

Optimal Designing of Micro-grid Systems with Hybrid Renewable Energy Technologies for Sustainable Environment

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Abstract- The reliance on fossil fuels and the need for effective battery management are significant challenges that renewable micro-grids seek to address. Fluctuations in supply and demand often result in higher operational costs and increased dependence on the external grid. With the urgent need to confront energy and environmental issues like global warming, transitioning to clean energy sources is becoming more viable. This study focuses on the Jetty 11kV feeder from the Abuloma 33kV injection substation in Port Harcourt, with an installed capacity of 1 x 7.5MVA. Currently, the feeder has a peak load of 3.9MW and an average load of 2.2 MW. To leverage the local abundance of water, the research aims to design a micro-grid using solar and wind energy. Using MATLAB Simulink, data from NASA meteorological sources will be simulated. The design features a 4.5MW photovoltaic (PV) array, a 2.5 MW wind energy source, and a 4 MWh battery storage unit. Despite variations in irradiance, significant improvements in power extraction were observed, with up to 4.5 MW generated by the PV array and 2.5MW by the wind turbine during peak times. The battery can be fully charged in four hours, and it was maintained at 40% capacity during low energy output periods. The State of Charge (SoC) of the battery showed dynamic behavior, enabling it to respond effectively to system imbalances and enhance microgrid resilience. A fuzzy logic controller (FLC) was used to manage charge and discharge cycles according to real-time parameters, ensuring reliable micro-grid operation even with low battery levels. The economic analysis revealed an initial cost of ₦990,251,352.19, a replacement cost of ₦414,669,375.12, a net present cost (NPC) of ₦10,813,540,000.00, and a levelized cost of electricity (COE) of ₦230.90/kWh. The low operation and maintenance (O&M) costs associated with renewable energy reduce reliance on the conventional grid and prolong infrastructure lifespan. Environmental assessments indicated a total greenhouse gas emission of 15,330,621 kg/year, significantly lower than that of conventional systems. The results confirm that the optimized hybrid renewable energy micro-grid enhances energy balance and resilience, showcasing its feasibility as a cost-effective and environmentally sustainable alternative to traditional power generation. The research aims to improve system resilience, reduce operating costs, and enhance micro-grid efficiency.

Keywords – Battery Energy Storage System (BESS), Economic and Environmental Analysis, Fuzzy Logic Controller (FLC), Hybrid Renewable Energy Micro-grid, System Resilience and Efficiency.

I. INTRODUCTION

Electrical power systems are designed to deliver consistent and reliable voltage to end users. Accurately predicting future energy demand is essential for effective planning of power generation, distribution, and infrastructure development to meet the anticipated needs of the community (Ijeoma and Odu, 2025a). Electricity can be generated in various types of power plants, including thermal, hydroelectric, and nuclear power plants. Once generated, this electricity is supplied to a transmission substation located near the generating plant. At the transmission substation, the voltage is significantly increased

using step-up transformers. This increase in voltage helps to reduce transmission losses over long distances (Ijeoma and Olisa, 2019). Due to the rapid expansion of globalization, power demand has risen considerably. This has resulted in a greater reliance on diverse energy sources, which has environmental implications, including the reduction of carbon dioxide (CO₂) emissions and related costs, highlighting the sustainability of Micro-Grids (MG) (Tanay and Nade, 2022). Renewable energy is increasingly recognized as an alternative to traditional fossil fuel-based power generation. Consequently, integration of distributed Renewable Energy (RE) generation into existing distribution networks is growing in importance.

However, despite the numerous advantages of renewable energy, its intermittent and variable nature can cause challenges within distribution circuits.

To address this, Hybrid Renewable Energy Systems (HRES), which combine two or more renewable energy sources, offer a solution by reducing intermittency, enhancing system efficiency, and ensuring a more stable energy supply. Nevertheless, these systems have received limited focus due to the complexities involved in achieving optimal planning and design. Traditional methods often lead to renewable energy configurations that are either oversized or inadequately planned (Ravita et al. 2014)

The relevance of micro-grids has increased with the growing adoption of renewable energy. These localized systems address urban energy challenges, such as erratic power supply and environmental concerns, by integrating solar, wind, and energy storage technologies. In Nigeria, for example, unreliable electricity and depleting fossil fuels underscore the need for alternative solutions (Emenuvwe et al. 2022). This research focuses on the Jetty community in Abuloma, Rivers State, with a peak load of 3.9 MW, using a micro-grid system to reduce grid dependence and lower greenhouse gas emissions.

