Comparative Analysis and Optimization of PV/Wind/Diesel/Grid/Battery Hybrid System

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***Abstract*- This paper describes the Comparative Analysis of different renewable energy sources with current grid energy systems for sustainable supply. A case study of backup power for an ICT infrastructure of the Piwoyi Village located along the Abuja airport expressway, the hybrid combination is PV/wind/diesel/grid/battery system. The overall objective is to compare the most sustainable, minimum emission and cost-effective combination using Homer software. The results from the software indicated that the optimal combination Grid/PV and Grid/PV/Battery will be adopted for the ICT infrastructure. The proposed hybrid system is designed to power two suspended floors and the ground floor, each proposed to have a 20kVA inverter system. The proposed combination of a PV/wind/diesel/grid/battery storage hybrid system has been successfully simulated using HOMER software, the results were analyzed and it was found that the Grid system configuration has the least NPC of N1, 012, 000.00 and Grid/DGS/PV/Wind/Battery has the highest NPC of N110, 050, 100.00. While a combination of Grid/PV and Grid/PV/Battery emitted the least greenhouse gasses of 976kg/year of CO_2, 0kg/year of CO, 4.23kg/year of SO_2 and 2.07kg/year of NO_2.**

Keywords—renewable energy, hybrid system, photovoltaic cell, storage system, greenhouse gasses, grid system.

I. INTRODUCTON

Due to dwindling reserves of fossil fuels and commonly associated greenhouse gas emissions, the world's attention has primarily switched to the production of electricity via hybrid renewable technologies. Through exchangeable green certificates, the governments of numerous countries throughout the world have also directly nominated these renewable energy systems. This has greatly encouraged attempts to investigate renewable energy solutions, particularly in remote places where the grid connection is impractical due to the harsh terrain, insecurity, capital intensive, and small population. In light of this, many scholars have proposed various accepted software tools for the simulation and optimization of hybrid renewable energy HRE. Well-liked techno-economic instruments include HOMER, SAM, HOGA, and RET Screen. The HOMER algorithm has been hailed as the gold standard for hybrid renewable energy systems (HRES) and is one of the tools that have gained popularity for optimization and sensitivity analysis. Despite these advantages, the software has some setbacks such as its inability to show the optimization techniques adopted during the process and it does not permit the user to adjust the optimization constraints [1]. For our intention, this paper narrowed the software usage to HOMER software to achieve the proposed objectives. Despite the efforts to shift away from fossil fuels, the exploration and utilization of fossil fuels still constitute huge emissions, especially during the year 2019 fossil fuels accounted for nearly 74% of the greenhouse emissions in the USA [2]. This research is geared toward harnessing the energy potentials in solar PV, wind, diesel, grid and battery storage to form hybrid energy technologies. In this part of the world, solar energy has greater advantages due to its abundant resources. Despite all these, 42% of the global world still lives without the right to power supply mostly from Africa and 93 million of this population are Nigerians. Globally, renewable energy sources are being adopted in commercial and small-scale applications but renewable are irregular by nature and dependent on local meteorology, in order to increase system reliability, power outputs are typically synchronized by energy storage devices [3]. The paper is not only interested in generating energy for the ICT infrastructure using solar PV/wind/generator/grid/battery storage but going to compare the different configurations to determine the best combinations, in terms of cost-effectiveness, percentage of emission and energy security. Hybrid systems are gaining acceptance worldwide as decentralized, distributed power generation is identified as another pathway that increases the production and application of renewal energy sources, hybrid energy system creates or offer flexible power grids that operate autonomously, remain connected with the grids, and deliver quality power when needed at high efficiency with minimum or no emission [4].

II. STATEMENT OF PROBLEM

The exploration of fossil fuels has caused lots of greenhouse gas emissions, and other environmental degradation. The construction of conventional power generation systems, and transmission is huge capital intensive with lots of energy loss, yet many rural/urban areas are not sufficiently electrified or fully connected to the grid systems and most of the time suffer system collapse, security threats and vandalism of power infrastructure.

III. AIM AND OBJECTIVES

This research work aims to compare the PV/wind/diesel/grid/battery storage hybrid energy systems to determine the most suitable configuration for the ICT infrastructure of Piwoyi, Abuja.

