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Feasibility Study on Renewable Energy-Based Micro Grid Power Generation System in Rural Areas of Yobe State Nigeria.

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Abstract: *This study aims to investigate the possibility of supplying electricity from a renewable energy-supplemented hybrid system to Geidam. One of the major rural centers in Yobe state. The town despite having a population of more than 157 thousand people (according to 2006 census), is yet to enjoy its own quota of the national electricity grid due to remoteness and distance from the generating stations available in the country and the environmental condition of the area doesn't allow poles to stay long, this makes transmission to these areas uneconomical. Because of the great need to reduce the cost of erecting poles every year and the fact that there is abundance of renewable energy sources such as sun light, wind, and animal waste, a feasibility study of the area in question was carried out on how to design a micro grid system that will act to supplement the existing national grid in the study area. In the study the load demand of the area was sampled into residential and commercial loads. The electric load consists of only the primary type considering the present electricity consumption in the area. The design was carried out using HOMER software.*

Keywords:*Electricity grid, Feasibility study, Renewable energy, Rural center, Supplemented hybrid,*

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I. Introduction

Major part of energy utilized today in modern society is handled in the form of electrical energy. It was said by Brink worth (1972) that the process of economic growth, which ultimately results in the improvement of the living standards of the society is traceable to, and depends, to a large extent, on the substitution of machine power for muscle power for fast and efficient performance of every type of physical task**.**

Over the years Geidam town and its environs have been facing a lot of problems with regards to electric power supply, their connection to the national grid has always proved to be unreliable due to distance from the transmission stations, the soil nature (loose soil) and wind storm that causes poles not to stay long. The cost of transmission and maintenance every year make the supply to Geidam community unaffordable to both government and the distribution companies (DISCOs).

The inefficient use of the transmission network has already led to a situation in which the power supply to those areas is no longer feasible resulting in a higher probability of voltage instability or collapse. IEEE defines voltage collapse as: the process by which voltage instability leads to loss of voltage in significant part of the power system[1]. In order to prevent a voltage collapse, there is a desperate need to identify the methods which can be used to supplement the existing system.

Moreover the cost of running diesel generators on which many businesses rely is also high. This make business in Geidam (which is one of the three major market centers in Yobe State) unprofitable. The domestic/residential consumers can no longer afford to run generators every day, this keeps them in a total blackout over the years.

The studies conducted byAdekunle Ayodotun Osinowo etal[2], Abdulsalam D**.**[3] Medugu D. W,& Adewole D[4] and other scholars, like the work of [5- 14],has revealed the scholarly awareness of the high prospect of solar energy availability in Geidam area which is in the Sahel savannah of the north eastern Nigeria. Renewable energy technologies, (solar energy in particular), are favorable alternatives by reason of availability and abundance. (Sunshine Duration and solar radiation). The available RE sources that can provide electricity in the area are wind, solar sources and animal waste.

There are many published literatures on hybrid micro-power systems (HMPS) study by researchers in different parts of the world. The viability of the hybrid system depends on the quality of RE resources and the climate, economic and regulatory conditions at the location / country in question[15]. These HMPS designs are carried out based on the research objectives. There are category of researchers that look at the design aspects of the systems under study and focus on theknowledge contribution without giving much attention to the study area. Such studies include the works of Hafez and Bhattacharya[16],Bagen and Roy Billinton's work[17], and[18] to name only a few. Another category of researchers are those that focus on the techno-economic viability and/or the practical aspect of the hybrid systems in a given situation, especially in areas where grids are not available such as rural areas or island electrification [19-21]. And also there are category of researchers whose focus is on specific site applications such as a university campus, hotels and resorts or any other building that might require some considerable amount of electricity[22-24]. A sub group of the second category mentioned above are researchers that look at the uniqueness of a specific area considering the economic condition such as the work of abdirahman etal[15].

In this work also the second category was choosing but its uniqueness, however, is the fact that it considers economic conditions, population density and load demand of the study area and tries to integrate the excess generated power to the grid to serve the neighbouring towns. A hybrid RE-based (PV/Wind) microgrid system for an urban residential and commercial loads was proposed and a techno-economic feasibility assessment was performed, the capital investment related to the installation of the project was obtained as well as proposed electrical tariff and storage system.