Hybrid energy systems, which combine renewable and non-renewable energy sources, are cost-effective, durable, and environmentally friendly alternatives to traditional single-source systems (Oladigbolu et al. 2021). Optimal planning of these systems, which includes energy dispatch strategies, can significantly reduce costs, fuel consumption, and carbon emissions while meeting energy demands effectively.

The study also explores the technical, environmental, and economic feasibility of wind and solar energy integration into micro-grids in Nigeria. With abundant renewable energy resources, the country offers significant potential for micro-grid adoption. The analysis includes diverse locations to account for varying climatic conditions, highlighting the cost-effectiveness and sustainability of hybrid renewable energy systems.

Lee and Kum (2019) studied the impact of different energy dispatch strategies on HRES design optimization in remote off-grid areas. The paper recommended replacing diesel generators with hybrid systems to reduce greenhouse gas emissions and operating costs. The study compared three control strategies: dynamic programming, simple rule-based, and advanced rule-based validated by life cycle cost analysis. Results showed that dynamic programming had the lowest fuel consumption, followed by advanced and simple rule-based control strategies. Optimal control reduced life cycle costs by 5–10% compared to other strategies. However, the research did not consider the influence of renewable energy resources or the potential of real-time adaptive control strategies to improve HRES efficiency and cost-effectiveness.

Just as the continuous flow of blood is essential for human survival, a stable and reliable supply of electricity is fundamental for national development. Without electricity, no city or nation can thrive (Fubara and Ijeoma, 2019). Transformative energy practices and innovations provide a clear pathway to uplifting communities worldwide. By prioritizing localized energy systems, adopting renewable technologies, enhancing energy efficiency, and fostering inclusive policies, we can create a world where energy access is not a privilege but a fundamental right (Ijeoma, 2025c).

Sharma et al. (2022) conducted a comparative analysis of various HRES configurations based on cost of energy (COE), total net present cost (NPC), operating cost, and initial capital cost (ICC). They carried out sensitivity analyses to examine the impact of changes in input variables on cost patterns. Their study proposed an HRES configuration utilizing solar, wind, and biomass energy sources with pumped hydro storage to meet the electricity needs of an unelectrified rural village in the Chamarajanagar district of Karnataka, India. Despite its merits, the research failed to address the impacts of seasonal and daily variations in renewable energy availability, which could influence the system's overall performance and reliability.

Agajie et al. (2023) investigated hybrid renewable energy power systems, focusing on energy sustainability, reliability, techno-economic feasibility, and environmental friendliness in both grid-connected and standalone applications. They emphasized the importance of optimal sizing for HRES to ensure clean, cost-effective, and reliable energy systems. The paper outlined best practices for sizing HRES components, considering goal functions, design constraints, and optimization methods, and reviewed state-of-the-art tools and algorithms. The authors also discussed issues related to scaling HRES and identified trends in planning methodologies. However, while the paper highlighted key aspects of HRES design, it did not delve into the real-world challenges of implementing advanced optimization techniques in diverse geographic and socio-economic contexts.

Janardhan et al., (2020) noted that as a traditional technique or system, energy management system remains a key part of the general information communication system, and stressed that constant deregulation environment is having a serious impact on information communication system. The ability of some current systems to map a market participant's internal processes and market rules adequately is a challenge. Therefore, the authors stressed that energy management system remains a useful platform that can be used to define BMS (business management system).

WeiQi et al. (2022) conducted a thorough and exhaustive review of integrated energy system models, focusing on optimization methods, modeling tools, and related methodologies. They began by utilizing CiteSpace to analyze the collaboration and

co-occurrence networks of relevant articles published over the past two decades. A total of 243 works, primarily centered on integrated energy systems, were meticulously reviewed, forming the foundation for a systematic analysis and integration of related studies. Based on this analysis, the authors summarized various global definitions of integrated energy systems and identified twelve key research areas within the field.