The following objectives are set out to achieve the aim:

- To obtain data relevant to the study (e.g. temperature, solar irradiance, wind speed etc.).
- To analyze the data obtained from one (1).
- To investigate the cost-effectiveness of developing PV/wind/diesel/grid/batter storage hybrid systems.
- To carry out a comparative analysis of different system configurations using Homer Grid software.

IV. SIGNIFICANT OF THE RESEARCH

Due to the unreliability of the National grid, the optimization of different renewable energy technologies to generate energy is applied to guarantee energy security for the ICT infrastructure of Piwoyi, Abuja. If properly managed it will go a long way in solving challenges in the energy sector and the reduction of toxic gas emissions caused using fossil fuels. Nigerian energy sector and other parts of the world can tap into the technology to improve energy generation and storage capability.

V. SCOPE AND LIMITATION

This research work determined the optimal combination of efficient energy solutions for the ICT infrastructure of Piwoyi, Abuja to mitigate the use of an unreliable grid. The performance was simulated using Homer Grid software to identify the most suitable combination in terms of energy security and cost-effectiveness of the hybrid system.

VI. REVIEW OF RELATED LITERATURE

This chapter will discuss the fundamental concept and review related research work. The hybrid photovoltaic renewable energy system is a renewable energy system that harnesses potential energy resources in solar systems. According to M.S. Okundamiya renewable sources are irregular or intermittent by nature and dependent on a meteorological approach, in order to increase system reliability, power outputs are typically synchronized by energy storage devices, secondly, the deployment for extensive use is a serious drawback due to the requirement for large spaces. DC microgrid integrating battery storage is unable to provide long-term energy demands due to the capacity limitations of the batteries. The usage of batteries as a storage system has recently been found to be less efficient, suffer from a lack of prompt response, have greater deviations in DC voltage regulation, and be slow to maintain active power balance compared to supercapacitor storage systems [9]. Subramanian Vasantharaj listed some setbacks of microgrid system Distribution generation may be simple to interface with a DC microgrid as compared with interconnection steps of AC/DC and DC/AC transformation. AC/DC microgrid experiences sophisticated frequency problems or reactive power problems. Therefore, the integration of distributed generation in DC microgrids, DC/DC converters is crucial [10]. The author of this paper Alexandros Arsalis outlines the merits and demerits as most renewable energy sources are intermittent, and an efficient and stable energy storage system is needed. Considering the intermittent characteristics of renewable sources, the generation of electricity is difficult to use consistently and steadily, and it creates gaps in both time and space between the power that is available and the power for the chain dependent. The integration of energy storage with RES-based power generators may significantly increase the utilization rate and stability of RES-based systems to assist in addressing this problem. The expansion of RES-based power production has been linked to the possibility of decentralized, distributed power generation systems. These technologies, called microgrids, make it possible to design more compact and adaptable power grids. Microgrids can run entirely independently or even while connected to bigger central power grids, delivering power as demanded [11]. The difficulties of grid-connected microgrids can be lessened by methods like Model Predictive Control and other various communication protocols that incorporate machine learning. Research and development are on the way to create a microgrid digital that will communicate with the actual microgrid in real-time [12]. Erasmus Muh and Fouzi Tabet reported that to carry out a comparison analysis, HOMER software was employed to consider some of the renewable energies and other resources: PV modules, wind turbines, micro-hydro turbines, diesel generators, batteries, charge controllers, and inverters were considered in the microgrid system. Each system had two energy sources and a storage battery. With an energy cost of 0.443$/kWh, it was determined that the PV/diesel/small hydro/battery system was the most practical economic system for Southern Cameroons. It was found that the ideal system was particularly resilient to changes in streamflow, interest rates, fuel prices, and PV cost [13]. A case study in which a 250kW solar PV system is taken into consideration is one in which no diesel generators are in operation. However, it does not indicate a major decrease in O&M expenses. Taking this method also necessitates the addition of extra batteries, which substantially raises capital and replacement costs. Resources for producing renewable energy are widely used and growing globally. By employing a hybrid system, a large-scale organization or company can decrease costs while also being more environmentally friendly. Utilization of the resources that are close by is another result of this. Other organizations in Nepal and worldwide may use a similar hybrid energy system concept when abundant resources such as solar, biomass, solid waste, wind, etc. are available [14]. Resources for fossil fuels is in a state of depletion, at the same time the pricing is influenced by both political and economic considerations. Also, compared to conventional technologies, the cost-effectiveness of renewable energy technologies and resource reliability concerns are still barriers that prevent the rapid substitution of clean, abundant trending energies for their outdated counterparts. However, using hybrid renewable energy systems as standalone systems for remote locations, such as environmental research institutes, might be a suitable strategy to address the aforementioned shortcomings [15]. In this modern era relying on a single source of energy is a great setback for energy security, due to this, the opportunity in renewable become the trending hub for global energy production. The energy need of individual end users varies from small-scale user to industrial application where the stability of the grid system is laid on the production capacity [20]. The hybrid system combines a variety of renewable resources and sometimes their availability depends on a given condition, that's what make renewable energy source intermittent in their characteristics. Therefore, operating a hybrid system requires diligence and absolute knowledge of the system and this brings about the application of artificial intelligence, simulated annealing algorithm (ASA) particle swarm optimization (PSO) etc various techniques applied for the smooth operation and control of renewable energy [21]. Because hybrid power systems combine many energy sources, many of which are intermittent in nature, they need complex, effective, and all-encompassing control systems to function properly under a variety of circumstances. The most widely utilized methodologies and techniques for control systems include Artificial Intelligence Techniques (AIT), Simulated Annealing Algorithms (ASA), Particle Swarm Optimization (PSO), Proportional Integrals (PI), and Linear Programming (LP) [19].

