 2020	To ascertain the micro-grid components' efficiency performance, projected energy generation and demand.	Both the current situation and long-term projections of energy production and consumption have been taken into consideration.	There was an increase in the cost per day when using only grid energy.

S/N	Author	Aim	Strength	Weakness
17.	Hosseinnezhad and Shafie-Khan, 2020	To provides consumers with a high level of comfort.	HEMS determines an operational scenario with an acceptable success rule for real-time regulation. Regulate the discrepancies between the forecasted and actual values.	The local market and local energy exchange concepts were not covered.
18	Meje *et al.*, 2020	Presented a sophisticated control strategy for managing and regulating the flow of hybrid renewable energy (HRE) in rural applications.	It controls the power flow between the sources while accommodating the demands of various loads	Lack of smooth and optimal performance in HRES operation.
19	Zand *et al.*, 2020	To integrate the control network based on the intelligent control system of the PV-wind power system's combined and the electric vehicle's battery replacement.	The wavelet conversion can distribute power at various frequencies to pertinent sources in an optimal manner, making it simple to control the optimized power.	Fuel cell require a continuous source of hydrogen and oxygen as reactants to sustain a chemical reaction to produce electrical energy.

S/N	Author	Aim	Strength	Weakness
20	Yasin and Alsayed, 2021	To address the power converters' switching problems and load dynamic performance problems that the deterministic approach had.	It lowers the output signal's total harmonic distortion of voltage (THDV).	Less energy is injected into dump load (DL).
21	Busisiwe *et al.*, 2021	To control the electricity flows in a compact, neighborhood-based distributed generation system.	The SC is used to make up for the lack of power experienced when the DG first starts up and to make up for the BSS's charging and discharging current limitations.	It inconvenient the user when the daily electricity cap is lower and allows for low load consumption.
22	Arcos-Aviles *et al.*, 2021A	To reduce power peaks and fluctuations in the utility network exchanged profile.	Reduction in the maximum power derivative of over 40% when being compared with fuzzy-based EMS which uses a heuristic approach.	It does not update the forecast variables and fuzzy logic control parameters simultaneously, which could increase EMS efficiency.

S/N	Author	Aim	Strength	Weakness
23	Meliani *et al.*, 2021	To effectively balance supply and demand, reduce peak load during the unplanned duration, and increase efficiency	The system lowers the price of electricity by about 20 to 30%.	The distributed energy grid system lacks an integrated system configuration and operation management approach.
24	Sultan *et al.*, 2021	To provide families with comfortable services and increase uninterrupted electricity production.	It offers a smooth, continuous electrification operation in housing developments with demand rationalization.	Low power consumption because electricity is frequently unavailable; the charging condition has the biggest impact on the transported active flows.
25	Esmaeel *et al.*, 2021	To reduce the cost of electricity each day.	The indoor temperature was maintained within a predetermined margin and the air conditioner system was set using the indoor-outdoor temperature model.	There is a tradeoff between reducing the energy bill with relative discomfort.

S/N	Author	Aim	Strength	Weakness
26	Tuomela *et al*., 2021	To direct energy demand to off-peak hours by using renewable energy.	There was a rise in energy efficiency.	The electricity used for heating was not metered.
27	Arcos-Arvile *et al*., 2021B	To minimize power peak and fluctuation of the power profile exchanged with the utility network through particle swarm optimization and differential evolution.	It minimizes the operating cost of the MG or maximize its income.	Unpredictable weather changes affect the system's performance.

The summary of the limitation from the literature in Table 2.1 are;

i. Lacks of monitoring of the energy sources and control software architecture for a smart energy management system.
ii. Lack of accurate and rapidly modeling of uncertainty, as well as the lack of an integrated system configuration and operation management approach for distributed energy grid system.
iii. Increase in the cost per day when using only grid energy.
iv. There is a tradeoff between reducing the energy bill with relative discomfort.

From the listed limitation above, this research work hopes to address the limitation found in (Okae *et al*., 2017);

i. Poor energy management from consumer end.
ii. Lack of prioritization of multiple energy sources.
iii. Lack of an intelligence system for multiply energy source prioritization.

Hence, the design methodology, performance investigation as discussed in chapter three and chapter four.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

This chapter describes the methodology and procedures of the proposed smart distribution algorithm MATLAB version. Fuzzy logic toolbox is employed in the design and simulation and evaluation the performance of the smart distribution algorithms. Therefore, the choice of fuzzy logic was based on its ability to handle uncertainty and impression in the data, as well as its ability to incorporate human expertise in the control deign.

Fuzzy logic allows for use of human expertise in control design, and it include an input stage, a process stage, and an output stage (Uddin and Islam, 2018). Additionally, the fuzzy logic system utilized Mandani Fuzzy Inference (FIS) to dynamically map sources to load, because of its simplicity in design and high level of accuracy (Prajwal and Gupta, 2018).

3.1 Tools and Material

Power sources: Photovoltaic panels, power inverter, grid, deep batteries (energy storage) and generator.

Electrical load: All lighting points, ceiling fans, all 13 amp. socket loads, 15 amp. socket loads.

3.1.1 Software tools

The software tools needed are Matlab, Microsoft Visio and snipping tool.

3.1.2 Description of Engineering complex in terms of source and load model

S1, S2, S3, and S4 are four power sources considered in this research. Solar panel power is source S1, grid power is S2, battery power is S3, which will be charge by solar panel through DC-DC converter (Ghaffar *et al*., 2019), and generator power is S4. While E_{S1}, E_{S2}, E_{S3}, and E_{S4} are their respective source ratings in watts. Solar panel supply (S1), which is more affordable (Ghaffar *et al*., 2019) is given priority over other sources. In addition, segment loads L1, L2, L3, and L4 have wattage ratings of W_{L1}, W_{L2}, W_{L3}, and W_{L4}, respectively. All lighting fixtures and ceiling fans together make up load L1, all 13-amp socket loads make up load L2, all 15-amp socket loads make up load L3, and all security lighting points make up load L4. In the loading domain, during the day (between the hours of 7 am to 6 pm), L1 has the highest priority because it consumes the least amount of power and is the most vital for buildings, while L3 has the lowest priority. At night (between the hours of 6 pm to 7 am), L4 is the only priority. The system model is shown in Figure 3.1.

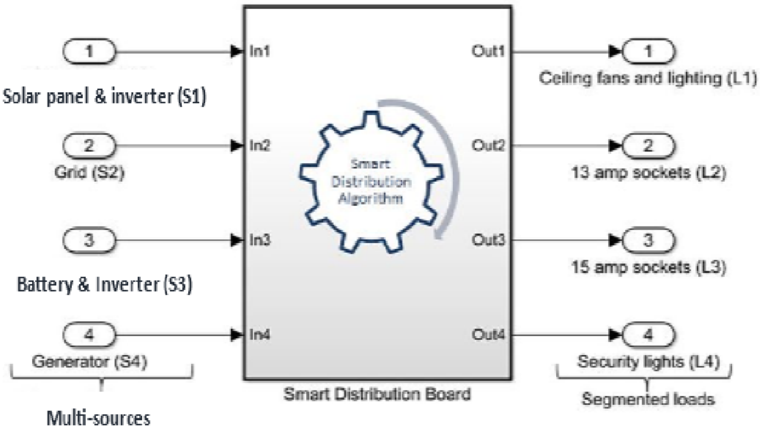


Figure 3.1: Model of Smart Distribution board

3.2 Fuzzy Logic System

There are two types of fuzzy logic systems which are Mamdani fuzzy model and Sugeno fuzzy model. The Mamdani fuzzy inference gives an output that is fuzzy set, while Sugeno inference gives an output that is either constant or a linear. Mamdani type has multiple input single output (MISO) and multiple input multiple output (MIMO), while Sugeno type has only multiple input single output (MISO). The fuzzy logic system utilized the Mandani FIS to dynamically map sources to loads (Prajwal and Gupta, 2018). The Mandani FIS was used because of its simplicity in design and high level of accuracy. The model of the Fuzzy logic system was adopted in Matlab and presented in Figure 3.2.