They proposed a novel classification for integrated energy system modeling approaches and provided a comprehensive examination of operation optimization methods. In particular, they explored three main optimization problems: Optimal Power Flow, Economic Dispatch, and Unit Commitment. Furthermore, the review discussed twenty-two different energy modeling tools at national, regional, and user levels. The paper concluded by outlining seven advantages and three challenges associated with the integration of energy systems.

Hybrid Renewable Energy Technologies (HRET)

A Hybrid Renewable Energy System (HRES) integrates two or more renewable energy sources, such as wind turbines and solar photovoltaic (PV) systems, to optimize system efficiency and ensure a stable energy supply (Roy, 2022).

There are several types of hybrid systems, including Wind-Diesel, Wind-Photovoltaic, and Photovoltaic-Diesel systems. Among these, the Wind-Photovoltaic hybrid system is ideal for locations where wind and solar resources complement each other. Typically, stronger wind conditions correspond with reduced solar radiation and vice versa. This complementary nature is also evident across seasonal cycles. When strategically sited, carefully designed, and paired with energy storage, this hybrid setup can achieve high efficiency and stability (Lazarov, 2005).

In a PV-Diesel hybrid system, solar energy is combined with a diesel generator to ensure reliable power supply. Energy generated by PV panels is prioritized to meet load demands and is stored in a battery bank. If the battery discharges to its minimum allowable level, the diesel generator acts as a backup source. A simulation program manages this system by comparing the load demand with the energy generated by the PV system at hourly intervals. Based on this analysis, the system decides whether to charge the battery, discharge it, or activate the diesel generator to maintain a seamless energy supply.

Power Conditioning Units (Pcu)

Photovoltaic and fuel cells used in this hybrid power system generate DC voltage, hence power conditioning units (PCU) are required to convert it to usable AC voltage or to another required level of DC voltage. The following section will discuss the various power conversion components use for hybrid power systems:

DC – DC Converters

The voltage outputs of renewable energy sources can vary over time and, even when stable, may not meet the specific requirements of the system they power. To ensure a steady and reliable energy supply, DC-DC converters are employed to adjust the voltage levels, either increasing or decreasing them as needed. Power Conditioning Units (PCUs) typically use two types of DC-DC converters: Boost Converters for stepping up voltage and Buck Converters for stepping it down.

Boost Converters: These converters as the name implies are used to boost the Dc voltage to a required level. Boost Converters: As the name suggests, these converters are used to increase DC voltage to a desired level. Their operation is based on the inductor's ability to resist changes in current by storing energy in a magnetic field. When the switch (S) is turned 'ON,' the diode (D) is reverse-biased, and the inductor current (I_L) increases. When the switch is turned 'OFF,' the diode becomes forward-biased, allowing the inductor current (I_L) to flow through the load (R). The circuit diagram of a boost converter is shown in fig 2.4 below.

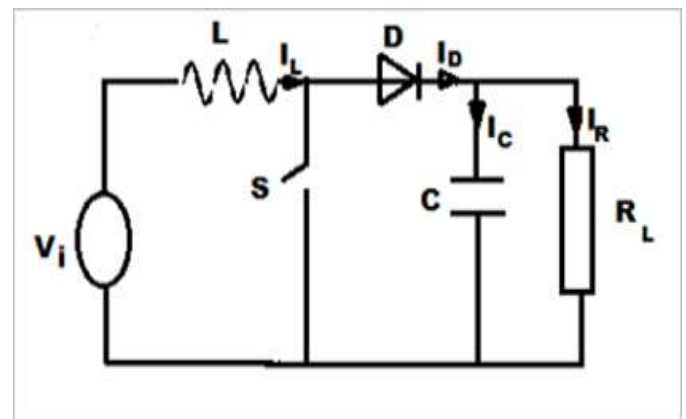


Figure 1: DC-DC Boost Converter (Mebarki et al., 2016)

Buck Converter: A buck converter is a step-down DC/DC switching converter. It typically consists of a switch (S), a diode (D), and two energy storage components: an inductor (L) and a capacitor (C), as depicted below.