Since a bigger portion of the overall power supply comes from intermittent renewable sources, power quality problems are inevitable. Systems for storing energy delivered from renewables have been developed to offer an effective, modular answer to these problems. In reality, grid-connected and stand-alone applications will continue to harness hybrid energy systems, which combine energy storage systems with renewable energy sources [20]. [21]. The conventional power system included a substantial number of generating sources whose output could be easily adjusted to fit the load demand. Additionally, due to the fact that the majority of these systems are interconnected, it is achievable to balance the load demand by utilizing electricity supplied from generators in other locations. It is extremely difficult to defend the financial benefits of adopting storage technology in such a circumstance, a lack of practical knowledge and the absence of instruments that may be used to optimize operational costs and (ii) evaluate the advantages of storage technology (taking into account market models) during the planning [22].

VII. METHODOLOGY

The research paper procedure in this study is primarily concerned with power generation, design, and comparative analysis of different system configurations to select the best option. Since the main focus of the research is a comparative analysis of a hybrid renewable energy system using a combination of solar PV/battery storage/grid, PV/Wind/battery/DGS/Grid, PV/Wind/Grid, Wing/DGS/Grid, Wind/Grid, Grid to select the most suitable and cost-effective combination of power for the ICT infrastructure of the Piwoyi, Nigeria located along airport road, Abuja.

A. Site Selection

The ICT Infrastructure in Piwoyi, Abuja was used as a case study. The proposed site is under construction and located along the Abuja airport express road with coordinates 07°54′26.82″ N, 06° 17′ 03.05°E [28]. The aim of this research work is to provide a reliable and sustained alternative power supply to the ICT infrastructure of the Institute to reduce over-dependent on the use of generators thereby maximizing profit. According to the global solar atlas, the site has sufficient annual average direct normal irradiation of 1123.1Kwh/M2 of PV electricity of solar radiation [27].

B. Data Collection

The data such as temperature, wind speed and solar irradiance were obtained from the websites of the National Aeronautics and Space Administration (NASA) and National Renewable Energy Laboratory (NREL) respectively. Data on equipment power rating, quantity, and behaviour information on electrical energy users in the ICT Infrastructure of Piwoyi, Abuja were obtained from physical energy audits of the facility and direct interviews with staff.

C. Data Analysis

Data obtained were analyzed using an Excel spreadsheet to calculate the power demand, energy demand and load profile of selected infrastructure and the values were used in calculating the sizes of system components relevant to the research such as the size of the generator, wind turbine, inverter, Solar PV Array etc. The Homer Grid was used for comparative analysis, sensitivity analysis and system optimization of different system configurations.