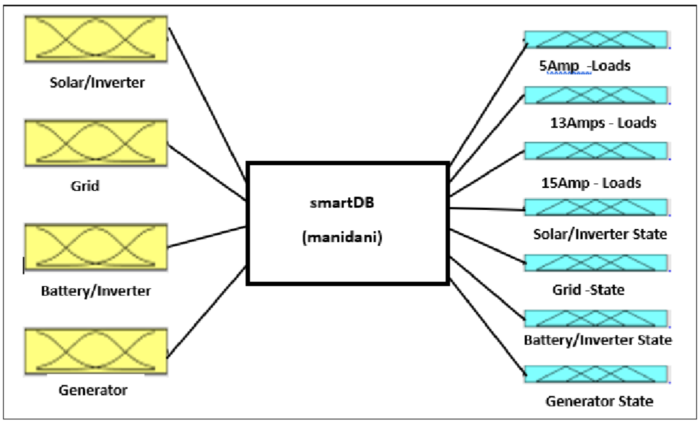


Figure 3.2: Fuzzy Logic System Model

The four (4) inputs that make up the FIS are the four (4) power sources that were taken into consideration for the study: the solar panel and inverter (S1), the grid (S2), the battery and inverter (S3), and the generator (S4). Due to its high computational efficiency, a triangular membership function was used to fuzzifier the inputs, as shown in Figure 3.3. Each input can be turned on, off, low, medium, or high. Where "off" denotes a decreased volume of the specified source. On the other hand, "low" indicates that the source can only support L1. "Medium" means that it can only serve L1 and L2, while "high" means that the source can serve L1, L2, and L3.

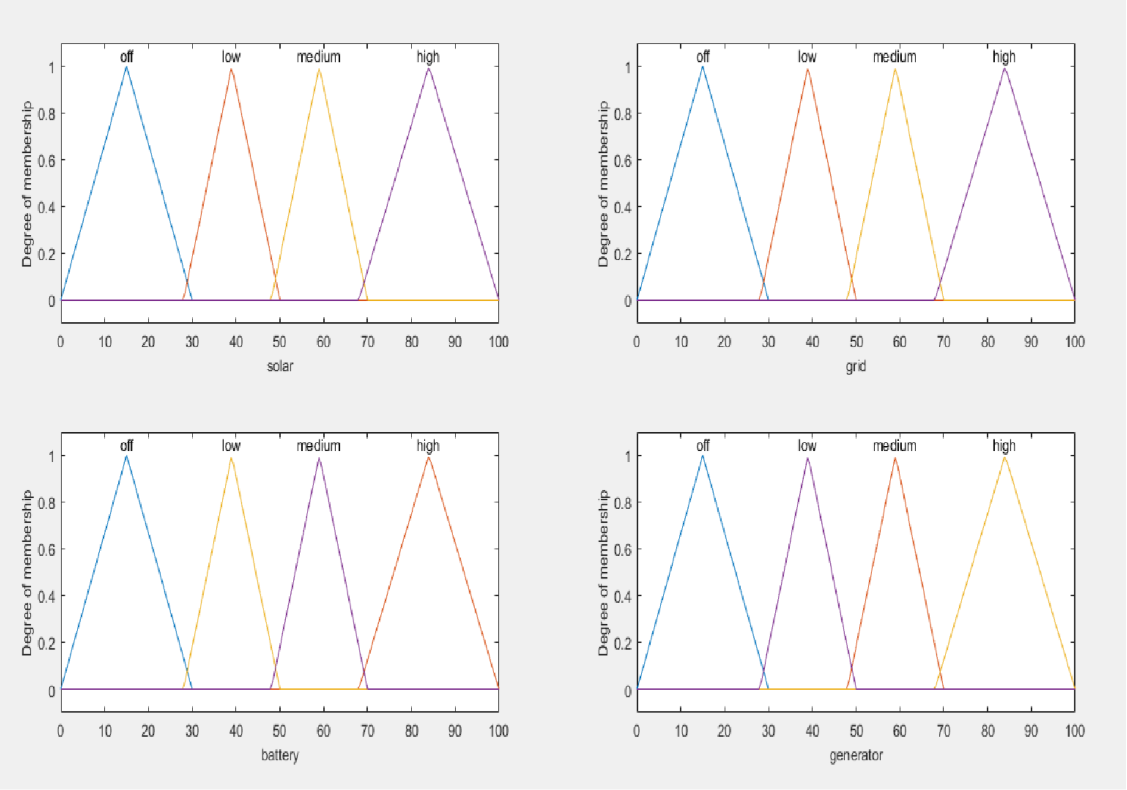


Figure 3.3: Input membership functions

The 5 amps (L1), 13 amps (L2), 15 amps (L3) loads, and the states of the four sources are the FIS's output variables. A triangular membership function and a centroid function were both used in the defuzzification process. Since the centroid function requires little computational complexity, it was chosen over other defuzzification methods. The output variables' membership functions are displayed in Figures 3.4 and 3.5. While the source is either "active" or "idle," the output variables for the loads are either "off" or "on." The terms "off" denote that the load is switched off, "on" denotes that the load is being served, "active" denotes that the source is serving a load, and "idle" denotes that the source is either turned off or that it is "on" but not serving any load.