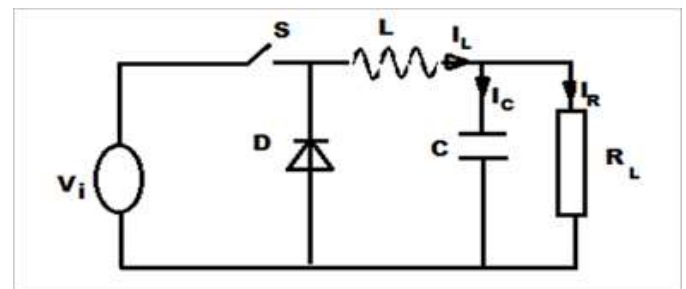


Figure 2: Schematic diagram of DC-DC Buck Converter (Mebarki et al., 2016)

If the switch and diode are assumed to have no voltage drops and the inductor is considered ideal, Kirchhoff's laws can be used to establish the relationship between the input voltage (V_i) and the output voltage (V_0). During continuous mode operation, when the switch is turned "OFF," the diode becomes forward biased, enabling the inductor to release its stored energy through the load. On the other hand, when the switch is turned "ON," the diode is reversed biased, preventing any current from passing through it.

DC – AC Inverters

An inverter is used in the hybrid system to convert the system output power which is in the DC into AC power output to feed AC consumer loads. For instance, a power inverter can be connected to a 12Vdc Lead-Acid battery to produce 240V at a frequency of 50Hz. Figure 3 below shows a typical AC/DC inverter, consisting of two pairs of semiconductor switches S_1 – S_3 and S_2 – S_4 operated alternately with their duty cycle for each switching period and an inductor L connected to the load.

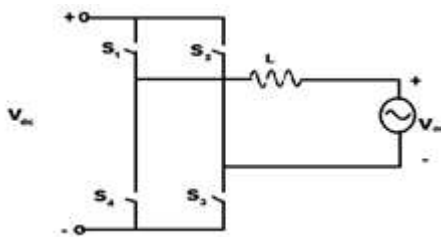


Figure 3: Block diagram of a DC-AC Power Converter (Mebarki et al., 2016)

The study involves the assessment, design, optimization, and analysis of integrating Hybrid Renewable Energy systems (HRES) into Jetty Community.

Jetty 11kV feeder is an urban feeder which radiates from the Abuloma 33kV injection substation. The feeder has an installed capacity of 1X7.5MVA. The Jetty 11kV feeder has a peak load of 3.9MW and average load of 2.2MW. Jetty 11kVfeeder has a population size of over Eighteen thousand, One hundred and Fourteen (18,114) persons. This region has a commercial grouping from the Disco in the following categories; Maximum Demand, Non-Maximum Demand Postpaid and Non-Maximum Demand Prepaid with population of 9,372 and 8733 respectively.

Jetty 11kV feeder has Revenue Per Unit (RPU) dwindling between ₦11 to ₦12.19 on its post-paid customers and a whopping ₦43.20 on Maximum demand customers which implies that for every unit of energy received by the feeder, this much is lost to Commercial, technical, Collection hence profit is not made. Following the data received from the PHED control centre, Jetty 11kV feeder has an average availability of supply of 360 hours a month and an average of 6-7hours a day.

Considering the grid limitation, it has been imminent to incorporate renewable energy sources into the network.

For a community that houses companies such as NESTOIL on a 95hectare, if assurance of supply is given using the HRETs, the business is commercially viable. The feeder has been modelled using PSS Sincal software and also a power flow and voltage profile analysis carried out.

Table 1: Monthly Load Profile (MW) for Jetty 11kV feeder from 2019-2024

Mont h	2019	2020	2021	2022	2023	2024	2025
Jan	3.4	3.4	3.2	3.5	3.2	3.6	3.6
Feb	3.5	3.5	3.2	3.1	3.1	3.6	3.6
Mar	3.6	3.6	3.4	3.7	3.3	4.8	3.5
Apr	3.1	3.1	3.2	3.0	3.4	3.9	3.3
May	3.9	3.9	2.6	3.3	4.3	3.5	3.5
Jun	3.2	3.2	2.7	3.0	3.2	3.3	
Jul	3.3	3.3	2.8	2.6	2.9	3.5	
Aug	3.2	3.2	2.9	3.1	3.2	4.2	
Sep	3.5	3.5	2.6	3.7	3.1	3.8	
Oct	3.6	3.6	2.9	4.1	3.4	3.5	
Nov	3.4	3.4	2.9	2.8	3.3	3.6	
Dec	3.2	3.2	3.0	3.1	3.2	4.2	