The energy generated by the solar cell during the daytime will be used to charge the batteries and supply power to the infrastructure. While wind turbine was used to compensate for the supply in the evening time. The estimated power and energy demand for the infrastructure are tabulated based on load type, power ratings, number of hours in operation in a day and average energy demand in Watt-hour per day. While the load profile from Homer Grid.

D. Design of PV Array

The system voltage is calculated using the formular:

$V_{idc}=(2\sqrt{2}V_{ll})/(\sqrt{3}\ ma) = (2\sqrt{2}\times 460)/(\sqrt{3}\times 0.9) = 835V$ 3.1. The selected string is 600V dc, to boost the voltage equivalent to the volt in equation 3. we need to use boost converter to boost the voltage to 835V.String voltage is about 550V. The number of the module in a string is =(V string)/(V MPP)=550/29=19. The string power is =number of module ×Power mpp=19 ×215W=4085W=4.085KW. The string voltage is =number of modules ×voltage mpp =19 ×29 =551V. The design is for three slap stages; each stage is 20Kw from the designed array. Therefore, the number of strings =(power of one array)/(power of string)=20Kw/4.085Kw=5 The number of the array for total power generation is =60kW/20kW=3

E. Design of Inverter

The work of the inverter is to convert direct current voltage (DC) to alternative current voltage, and they are rated in VA or KVA, power in VA is V x I, in KVA is V x I/1000, in watt is V x I x Power factor and in KW V x I X PF/1000. The standard nominal power factor to be used for the home is 0.8. Sizing of the 20KVA inverter we consider the load profile of the ICT Centre in stage one: ICT server switches 250 watts by 5 numbers = 1,250. Lighting points 1000watts = 1,000watts. Air conditioners 1.12Kw by 5 numbers by 12 hours = 5600 watts. Television 150 watts by 3 numbers = 450watts. All in one desktop 150 watts by 5 numbers = 750 watts. Printers and scanner 1200 watts by 3 numbers =3,600 watts. Projector 1500 watts by 1 number. The total load in stage one is 14,150 watts/pf = 14,150/0.8 = 17687.5/1000 =17.6875Kw. Total Inverter size is = total connected loads + (1 + future load)/inverter efficiency = 14150 + (1 + 0.2)/ 0.8 = 17689/1000 = 17.689KVA. Size of Inverter = 17.689KVA

Approximately 20KVA inverter is required to accommodate the loads. Future load expansion is about 20% at 80% of inverter efficiency.

F. Calculation for Battery Sizing

Battery backup time to sustain the load in an emergency is about 2 hours calculated as Battery backup time is = (battery Ampere hour × battery voltage × number of battery)/connected loads = 200 × 12 × 12/14150 = 28, 800/14150 Battery backup time = 2.04 hours. The loss factor is 20%. The battery ageing factor is 20%. Depth of Discharge DOD is 50%. Battery operating temperature is 46% at a correction factor of 1. Total battery load capacity = (total connected loads × number of batteries)/total battery voltage
= (14150watts × 12 batteries)/12volts × number of batteries
= 169,800/144= 1,179.167Ah. Battery bank sizing = {(total connected loads × 1 + loss factor) × (1 + aging factor) × (correction factor)}/ (Battery Efficiency × duty cycle) [27]
= {(4150 × (1 + 20%) × (1 + 20%) × (1)}/ (90% × 50%)= (16,980 × 1.2)/ (0.45). Battery bank size = 4506 Ampere Hour. In terms of the number of batteries = (battery bank size)/(battery ampare hour rating)=4506/200 =22.53. The total number of batteries is approximately 24 batteries per stage or floor.

G. Cost Estimate

This research work analyses different costs of various system configurations that includes net present cost, levelized cost of energy, annualized cost, return on investment etc to ease the selection of least reasonable system. The study varies the configuration of system components to get different results. The study made a comparison between eight (8) system configurations as listed below.

1. Grid
2. Grid/PV
3. Grid/Wind
4. Grid/PV/Wind
5. Grid/PV/Wind/Battery
6. Grid/PV/DGS/Wind/Battery
7. Grid/PV/Battery
8. Grid/PV/DGS/Battery
9. Grid/DGS/Wind
10. Grid/DGS/PV
11. Grid/DGS

Based on the designed parameters, various configurations of systems have been modelled using Homer Grid software.