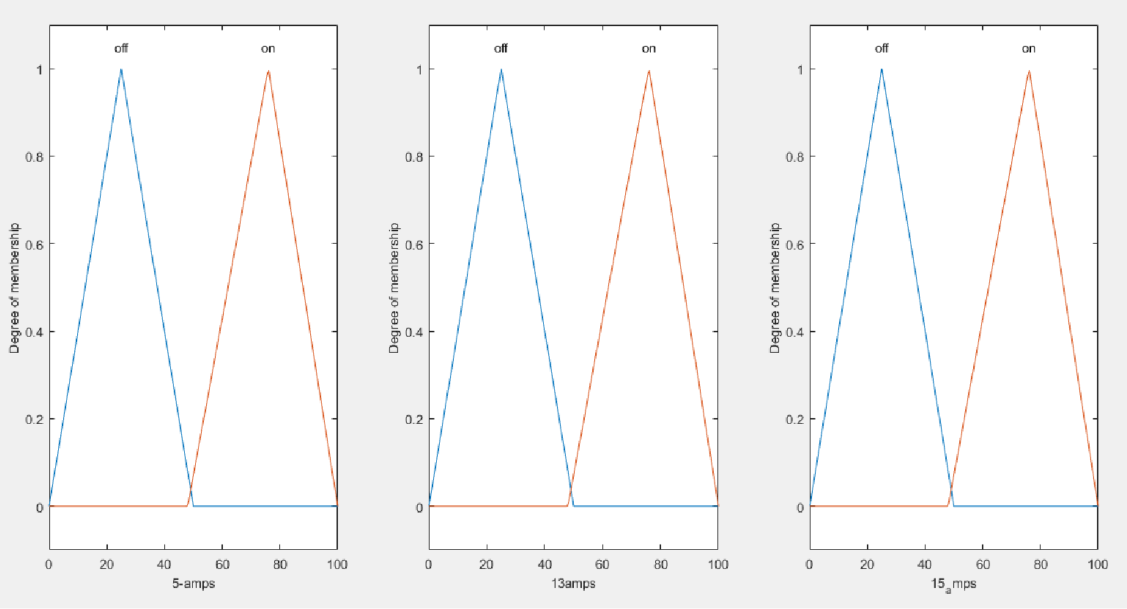


Figure 3.4: Output membership function of the loads

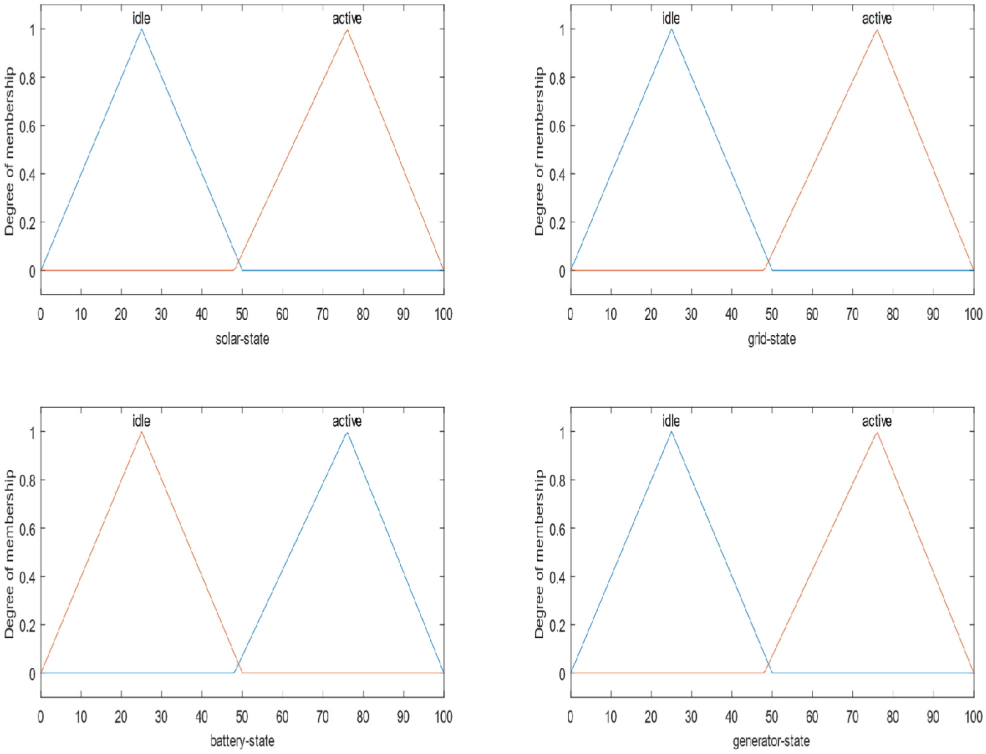
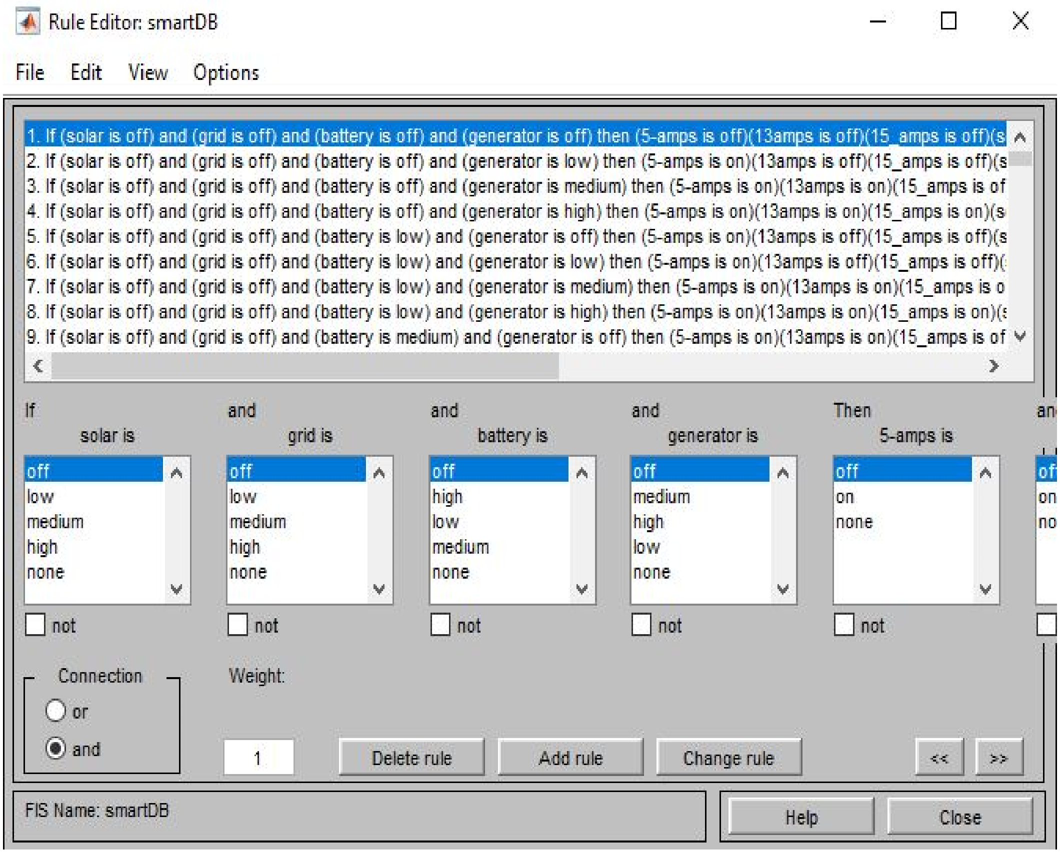


Figure 3.5: Output membership function of the sources

In the FIS, a total of 256 rules were used to determine the output as shown in Figure3.6.



```
1. If (solar is off) and (grid is off) and (battery is off) and (generator is off) then (5-amps is off)(13amps is off)(15_amps is off)(s
2. If (solar is off) and (grid is off) and (battery is off) and (generator is low) then (5-amps is on)(13amps is off)(15_amps is off)(s
3. If (solar is off) and (grid is off) and (battery is off) and (generator is medium) then (5-amps is on)(13amps is on)(15_amps is of
4. If (solar is off) and (grid is off) and (battery is off) and (generator is high) then (5-amps is on)(13amps is on)(15_amps is on)(s
5. If (solar is off) and (grid is off) and (battery is low) and (generator is off) then (5-amps is on)(13amps is off)(15_amps is off)(s
6. If (solar is off) and (grid is off) and (battery is low) and (generator is low) then (5-amps is on)(13amps is off)(15_amps is off)(
7. If (solar is off) and (grid is off) and (battery is low) and (generator is medium) then (5-amps is on)(13amps is on)(15_amps is o
8. If (solar is off) and (grid is off) and (battery is low) and (generator is high) then (5-amps is on)(13amps is on)(15_amps is on)(
9. If (solar is off) and (grid is off) and (battery is medium) and (generator is off) then (5-amps is on)(13amps is on)(15_amps is of
```

Figure 3.6: Fuzzy logic rules

Figure 3.6 illustrates how Rule 1 disconnects all loads while Rule 2 only uses S4 to serve L1. Contrarily, Rule 3 uses S4 to serve only L1 and L2, whereas Rule 4 uses S4 to serve L1, L2, and L3. This continued until all possible combinations between the sources and loads were satisfied.

3.2.1 Parametric definition of proposed algorithm

The power requirement of loads in the Engineering complex of Niger State Polytechnic, Zungeru Nigeria was measured and presented in Table 3.1.

Table 3.1: Power requirement of loads in Engineering complex, Niger state polytechnic Zungeru

Load point	**Average number of appliances**	**Wattage per device (Watts)**	**Total wattage (Watts)**
Lighting points (5 Amp)	352	40	14,080
Ceiling fans (5 Amp)	321	60	19,260
13 Amp. socket outlet	447	600	268,200
15 Amp. socket outlet	74	1500	111,000
Security lighting point	129	40	5,160
		Total	417,700

The measured values were normalized and converted to a percentage before being fed into the algorithm. The reason for the normalization of the measured value before converting them to percentages is to eliminate redundant data, minimize data modification errors and creating a single source of truth.