The design of wind and solar power renewable sources holds significant importance for several reasons. The highest level of efficiency must be planned and designed into solar and wind power systems in order to promote environmental sustainability, energy security, and economic development. By limiting greenhouse gas emissions and conserving natural resources, these renewable energy sources improve the environment and reduce air pollution and climate change. Enhancing national energy security, diversifying energy sources, and reducing dependency on imported fossil fuels are further benefits of integrating solar and wind power into the energy mix. Using locally produced renewable energy ensures a steady supply of energy for both urban and rural areas, thereby mitigating a region's vulnerability to fluctuations in the global energy market.

Benefits from an economic and technological standpoint are also important factors in the significance of this research. Opportunities in production, installation, maintenance, and research are some of the ways that the renewable energy industry promotes economic growth and job creation. Grid resilience and reliability are increased by technological developments in energy systems, such as enhanced energy storage, smart grid technologies, and grid management.

Furthermore, the adoption of renewable energy can be accelerated by well-informed policymaking and sustainable urban planning, which will support international objectives for climate action and sustainable development. In order to ensure that underprivileged populations have equitable access to energy in the future and that cleaner, more sustainable energy sources are available; this research intends to offer insightful information to communities, urban planners, and policymakers.

II. MATERIALS AND METHOD

Materials Used

- Solar Photovoltaic Generator of 4.5MW capacity
- Wind Energy Converter of 2.5MW capacity
- New Energy box type substation.
- ESS boost unit of 1.5MW capacity.
- DC/AC Converter of 5MW capacity (Inverter)
- Step-up transformer (600V/11KV)
- Battery Storage of 4MWh capacity
- MATLAB/SIMULINK software

System Components

- **Wind Turbines (WT):** Convert wind energy into electrical power. The power output is variable and depends on wind speed.
- **Solar Photovoltaic (PV) Panels:** Convert sunlight into electrical power. The power output is variable and depends on solar irradiance.
- **New Energy box type substation:** Integrates electrical components into a compact, factory-assembled steel enclosure to provide power distribution for modern applications like wind and solar farms, offering a prefabricated, space-saving, and secure alternative to traditional substations.
- **ESS boost unit (Energy Storage System):** An ESS allows for storage of electricity generated from renewable sources, such as solar panels, for use during peak hours or power outages. This promotes energy independence, reduces reliance on the grid, and can lower energy costs.
- **Battery Storage:** Stores excess energy from WT and PV and provides power during periods of low renewable generation.
- **Grid Connection:** Acts as an additional source of power when renewable generation is insufficient. Can absorb excess power generated by wind turbine system and solar photovoltaic generator.
- **Step up transformer:** Renewable sources like solar PV and wind turbines generate electricity at relatively low voltages (e.g., a few hundred volts). The step-up transformer increases this voltage (e.g., to 11 kV, 33 kV, or higher) so it can be transmitted efficiently over long distances with minimal power loss.

- **Load:** Represents the energy demand of the microgrid consumers.
- The solar PV and wind turbine (WT) system are designed to meet the load demand while simultaneously charging the battery during periods of surplus generation. Any excess power generated by the PV and WT system, after satisfying the load demand and charging the battery, will be exported to the grid.

Method Used

The fuzzy logic control strategy was used to manage and optimize the energy flow between different energy sources in the micro-grid to ensure a reliable power supply to the load and minimize reliance on the grid based on an established fuzzy logic rule.

Fuzzy logic controller was used for this study because of its adaptability in handling dynamic changes in wind speed, solar irradiance, and load demand. Secondly, its robustness to effectively manage the inherent uncertainties and nonlinearities of the system and lastly its simplicity to implement without requiring precise mathematical modeling.