H. Design Parameter for Wind

The formular used in designing wind system are:

ER=1/2mV^2w 3.2

Where m is the mass of the win3

Pw=ðER/ðtV^2w 3.3

And P is the wind power

Pw=1/2(ðAVw)V^2ω 3.4

And the equation for wind power become

Pω=1/2ρAV^2ω 3.5

Where ρ is the air density and the extracted mechanical power Pm is formulated as

Pm=Cp(τ,β)Pω 3.6

Pm=Cp(τ,β)1/2ρAVA²ω 3.7

Therefore the, Pm is the extraction of mechanical power

Cp(τ,β) are the performance coefficient [27]

Air density =1.20kg/m³, The equation 3.5 become

Diameter of rotor =60m, Rotor speed =25rpm, Gearbox efficiency =0.9, Turbine power 5.1kW, Blade length =20m
Wind speed= 2.4m/s, BELT LIMIT is 0.593, Diameter of rotor =50m. Where area is, A=πr²
=π×400
=1256m²
From the power equation 3.5, We have P=1/2*1.20*1256*1000 = 753,600W, A=3.14*50²/4 =1962.5m,Pw=0.5*1.20*1962*10³=1177.2kW, PR=1177*0.5938*0.9*095 =597.25kW.

I. Diesel Generator Set

The diesel generator system is mainly used as an alternative power supply when there is an outage from the mains supply to effectively meet the full load demand of the ICT Infrastructure. The price of a 100kVA Perkins generator set in Nigeria from Afri-Med Nig. Ltd is about N15, 000, 000.00, 100kVA, the generator is used to achieve the load demand and the excess would be used as a spinning reserve [13]. The fuel consumption of the generator is given as, at ¼ load is 2.6 (gal/hr), at ½ load is 4.1 (gal/hr), at ¾ load is 5.8 (gal/hr) and at full load it consumes 7.4 (gal/hr) [28]. The current price of diesel is about N789.90/litre in Nigeria [29].

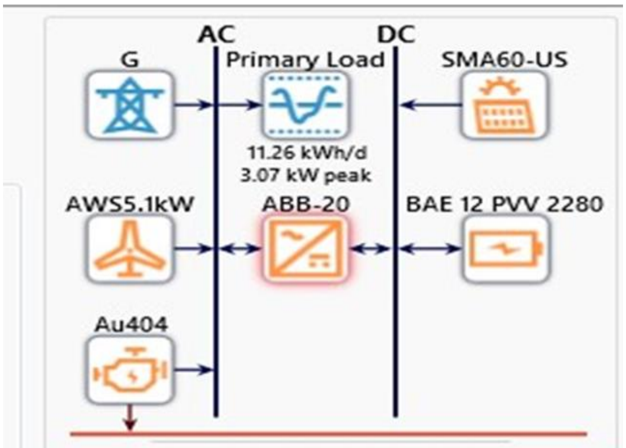

Figure3.1. Schematic Diagram of the Project Using Homer Grid Software.

J. Comparative Analysis of System Configuration

In this research, the hybrid system consists of a PV system, wind turbine, diesel generator, inverter system, battery storage and grid system as shown in Figure 1 the configuration will be compared and analyzed using the Homer Grid software..

VIII. RESULTS

The proposed integration of hybrid system configurations into the microgrid system has been developed based on the load profile of the ICT infrastructure in Piwoyi as shown in Figure 4.1.