The algorithm represents the power output of a source input or output as a value between 0 and 30 when it is less than 35 kW. No output is delivered to the load in this situation. When it is between 35 kW and 305 kW, the algorithm, however, indicates 30-50. In this case, only the 5 Amp loads will be powered. When the source input or output is between 305 kW and 420 kW, it represents 50–70 similarly. This indicates that the source can only handle loads that are 5 Amp and 13 Amp. The algorithm interprets input or output above 420 kW as 70–100, implying that the source can supply all 5 Amp, 13 Amp, and 15 Amp loads. The developed algorithm was simulated in Matlab environment.

3.2.2 Pseudocode of smart distribution algorithm

The pseudocode of smart distribution algorithm of the system is as follow:

```
1. Initialize $V_{S1}$, $V_{S2}$, $V_{S3}$, $V_{S4}$, $I_{S1}$, $I_{S2}$, $I_{S3}$, $I_{S4}$, $V_{L1}$, $V_{L2}$, $V_{L3}$, $V_{L4}$, $I_{L1}$, $I_{L2}$, $I_{L3}$, $I_{L4}$, $E_{S1}$, $E_{S2}$, $E_{S3}$, $E_{S4}$, $W_{L1}$, $W_{L2}$, $W_{L3}$, $W_{L4}$.
```

2. Measure V_{S1}, V_{S2}, V_{S3}, V_{S4}, I_{S1}, I_{S2}, I_{S3}, I_{S4}, V_{L1}, V_{L2}, V_{L3}, VL4, I_{L1}, I_{L2}. I_{L3}, I_{L4}, E_{S1}, E_{S2}, E_{S3}, E_{S4}, W_{L1}, W_{L2}, W_{L3}, W_{L4}.
3. $If\,(7am \geq time \leq 6pm)$
4. Yes: $if\,(E_{S1} > (W_{L1} + W_{L2} + W_{L3}))$: Energy from source 1 > wattages of load 1, 2, 3.
5. $Display(S1 \rightarrow (L1 + L2 + L3))$: Display source 1 is serving load1, 2, 3.
6. $Elseif\,(E_{S2} > (\mathrm{W}_{L1} + W_{L2} + W_{L3}))$: Energy from source 2 > wattages of load 1, 2, 3.
7. $Display(S2 \rightarrow (L1 + L2 + L3))$: display source 2 is serving load 1, 2, 3.
8. $Elseif\,(E_{S3} > (\mathrm{W}_{L1} + W_{L2} + W_{L3}))$: Energy from source 3 > wattages of load 1,2, 3.
9. $Display(S3 \rightarrow (L1 + L2 + L3))$: Display source 3 is serving load 1, 2, 3.
10. $Elseif\,(E_{S4} > (\mathrm{W}_{L1} + W_{L2} + W_{L3}))$: Energy from source 4 > wattages of load 1, 2, 3.
11. $Display(S4 \rightarrow (L1 + L2 + L3))$: Display source 4 is serving the load 1, 2, 3.
12. $Elseif\,(E_{S1} > (\mathrm{W}_{L1} + W_{L2}))$: Energy from source 1 > wattages of load 1, 2.
13. $Display(S1 \rightarrow (L1 + L2))$: Display source is serving load 1, 2.
14. $Elseif\,(L1 = 0\ \&\ E_{S2} > W_{L3})$: Load 1 is idle, energy from source 2 > wattages of load 3
15. $Display(S2 \rightarrow L3)$: Display source 2 is serving load 3.
16. $Elseif\,(L2 = 0\ \&\ E_{S2} > W_{L3})$: load 2 is idle, energy from source 2 > wattages of load 3.
17. $Display(S2 \rightarrow L3)$: Display source 2 is serving load 3.
18. $Elseif\,(L3 = 0\ \&\ E_{S2} > W_{L3})$: Load 3 is idle, energy from source 2 > wattages of load 3.
19. $Display(S3 \rightarrow L3)$: Display source 3 is serving load 3.
20. $Elseif\,(L4 = 0\ \&\ E_{S4} > W_{L3})$: load 4 is idle, energy from source 4 > wattages of load 3.
21. $Display(S4 \rightarrow L3)$: Display source 4 is serving load 3.
22. No: Go to step 3
23. $Elseif\,(E_{S2} > (W_{L1} + W_{L2}))$: Energy from source 2 > wattages of load 1, 2.
24. $Display(S2 \rightarrow (L1 + L3))$ and go to step 14: Display source 2 is serving load 1, 2.
25. $Elseif\,(E_{S3} > (W_{L1} + W_{L2}))$: Energy from source 3 > wattages of load 1, 2.

```
26. $Display(S3 \rightarrow (L1 + L3))$ and go to step 14: Display source 3 is serving load 1, 2.
27. $Elseif(E_{S4} > (W_{L1} + W_{L2}))$: Energy from source 4 > wattages of load 1, 2.
28. $Display(S4 \rightarrow (L1 + L3))$ and go to step 14: Display source 4 is serving load 1, 2.
29. $Elseif(E_{S1} > W_{L1})$: Energy from source 1 > wattages of load 1.
30. $Display(S1 \rightarrow L1)$: Display source 1 is serving load 1.
31. $Elseif(E_{S2} > W_{L2})$: Energy from source 2 > wattages of load 2.
32. $Display(S2 \rightarrow L2)$: Display source 2 is serving load 2.
33. $Elseif(E_{S3} > W_{L3})$: Energy from source 3 > wattages of load 3.
34. $Display(S3 \rightarrow L3)$ and return to step 3: Display source 3 is serving load 3.
35. $Elseif(E_{S4} > W_{L3})$: Energy from source 4 > wattages of load 3.
36. $Display(S4 \rightarrow L3)$ and return to step 3: Display source 4 is serving load 3.
37. $Elseif(E_{S3} > W_{L2})$: Energy from source 3 > wattages of load 2.
38. $Display(S3 \rightarrow L2)$: Display source 3 is serving load 2.
39. $Elseif(E_{S4} > W_{L3})$: Energy from source 4 > wattages of load 3.
40. Return to steps 35 to 36
41. $Elseif(E_{S4} > W_{L2})$: Energy from source 4 > wattages of load 2.
42. $Display(S4 \rightarrow L2)$: Display source 4 is serving load 2.
43. Go to step 3
44. $Elseif(E_{S2} > W_{L1})$: Energy from source 2 > wattages of load 1.
45. $Display(S2 \rightarrow L1)$: Display source 2 is serving load 1.
46. $Elseif(E_{S3} > W_{L2})$: Energy from source 3 > wattages of load 2.
47. $Display(S3 \rightarrow L2)$: Display source 3 is serving load 2.
48. $Elseif(E_{S4} > W_{L3})$: Energy from source 4 > wattages of load 3.
49. $Display(S4 \rightarrow L3)$: Display source 4 is serving load 3.
50. Go to step 3
51. $Elseif(E_{S3} > W_{L2})$: Energy from source 3 > wattages of load 2.
52. $Display(S3 \rightarrow L2)$: Display source 3 is serving load 2.
```

```
53. $Elseif(E_{S4} > W_{L3})$: Energy from source 4 > wattages of load 3.
54.  $Display(S4 \rightarrow L3)$ : Display source 4 is serving load 3.
55. Return to step 3
56. $Elseif(E_{S3} > W_{L1})$: Energy from source 3 > wattages of load 1.
57. $Display(S3 \rightarrow L1)$: Display source 3 is serving load 1.
58.  $Elseif(E_{S4} > W_{L2})$: Energy from source 4 > wattages of load 2.
59. $Display(S4 \rightarrow L2)$: Display source 4 is serving load 2.
60. Go to step 3
61. $Elseif(E_{S4} > W_{L1})$: Energy from source 4 > wattages of load 1.
62. $Display(S4 \rightarrow L1)$: Display source 4 is serving load 1.
63.  Return to step 3
64. No: There is a power outage go to step 74
65. $Else(L1, L2, L3 = 0)$: Load 1,2 & 3 are idle.
66. $If(\mathrm{E}_{S2} > W_{L4})$: Energy from source 2 > wattages of load 2.
67. $Display(S2 \rightarrow L4)$ and return to step 3: Display source 2 is serving load 4.
68. $Elseif(E_{S3} > W_{L4})$: Energy from source 3 > wattages of load 4.
69. $Display(S3 \rightarrow L4)$ and return to step 3: Display source 3 is serving load 4.
70. $Elseif(E_{S4} > W_{L4})$: Energy from source 4 > wattages of load 4.
71. $Display(S4 \rightarrow L4)$: Display source 4 is serving load 4.

72. Endif

73. Endif

74. Stop
```