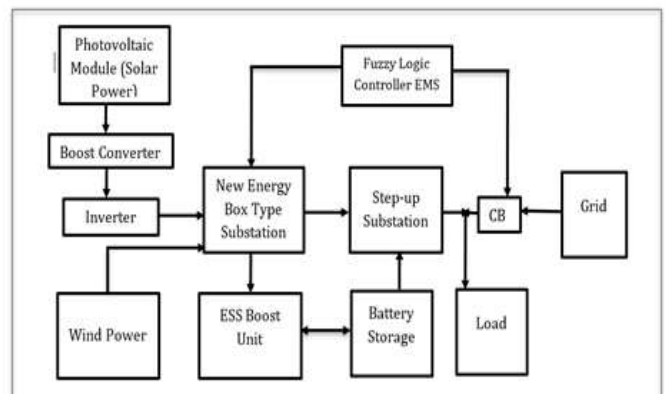


Figure 4: Block diagram of proposed optimized Hybrid Renewable Energy System

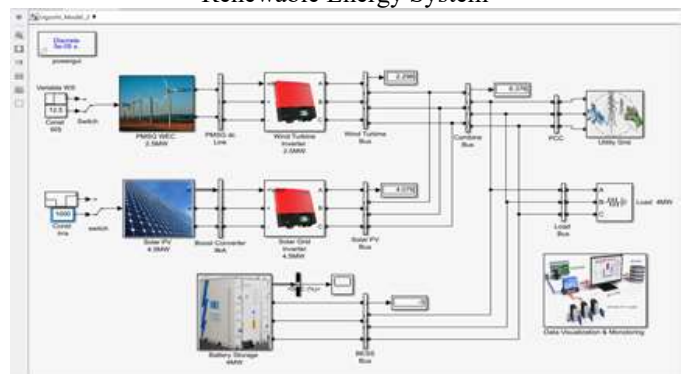


Figure 5: MATLAB Simulink diagram of proposed Hybrid Renewable Energy System

Photovoltaic System Modeling (Vinod, 2018)

The PV module consist of a semiconductor which convert light into electricity. The Conversion process is based on photovoltaic effect.

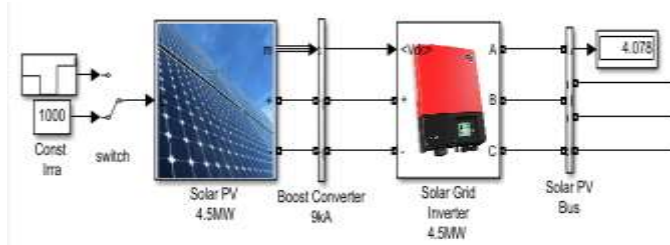


Figure 6: Photovoltaic System Modeling

The photo-current (I_L) given by

$$I_L = [I_{SC} + K_i(T - T_r)]G \quad (1)$$

Where;

I_{SC} short circuit current (A)

K_i : short circuit current at a 25°C and 1kW/m2,

T: operating temperature(K)

T_r : reference temperature =298.15K

G: solar irradiation in kW/m2

Module Reverse Saturation Current (I_{rs}) is given by

$$I_{rs} = \frac{I_{SC}}{\exp\left(\frac{qV_{oc}}{N_s k n T}\right)} - 1 \quad (2)$$

Where;

I_{rs} : reverse saturation current

q: electron charge, = 1.6×10^{-19} C

V_{oc} : open circuit voltage (V)

N_s : number of cells connected in series;

n: the ideality factor of the diode

k: Boltzmann's constant, = 1.3805×10^{-23} J/K.

Module Saturation Current (I_O) given by

$$I_O = I_{rs} \left(\frac{T}{T_r}\right)^3 \exp\left[\frac{qV_G}{Kn} \left(\frac{1}{T} - \frac{1}{T_r}\right)\right] \quad (3)$$

Where;

I_{rs} : reverse saturation current

T: operating temperature(K)

T_r : reference temperature =298.15K

Q: electron charge ($1.60217646 \times 10^{-19}$ C)

K: Boltzmann constant ($1.3806503 \times 10^{-23}$ J/K)

n: the ideality factor of the diode

V_G : band gap energy of the semiconductor

Diode Current (I_d) given by

$$I_d = I_O \left[\exp\left(\frac{qV_d}{KnT}\right) - 1 \right] \quad (4)$$

Where;

I_O : dark saturation current dependent on the cell temperature

q: electron charge ($1.60217646 \times 10^{-19}$ C)

K: Boltzmann constant ($1.3806503 \times 10^{-23}$ J/K)

n: cell idealizing factor

V_d : diode voltage

T: operating temperature (K)