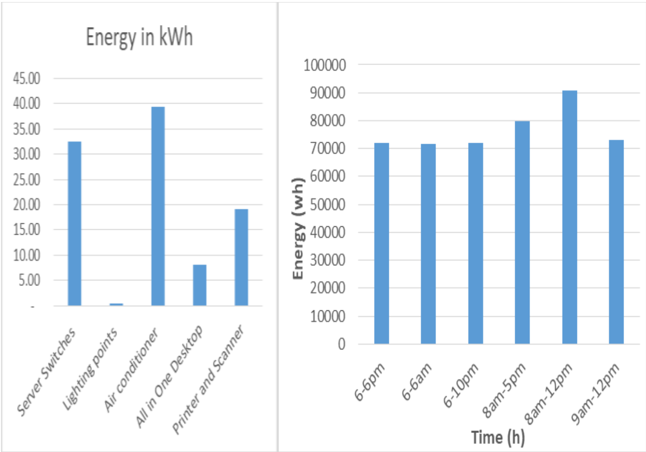

Figure 4.1 Load Profile and Energy Consumption Pattern

A. Cost Analysis

The cost analysis was carried out using Homer Grid and the result of Net Present Cost (NPC), Levelized Cost of Electricity (LCOE) and Operating Cost of different system configurations is tabulated. From the results obtained, it is determined that combination "5" has the highest Net Present Cost while combination "1" has the lowest Net Present Cost.

B. Environmental Analysis

The greenhouse gas (GHGs) emissions from different system configurations were tabulated. In this research work, CO2, CO, SO2, and NO2 were considered as greenhouse gasses that affect the environment, From the results obtained it has been determined that the grid system produces the greater toxic gases. While combination "2—6" produces zero CO and minimal CO2.

C. System Configuration

This refers to the selection of the best or most effective system configuration. In this research work, system configurations were optimized using the least reasonable cost, least greenhouse gasses emissions etc. An optimization result from Homer Grid for eleven (11) different system configurations was achieved.

D. Sensitivity Analysis

Sensitivity analysis to examine and assess the flexibility of the system optimization results by interchanging some parameters was performed. The parameters such as the capital cost of PV, temperature, wind speed, and price of diesel affect the cost of energy and the net present cost. The results were analyzed and found that Grid system configuration has the least NPC of N1, 012, 000.00 and Grid/DGS/PV/Wind/Battery has the highest NPC of N110, 050, 100.00. While a combination of Grid/PV and Grid/PV/Battery emitted the least gasses of 976kg/year of CO2, 0kg/year of CO, 4.23kg/year of SO2 and 2.07kg/year of NO2. The Homer software searches for the least cost system combination that satisfies the technical and economic constraints simulating multiple combinations.

IX. CONCLUSION

The PV/Wind/Generator/Grid/DC-AC converter/battery storage/ storage microgrid power system is designed for the ICT infrastructure application to meet the desired need of the ICT Infrastructure of Piwoyi Village, Abuja. The intermittent nature of single renewable resources and uncertainty of supply from the grid system can be overcome by using a hybrid microgrid system with synchronized battery storage technology, and the proposed hybrid microgrid system provides the needed power flow with high reliability and energy security. The integration of PV/Wind/Generator/Grid/DC-AC converter/battery storage system is modelled and has been simulated using Hybrid Optimization Multiple Electric Renewables Software (HOMER SOFTWARE) and the results obtained proved a success. The software was able to provide the Monthly and annual Average Temperature Data, Monthly Average Global Horizontal Solar Irradiance, results of the load profile obtained, and the location of the proposed project site at Km 12 Airport Road, 900109, the ICT Infrastructure of Piwoyi, Abuja, Nigeria is met with 20 kW of PV and 12 kWh of battery capacity and the operating costs. The results were analyzed and found that the Grid system configuration has the least NPC of N1, 012, 000.00 and Grid/DGS/PV/Wind/Battery has the highest NPC of N110, 050, 100.00. While a combination of Grid/PV and Grid/PV/Battery emitted the least gasses of 976kg/year of CO2, 0kg/year of CO, 4.23kg/year of SO2 and 2.07kg/year of NO2.

E. RECOMMENDATION

The research paper has been successfully modelled and demonstrated the operation of a hybrid energy system made up of a PV/Wind/DG/energy storage/DC/AC converter/ hybrid microgrid system. The fundamental concept and can be modified to incorporate additional energy sources such as fuel cell technology, biomass, micro-hydro power, tidal systems, wind turbines. The following are additional recommendations to improve the study:

a) The need for more research and development in the area of energy storage systems to replace battery storage with hydrogen technology to explore the great potential embedded in the technology

b) Though renewable energy technology is still capital intensive, hence, there is a need for a cost-effective methodology to cut down the cost of implementing the PV/Wind/DG/Grid/DC/AC Converter hybrid technology.