3.2.3 Flowchart of smart distribution algorithm

The flow chart of the algorithm is given in Figure 3.7

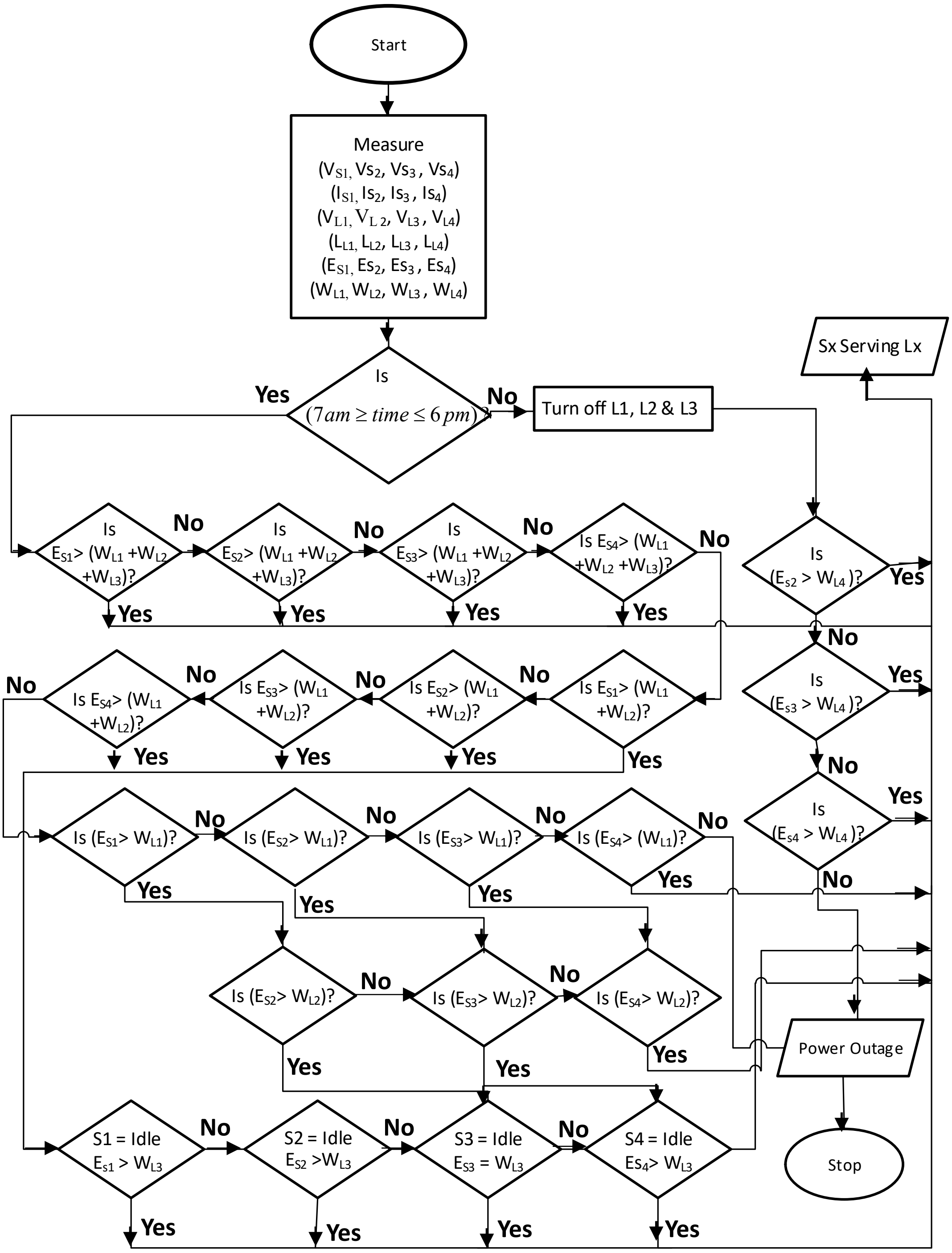


Figure 3.7: Flowchart of the algorithm for the system's mode of operation

The distribution algorithm, as seen in the pseudocode and flowchart, shuts down all loads at night and chooses a suitable source to power the security lighting points, starting with S2. Because there is no sunlight during the night, S1 is disregarded. The algorithm turns on the fuzzy logic system during the day to choose which load and appropriate source to be powered.

3.3 Simulation of Smart Distribution Algorithm in Matlab

The SDA was simulated in MATLAB (R2017a) environment using fuzzy inference system (FIS). The FIS files were load from the tipper.fis in MATLAB. The system parameter/property input and output arguments use are shown in Appendix A.

Table 3. 2: Simulation Parameters

Parameter	Description
Fuzzy logic system	Mamdani
Version	2.0
Number of inputs	4
Number of outputs	7
Number of rules	256
And Method	Minimum
Or Method	Maximum
Implication Method	Minimum
Aggregation Method	Maximum
Defuzzification Method	Centroid

3.4 Performance Evaluation of Smart Distribution Algorithm

The performance evaluation of the developed algorithm addresses the issues of energy consumption by prioritizing the energy sources. The result of this evaluation is presented in chapter four.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

This chapter presents fuzzy logic control rule's view, the results of inputs from the four (4) sources, output of the conventional distribution board (CDB), and the output of smart distribution board (SDA) using MALTAB as simulation environment. Furthermore, analysis of energy saving efficiency is presented.

4.1 Fuzzy Logic Control rule's view

Table 4.1 demonstrates how the algorithm serves all the loads using only solar power while leaving other sources idle when solar, grid, and battery are high (that is, >70%) and the generator is off (that is, <30%).

Table 4.1: FLC rules view of Solar power serve 5 Amp, 13 Amp and 15 Amp.

Energy sources	State of sources						Loads		
	High	Medium	Low	Off	Active	Idle	5 Amp	13 Amp	15 Amp
Solar and inverter	Yes	No	No	No	Yes	No	On	On	On
Grid	Yes	No	No	No	No	Yes	Off	Off	Off
Battery and inverter	Yes	No	No	No	No	Yes	Off	Off	Off
Generator	No	No	No	Yes	No	Off	Off	Off	Off

Similarly, in Table 4.2, the solar source is medium (50%-70%), the grid and battery are high (>70%) while the generator is off (<30%). In this scenario, solar powers the 5 Amp and 13Amp loads while the 15 Amp loads are powered by the grid.

Table 4.2: FLC rules view of solar power serve 5 Amp and 13 Amps, 15 Amp serve by grid.

Energy sources	**State of sources**						**Loads**		
	High	**Medium**	**Low**	**Off**	**Active**	**Idle**	**5 Amp**	**13 Amp**	**15 Amp**
Solar and inverter	No	Yes	No	No	Yes	No	On	On	Off
Grid	Yes	No	No	No	Yes	No	Off	Off	On
Battery and inverter	Yes	No	No	No	No	Yes	Off	Off	Off
Generator	No	No	No	Yes	No	No	Off	Off	Off

More so, when the solar source is low (30%-50%), the grid is medium, the battery is low and the generator is off, only 5 Amp and 13Amp loads are served by the algorithm. The 5Amp loads are served by solar while the 13 Amp loads are served by the grid as shown in Table 4.3.

Table 4.3: FLC rules view of solar power serve 5 Amp, 13 Amp serve by grid.