Shunt current (I_{sh}) is given by

$$I_{sh} = \frac{\frac{V \cdot N_p}{N_s} + I \cdot R_s}{R_{sh}} \quad (5)$$

Where;

N_s : No of modules in series

N_p : No of modules in parallel

I: generated current

The Current Output of PV Module is given by

$$I = I_{ph} - I_d - I_{sh} \quad (6)$$

$$I = I_{ph} - I_O \left[\exp\left(\frac{qV_d}{KnT}\right) - 1 \right] - \frac{V_d}{R_{sh}} \quad (7)$$

$$I = I_{ph} - I_O \left[\exp\left(\frac{qV_d}{KnT}\right) - 1 \right] - \frac{V_d}{R_{sh}} \quad (8)$$

Where;

I_{ph} : light generated current

I_O : dark saturation current dependent on the cell temperature

q: electron charge ($1.60217646 \times 10^{-19}$ C)

K: Boltzmann constant ($1.3806503 \times 10^{-23}$ J/K)

n: cell idealizing factor

V_d : diode voltage,

V_t : diode thermal voltage (V)

N_s : No of modules in series

N_p : No of modules in parallel

R_s : Series Resistance

T: operating temperature (K)

Photovoltaic Panel sizing

Target system capacity = 4.5 MW = 4,500,000 W

Choice Solar Panel and rating used; Sunpreme Inc. SNPM-GxB-500

Total power per module/panel= 499.38W approximately 500W

To derive number of Panels Needed;

Total Panels = (Modules per String) $\times$ (Number of Strings) = $11 \times 834 = 9,174$ modules

Panel Arrangement (Strings and Arrays);

Solar panels are typically arranged in series and parallel:

Series: This is the connection of panels end-to-end to form a string resulting in $\rightarrow$ increased voltage.

Parallel: This is the connection of panels in strings connected together resulting in $\rightarrow$ increased current.

We need to match the string voltage with the inverter input.

Following design simulation:

Panel Voc (Open Circuit Voltage): 72.9 V

Panel Vmp (Voltage at max power): 57.4 V

Inverter input voltage range: 600–1,000 V

Designing the Panels per String;

To stay within 631.4 V (maximum power point):

$$\text{Panels per string} = \frac{631.4V}{57.4V} = \text{panels.}$$

Hence, 11 panels per string.

Total number of Strings used;

$$\text{Number of strings} = \frac{9174 \text{ panels}}{11 \text{ panels/string}} = 834 \text{ strings.}$$

Therefore,

Total Panels: 9174 (rounded to a whole number for balance)

Panels per String: 11

Number of Strings: 834

System Capacity:

$$9174 \text{ panels} \times 500 \text{ W} = 4,580,000 \text{ W} = 4.58 \text{ MW}$$

Table 2: PV Array and Sizing Summary

Module	Sunpreme Inc. SNPM-GxB-500
Total panel Modules	9174
Nominal array DC power	4.58MW (DC)
MPP Voltage per string	631.4V
Total array MPP Current	7,255.8A
Maximum panel power Rating	499.38 approx. 500W
Open circuit voltage (Voc)	72.9V
Voltage at maximum power point (Vmp)	57.4V
Current at maximum power point (Imp)	8.7A
Series-connected Panels per String	11
Number of parallel Strings	834
Arrangement	11S X 834P

III. RESULTS AND DISCUSSION

Result of Historical Solar and Wind Data of Jetty Area of Abuloma Using Resource Map and On-Site Measurement.

Table 3 presents meteorological data for the Jetty Area of Abuloma Community. This data, obtained from the Resource Map and on-site measurements, details solar irradiance and wind speed variations at different times of the day. It also showcases the total power generated by the hybrid PV array and wind turbine system under these varying conditions.

The table highlights the importance of solar and wind energy as sustainable and reliable energy sources. However, their performance is influenced by several operating environmental

conditions, including operating temperature, solar insolation, shading of the array, wind speed, turbine height and size, site location, and terrain. These factors collectively determine the energy output, efficiency, and reliability of the hybrid renewable energy system deployed at the site.