F. REFERENCE

1. Comparative Analysis of the Implementation of Solar PV Systems using the ECOS Model and HOMER Software: A Kenyan Scenario
2.Fact Sheet Climate, Environmental, and Health Impacts of Fossil Fuels (2021)
3.Size optimization of a hybrid photovoltaic/fuel cell grid-connected power system including hydrogen storage (www.elsevier.com)
4.Optimal Hybrid Renewable Energy System: A Comparative Study of Wind/Hydrogen/Fuel-Cell and Wind/Battery Storage
5.Modelling and Simulation of a Photovoltaic Fuel Cell Hybrid System
6.Wind Energy Conversion System- Wind Turbine modelling https://ieeexplore.ieee.org/abstract/document

7.Comparative analysis of different hybrid energy system for sustainable power supply: A case study doi:10.1088/1755-1315/463/1/012045
8.Battery energy storage technology for power systems—An overview http://www.elsevier.com/locate/epsr doi:10.1016/j.epsr.2008.09.017
9.Size optimization of a hybrid photovoltaic/fuel cell grid-connected power system including hydrogen storage (www.elsevier.com)
10.Efficient Control of DC Microgrid with Hybrid PV—Fuel Cell and Energy Storage Systems https://www.mdpi.com/journal/energies
11.Recent Research Progress in Hybrid Photovoltaic–Regenerative Hydrogen Fuel Cell Microgrid Systems
12.A review of modeling and simulation tools for microgrids based on solar photovoltaics
13.Comparative analysis of hybrid renewable energy systems for off-grid applications in Southern Cameroons
14.Comparative analysis of different hybrid energy systems for sustainable power supply
15.Economic sizing of a hybrid (PV FC) renewable energy system(HRES) for stand-alone usages by an optimization-simulation model: Case study of Iran www.elsevier.com/locate/rser
16.Special Issue "Membranes in Fuel Cell and Electrolyzer Applications https://www.mdpi.com/about/journals
17.USE OF FUEL CELLS AND ELECTROLYZERS IN SPACE APPLICATIONS: FROM https://www.e3s-conferences.org/articles
18.A review on bi-source, off-grid hybrid power generation systems based on alternative http://dx.doi.org/10.1063/1.4929703
19.Hybrid power systems – Sizes, efficiencies, and economics https://doi.org/10.1177/0144598720965022
20.An evaluation of the spectral characteristics of switching converters with chaotic carrier-frequency modulation (https://www.researchgate.net/publication)
21.Electrical note and article - Calculate Size of Inverter & Battery Bank https://electricalnotes.wordpress.com
22.A. Comprehensive Review on Fuel Cell Technology for Stationary Applications as Sustainable and Efficient Poly-Generation Energy Systems https://www.mdpi.com/
B. Battery energy storage technology for power systems—An overview
23.Design and analysis of solar PV-fuel cell and wind energy-based microgrid system for power quality improvement https://www.researchgate.net/publication
24.Comparative study of different fuel cell technologies (https://www.academia.edu)
25.Comprehensive Review on Fuel Cell Technology for Stationary Applications as Sustainable and Efficient Poly-Generation Energy Systems https://www.mdpi.com
26.Calculate Size of Inverter & Battery Bank
27.Global solar alas report September 10, 2022 https://globalsolaratlas.info/map
28.Battery energy storage technology for power systems—An overview
29.Integrated technical analysis of wind speed data for wind energy potential assessment in parts of southern and central Nigeria https://doi.org/10.1016/j.clet.2021.100049
30. https://www.ftexploring.com/energy/wind-enrgy.html
31.https://www.researchgate.net/figure/Wind-and-Solar-Resource-for-Abuja-Nigeria
32.Adaptive terminal sliding mode power control of DFIG based wind energy conversion system for stability enhancement DOI: 10.1002/etep.2105
33.modelling and design of a hybrid solar and fuel cell stand alone power system for a remote area engineering project b https://www.researchgate.net/publication
34.https://www.generatorsource.com/Diesel_Fuel_Consumption.aspx
35.https://www.globalpetrolprices.com/Nigeria/diesel_prices/