Energy sources	**State of sources**						**Loads**		
	High	**Medium**	**Low**	**Off**	**Active**	**Idle**	**5 Amp**	**13 Amp**	**15 Amp**
Solar and inverter	No	No	Yes	No	Yes	No	On	Off	Off
Grid	No	Yes	No	No	Yes	No	Off	On	Off
Battery and inverter	No	No	Yes	No	No	Yes	Off	Off	Off
Generator	No	No	No	Yes	No	No	Off	Off	Off

Figure 4.1 depicts the inputs from the four (4) sources throughout a seven-day experimental period based on Matlab code in appendix A. Except for the generator source, which was off during the research period, all the other sources were high on day 1. The grid and battery were both high on Day 2, while solar was medium. On Day 3, solar and battery power were low, while the grid was medium.

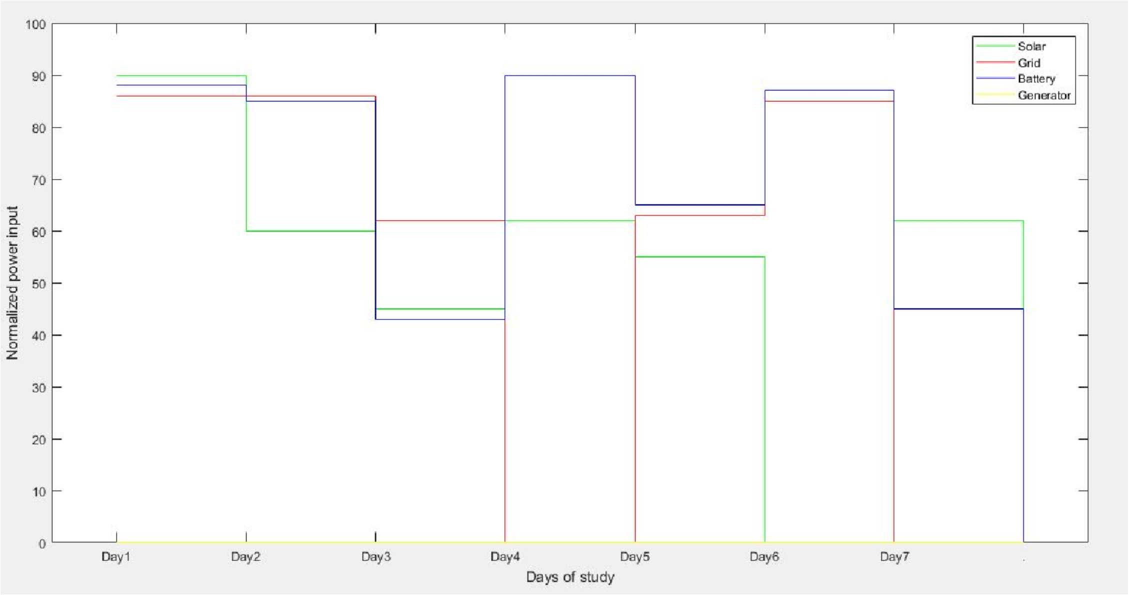


Figure 4.1: Energy source input states

Based on the energy source inputs presented in Figure 4.1, the output of the Conventional Distribution Board (CDB) is presented in Figure 4.2. Results showed that on day 1, CDB was switched to the solar source because all the sources except the generator were high and solar is the cheapest. However, on day 2, only the grid and battery were high. The CDB was switched to grid because it is cheaper. This continued until day 7. The plot of Figure 4.2 shows that the CDB takes the cheapest source that can drive the most loads.

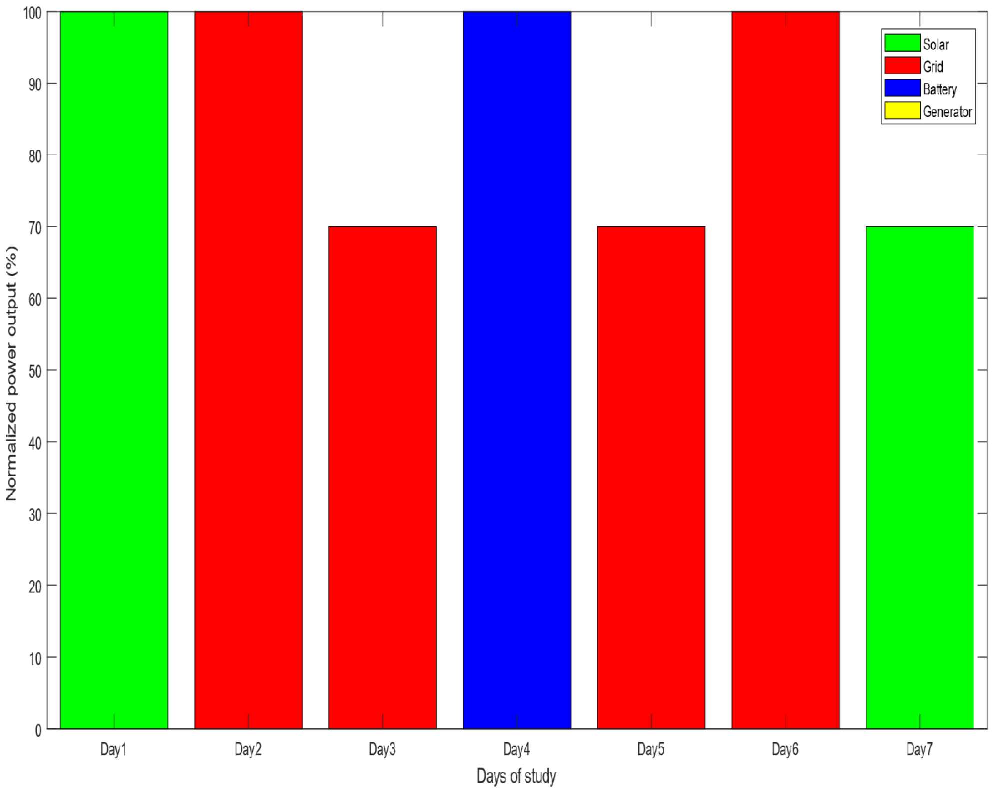


Figure 4.2: Output of conventional distribution board (CDB)

The Smart Distribution Board (SDB) on the other hand acts differently. For the first day of the study, solar was selected as the preferred source to serve all the loads as shown in Figure 4.3 which is the same with the CDB of Figure 4.2. On day 2, solar served the 5 Amp and 13 Amp loads while the 15 Amp loads were served by the grid. This is because solar is in a medium state, thus, it is capable of driving both 5 Amp and 13 Amp loads. Instead of using the grid to drive the entire loads because the grid is in the high state as the CDB, the SDB assigned the 5 Amp and 13 Amp loads to solar and use the grid to power only the 15 Amp loads. Thus, power is saved on the grid. Similarly, on day 3, solar served the 5Amp loads because solar is in a low state, while the grid served the 13 Amp loads. The system operated in like manner until day 7. The SDB when compared with the CDB saves an ample amount of energy because its sources and loads are segmented and the algorithm maps a suitable source to a suitable load dynamically.