Table 3: Historical Solar and Wind Data of Jetty Area

Time of Day (ToD)	Irradiance W/m ²	Wind Speed m/s
0	0	6
0.5	0	6
1	0	5.4
1.5	0	5.1
2	0	4.5
2.5	0	4.2
3	0	3.9
3.5	0	3.6
4	0	3.3
4.5	0	3
5	10	3
5.5	50	3.6
6	150	4.5
6.5	300	6
7	400	6.9
7.5	500	7.5
8	600	8.4
8.5	700	9
9	800	9.6
9.5	850	10.2
10	900	10.5
10.5	950	11.4
11	1000	12
11.5	1000	12.6
12	950	13.5
12.5	900	12.6
13	850	12
13.5	800	11.4
14	700	10.5
14.5	600	9.6
15	500	9
15.5	400	8.4
16	300	7.5
16.5	150	6.9
17	50	6
17.5	10	5.4
18	0	4.5
18.5	0	4.2
19	0	3.9
19.5	0	3.6
20	0	3.3
20.5	0	3

21	0	3
21.5	0	3.6
22	0	3.9
22.5	0	4.5
23	0	5.4
23.5	0	6
24	0	6

Result of Maximum Power Generation from Micro grid Resources

Figure 7 shows that the total power generated from the hybrid renewable is 6.9MW during peak generation and 2MW during off peak generation. The combine solar and wind and battery storage system which compensate for period of shortfall when the load is greater than the generation energy sources can provide a stable power to Jetty area of Abuloma community while reducing carbon emission.

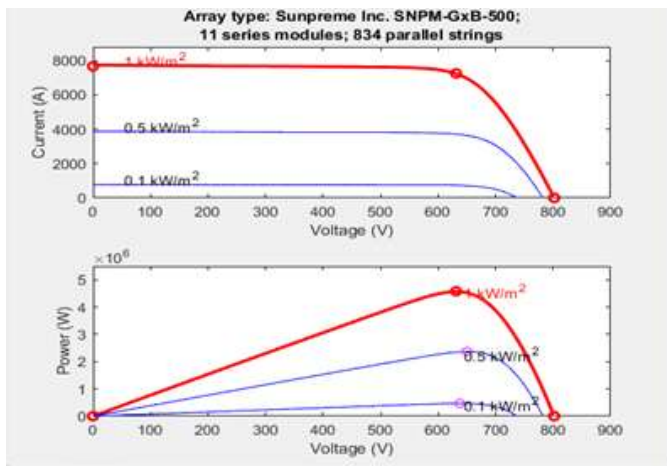


Figure 7: Scope Graphical Result Display of PV Model

IV. CONCLUSION

The study focused on the optimization, planning, and design of urban microgrids with hybrid renewable energy systems, evaluating their environmental and economic impacts while integrating them with existing infrastructure. The tools used for this research were HOMER Pro and MATLAB SIMULINK. With the rapid increase in energy demands and environmental challenges such as global warming, there is growing awareness of adopting clean energy sources as a viable solution to mitigate these crises. However, renewable energy systems rely on natural resources, and their energy generation is intermittent, depending on factors such as weather, seasons, and yearly variations.

To address these intermittencies, various technologies are deployed. The seamless integration of renewable energy sources with the utility grid is a critical aspect of future energy systems, offering numerous benefits, including voltage support,

load shifting, grid stability, and system resilience. Despite these advantages, power management remains a significant challenge in renewable power generation. The study employed an advanced optimization and energy management strategy based on a fuzzy logic algorithm to ensure the efficient operation of the hybrid system and achieve the desired outcomes.

The research successfully achieved its objectives, demonstrating the effectiveness of the proposed approach. Hence, the historical solar and wind data of Jetty area of Abuloma was collected using resource map from NASA access power viewer and on-site measurement. The maximum power obtainable from a scalable and flexible microgrid system that integrates solar, wind, battery storage and grid optimal operation in Jetty area of Abuloma was determined. An intelligent Battery management system (BMS) that monitors the generation and load to maintain battery SoC within 20-80% using fuzzy logic control strategy was designed. An advanced controller for seamless grid synchronization for providing peak demand management services was designed. Techno-economic analysis to indicate the net present cost (NPC) and compared GHG (Greenhouse gas) emission using Homer Pro to provide critical insights into the environmental impact and emissions savings associated with renewable energy integration.

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