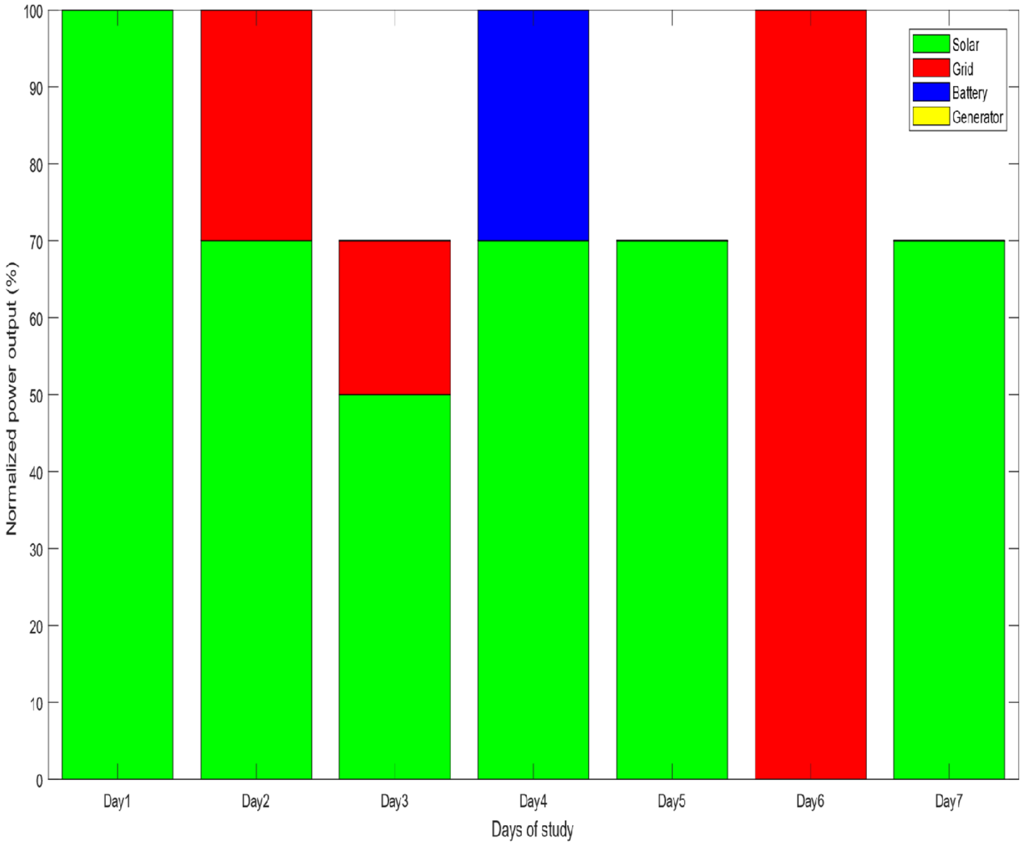


Figure 4.3: Output of Smart Distribution Algorithm (SDB)

4.2 Energy Saving Efficiency

This examines the Smart Distribution Algorithm's (SDA) energy-saving efficiency across the experimental period. Table 4.4 shows the daily energy consumption by the loads using CDB, which was derived from Figure 4.2. The total energy of the load consumption on the grid using CDB is 15,978.08 kW.

Table 4.4: Daily energy consumption by the loads using CDB

Day	Load Points	Total wattage (kW)	Power consumption (11hours) Daytime (kW)	Power consumption (13 hours) Night (kW)
1	Lighting points	14.08	154.88	0
Solar	(5Amps)	19.26	211.86	0
	Ceiling fans (5Amps)	268.20	2950.20	0
	13 Amp. socket outlet	111.00	1221.00	0
Battery	15 Amp. Socket outlet	5.16	0	67.08
(High)	Security lighting point			
	Total	417.70	4537.94	67.08
2	Lighting points	14.08	154.88	0
Grid	(5Amps)	19.26	211.86	0
(High)	Ceiling fans (5Amps)	268.20	2950.20	0
	13 Amp. socket outlet	111.00	1221.00	0
	15 Amp. Socket outlet	5.16	0	67.08
	Security lighting point			
	Total	417.70	4537.94	67.08
3	Lighting points	14.08	154.88	0
Grid	(5Amps)	19.26	211.86	0
(Medium)	Ceiling fans (5Amps)	268.20	2950.20	0
	13 Amp. socket outlet	5.16	0	67.08
	Security lighting point			
	Total	305.70	3316.94	67.08
4	Lighting points	14.08	154.88	0
Battery	(5Amps)	19.26	211.86	0
(High)	Ceiling fans (5Amps)	268.20	2950.20	0
	13 Amp. socket outlet	111.00	1221.00	0
	15 Amp. Socket outlet	5.16	0	67.08
	Security lighting point			
	Total	417.70	4537.94	67.08
5	Lighting points	14.08	154.88	0
Grid	(5Amps)	19.26	211.86	0
(Medium)	Ceiling fans (5Amps)	268.20	2950.20	0
	13 Amp. socket outlet	5.16	0	67.08
	Security lighting point			
	Total	305.70	3316.94	67.08
6	Lighting points	14.08	154.88	0
Grid	(5Amps)	19.26	211.86	0
(High)	Ceiling fans (5Amps)	268.20	2950.20	0
	13 Amp. socket outlet	111.00	1221.00	0
	15 Amp. Socket outlet	5.16	0	67.08
	Security lighting point			
	Total	417.70	4537.94	67.08
7	Lighting points	14.08	154.88	0
Solar	(5Amps)	19.26	211.86	0

(Medium)	Ceiling fans (5Amps)	268.20	2950.20	0
Battery	13 Amp. socket outlet	5.16	0	67.08
(Medium)	Security lighting point			
	Total	305.70	3316.94	67.08

Table 4.5 shows the daily energy consumption by the loads using SDA, which was derived from Figure 4.3. The total energy of the load consumption on the grid using SDA is 8,910.38 kW.

Table 4.5: Daily energy consumption by the loads using SDA

Day	Load point	Total wattages (kW)	Power consumption (11 hours) Daytime (kW)	Power consumption (13 hours) Night time (kW)
1	Lighting points (5 Amp)	14.08	154.88	0
Solar (High)	Ceiling fan (5 Amp)	19.26	211.86	0
	13 Amp, socket outlet	268.20	2950.20	0
	15 Amp. socket outlet	111.00	1221.00	0
	Total	412.54	4537.94	0
Battery (High)	Security lighting point	5.16	0	67.08
	Total	5.16	0	67.08
2	Lighting point (5 Amp)	14.08	154.88	0
Solar	Ceiling fan (5 Amp)	19.26	211.86	0
(Medium)	13 Amp. socket outlet	268.20	2950.20	0
	Total	301.54	3316.94	0
	15 Amp. socket outlet	111.00	1221.00	0
Grid (High)	Security lighting point	5.16	0	67.08
	Total	116.16	1221.00	67.08
3	Lighting point (5 Amp)	14.08	154.88	0
Solar (Low)	Ceiling fan (5 Amp)	19.26	211.86	0
	Total	33.28	366.74	0
Grid (Medium)	13 amp. socket outlet	268.20	2950.20	0
	Security lighting point	5.16	0	67.08
	Total	273.35	2950.20	67.08
4	Lighting point (5 Amp)	14.08	154.88	0
Solar	Ceiling fan (5 Amp)	19.26	211.86	0
(Medium)	13 Amp. socket outlet	268.20	2950.20	0
	Total	301.54	3316.94	0
	15 Amp. socket outlet	111.00	1221.00	0
Battery (High)	Security lighting point	5.16	0	67.08
	Total	116.16	1221.00	67.08
5	Lighting point (5 Amp)	14.08	154.88	0
Solar	Ceiling fan (5 Amp)	19.26	211.86	0
(Medium)	13 Amp. socket outlet	268.20	2950.20	0
	Total	301.54	3316.94	0
	Security lighting point	5.16	0	67.08

Battery (Medium)	Total	5.16	0	67.08
6	Lighting point (5 Amp)	14.08	154.88	0
Grid (High)	Ceiling fan (5 Amp)	19.26	211.86	0
	13 Amp. socket outlet	268.20	2950.20	0
	15 Amp. socket outlet	111.00	1221.00	0
	Security lighting point	5.16	0	67.08
	Total	417.70	4537.94	67.08
7	Lighting point (5 Amp)	14.08	154.88	0
Solar	Ceiling fan (5 Amp)	19.26	211.86	0
(Medium)	13 Amp. socket outlet	268.20	2950.20	0
	Total	301.54	3316.94	0
Battery (Medium)	Security lighting point	5.16	0	67.08
	Total	5.16	0	67.08

From Table 4.4, the total energy consumption on the grid by CDB is 15,978.08 kW while from Table 4.5, SDA consumed 8,910.38 kW. This implies that the energy saved by the SDA during the research period is 7,067.70 kW.

The energy tariff of Niger State Polytechnic, Zungeru is A_2, band *E* which is ₦48.37k per *Kwh* (AEDC,2023). Energy consumed from the grid through CDB is 15978.08 x ₦48.37 = ₦772,859.73k. While that of SDA is 8910.38 X ₦48.37 = ₦430,995.08k. The money saved from using SDA is ₦772,859.73 - ₦430,995.08 = ₦341,864.65k for a week. For one month is ₦341,864.65 x 4 = ₦1,367,458.60k. While for a year is ₦1,367,458.60 x 12 = ₦16,409,503.20k

Table 4.6 shows the daily power consumption on the grid and battery by the SDA as compared to the CDB for the daytime.

Table 4.6: Power consumption on the grid and battery

SN	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Total
CDB (kW)	0	417.70	301.54	417.70	301.54	417.70	0	1856.18
SDA (kW)	0	111.00	268.20	111.00	0	417.70	0	907.90

From Table 4.6, the total power consumption on the grid and battery by the CDB is 1,856.18 kW while the SDA consumed 907.90 kW. This implies that the power saved by the SDA during the study period is 948.28 kW. Thus, the energy saving efficiency is 51.09% according to equation (4.1)

$$\eta = \frac{E_{CDB} - E_{SDB}}{E_{CDB}} \tag{4.1}$$

where η is the energy saving efficiency of the SDA, E_{CDB} and E_{SDB} are the energies consumed by the CDB and SDB respectively.

Table 4.7 shows the daily energy saving efficiency of in the Engineering complex of Niger State Polytechnic, Zungeru Nigeria.

Table 4.7: Daily energy saving efficiency in the Engineering complex

SN	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Efficiency (%)	100	35.1	55.5	35.1	100	0	100

From Table 4.7, the solar source serves the all loads in the first day being the preference source, which implies 100% of energy saving. Second day energy saving is 35.1%, third day is 55.5%, fourth day is 35.1%, fifth day is 100%, sixth day is 0%, because the grid serves all the loads and seventh day is 100%.

The next chapter contains the conclusion and recommendations. It also presents the contribution to knowledge from this research work.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

This chapter presents the conclusion, recommendation and contributions to knowledge from this research work. This research work provides a new and better SMES for high efficiency performance and save cost.

5.1 Conclusion

An SDA that can operate on distribution boards with segmented multiple power sources and segmented loads in buildings was developed in this research project. By dynamically allocating different sources to various loads in buildings according to demand, the SDA transforms the CDB into a smart device. From simulation results, SDBs that use the developed algorithm was able to conserve electricity energy by 51.09% when compared to CDBs. Furthermore, the developed SDB's energy-saving effectiveness surpasses that of (Okae et al. 2017), which uses segmented loads and multiple combined sources with a maximum energy-saving capacity of 25%. This demonstrates how segmenting sources and loads makes a distribution board simpler and enables more flexible power control and distribution. A microcontroller unit (MCU), which is used by the algorithm, as well as a system of relays for switching are just a few of the electronic components that must be installed to deploy the algorithm on CDB.

This study leverages on communication principles to match the most effective energy source to the most suitable loads, leading to energy conservation, reduce utility bills, and availability of power. It also enables homes and buildings to integrate seamlessly into the smart grid system, making it an ideal solution for smart city applications.

5.2 Recommendations

The research on the smart electricity distribution algorithm for multiple-source and segmented loads in buildings has achieved better performance compared to others without segmented load. Listed are recommendations to consider in future as follows:

i. A hardware of smart electricity distribution algorithm for multiple-source and segmented loads in buildings should be developed for future study.
ii. The smart electricity distribution algorithm for multiple-source and segmented loads in buildings should still be upgraded to service additional multiple loads.
iii. Other simulation techniques should be engaged considering the new segmented approach. This is to determine the dominant load source.
iv. The GSM module and the Wi-Fi module can be an interface to the microcontroller unit via universal asynchronous receiver transmitter to monitor and control all sources and loads.

5.3 Contribution to Knowledge

This research work has contributed to knowledge by developing a smart distribution algorithm (SDA) that is capable of running multiple segmented powers and segmented loads in a building. The developed algorithm saved 51.09% of power when run on the SDB when compared to the CBD. This demonstrates how segmenting sources and loads makes a distribution board simpler and enables more flexible power control and distribution.

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Appendix A

MALTAB CODE FOR SMART DISTRIBUTION ALGORITHM

```
[System]
Name='smartDB'
Type='mamdani'
Version=2.0
NumInputs=4
NumOutputs=7
NumRules=256
AndMethod='min'
OrMethod='max'
ImpMethod='min'
AggMethod='max'
DefuzzMethod='centroid'

[Input1]
Name='solar'
Range=[0 100]
NumMFs=4
MF1='off':'trimf',[0 15 30]
MF2='low':'trimf',[28 39 50]
MF3='medium':'trimf',[48 59 70]
MF4='high':'trimf',[68 84 100]

[Input2]
Name='grid'
Range=[0 100]
NumMFs=4
MF1='off':'trimf',[0 15 30]
MF2='low':'trimf',[28 39 50]
MF3='medium':'trimf',[48 59 70]
MF4='high':'trimf',[68 84 100]
```

```
[Input3]
Name='battery'
Range=[0 100]
NumMFs=4
MF1='off':'trimf',[0 15 30]
MF2='high':'trimf',[68 84 100]
MF3='low':'trimf',[28 39 50]
MF4='medium':'trimf',[48 59 70]

[Input4]
Name='generator'
Range=[0 100]
NumMFs=4
MF1='off':'trimf',[0 15 30]
MF2='medium':'trimf',[48 59 70]
MF3='high':'trimf',[68 84 100]
MF4='low':'trimf',[28 39 50]

[Output1]
Name='5-amps'
Range=[0 100]
NumMFs=2
MF1='off':'trimf',[0 25 50]
MF2='on':'trimf',[48 76 100]

[Output2]
Name='13amps'
Range=[0 100]
NumMFs=2
MF1='off':'trimf',[0 25 50]
MF2='on':'trimf',[48 76 100]
```

```
[Output3]
Name='15_amps'
Range=[0 100]
NumMFs=2
MF1='off':'trimf',[0 25 50]
MF2='on':'trimf',[48 76 100]

[Output4]
Name='solar_state'
Range=[0 100]
NumMFs=2
MF1='idle':'trimf',[0 25 50]
MF2='active':'trimf',[48 76 100]

[Output5]
Name='grid_state'
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NumMFs=2
MF1='idle':'trimf',[0 25 50]
MF2='active':'trimf',[48 76 100]

[Output6]
Name='battery-state'
Range=[0 100]
NumMFs=2
MF1='active':'trimf',[48 76 100]
MF2='idle':'trimf',[0 25 50]

[Output7]
Name='generator-state'
Range=[0 100]
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NumMFs=2
MF1='idle':'trimf',[0 25 50]
MF2='active':'trimf',[48 76 100]

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Publication

The following are the conference papers presented during the course of this research work:

i. Abdul-Azeez Dauda, Stephen Oyewobi, Supreme Ayewoh Okoh and Umar Suleiman Dauda (2022). 'Development of Smart Electricity Distribution Algorithm for Multi-Source and Segmented Loads in Buildings' 5th European International Conference on Industrial Engineering and Operations Management Rome, Italy. Published.

ii. Abdul-Azeez Dauda, Stephen Oyewobi, Umar Suleiman Dauda and Farouq E. Shaibu (2023). 'Fuzzy Logic-Based Electrical Energy Management of Building' 4th International Engineering Conference (IEC 2023), Federal University of Technology, Minna, Niger State, Nigeria. Published.