II. Materials and Methods

Study Area: This study is conducted in Geidam area of Yobe State Nigeria. Geidam is located in the north eastern part of Yobe State which is in the heart of the Sahel Savannah with latitude12 degrees 37.54 minutes N and longitude of 11 degrees 58.83 minutes E. currently the area relies primarily (almost 100%) on diesel generators for electric power. Thesample size was taken to be 1000 Houses, 3 Hospitals, 1 Market, 1 Polytechnic, 1 Technical College and 2 Secondary Schools.The sample size was estimated on the basis of a single proportion design. The target population from which the samples were randomly selected was considered 100,000 houses for residential loads and the rest are considered commercial loads. A confidence interval of 10% and confidence level of 95% was assumed. The sample size actually obtained for this study was 100 houses for each group. 100 Houses were selected from each ward to make up the groups of the sample population.

Microgrid: A microgrid is a discrete energy system consisting of distributed energy sources (including demand management, storage, and generation) and loads capable of operating in parallel with, or independently from, the main power grid. The primary purpose is to ensure local, reliable, and affordable energy security for urban and rural communities, while also providing solutions for commercial, industrial, and government consumers. Benefits that extend to utilities and the community at large include lowering greenhouse gas (GHG) emissions and lowering stress on the transmission and distribution system [26].

Micro grids are just smaller versions of the normal utility power grid. Theyalso consist of power generation, distribution, and controls (such as voltage regulation and switch gears). Micro grid are different from normal electrical grids because of the close proximity between power generation and power users, this result in increased efficiency and transmission reductions. Micro grids also integrate with renewable energy sources such as solar, wind power, small hydro, geothermal, waste-to-energy, and combined heat and power (CHP) systems [15]. It is in this connection therefore that this research is aimed at designing a power supply system that will supplement the existing power supply in the study area where total blackout is mostly the order of the day for decades.

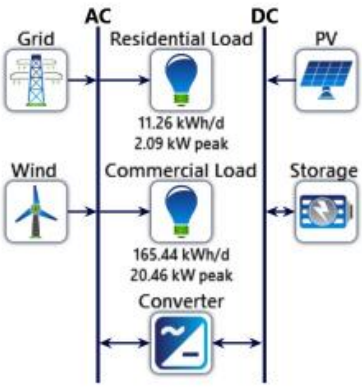

Figure 1: System Diagram

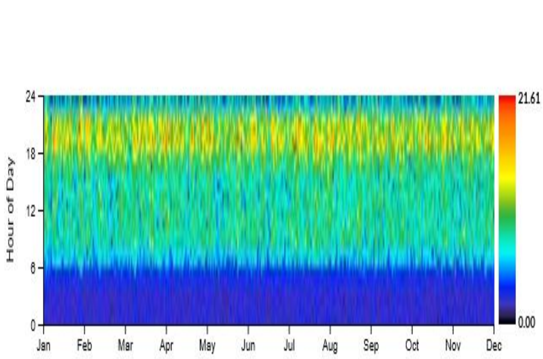

Figure 2: Heat Map, showing Energy Consumption Patterns

Load Demand: One of the most important steps in this type of studies is proposing a realistic model of the electrical load [5]. In this study, the loads were divided into residential and commercial, where a typical urban house load requirements are considered residential and market, schools and hospital loads requirements are considered commercial as. The most important uses of electricity in this house are mostly lighting, entertainment, cooking and refrigeration. In addition to these major usages, there are also other possible usages for electricity in an urban environment such as the use of electric washing machines, irons, and other electronic stuff. Even though most homes in Geidam uses charcoal as their main source of energy for cooking purposes due to lack of stable electricity but the study assumes future inclusion of because cooking appliances as part of residential load.

However, the second load category which was termed the commercial loads includes workshops and laboratory equipment in schools, hospital equipment and market usage of electricity like grinding and so on. The energy consumption pattern is shown on the heat map in fig 2.

Solar and Wind energy resources: To the best of author's knowledge there is a very limited documentation in regard to any data available about the solar and wind resources of the study area, therefore the solar and wind resource of Geidam were taken from HOMER which uses NASA satellite data at approximately this location. This include daily radiation and clearness index as well as the wind speed. The data is imported online through HOMER software in Homer's solar and wind input window. Monthly average of two solar parameters, which confirms the steady availability of solar radiation throughout the year. The annual average solar radiation for this town is 7.4 kW h/m^2/day this is then compared with the data available in some literatures about closer locations. Thus, solar radiation obtained qualifies to be a considerable alternative source for hybrid microgrid system in Geidam area.The data records obtained from the NASA Surface Meteorology and Solar Energy website assessed a 10 year averaged annual wind speed for the Geidam area to be only 6.468 m/s at the same 10 m height.

Simulation software: This study was conducted using HOMER software which is developed in the National Renewable Energy Laboratory (NREL) in the United States. Like most researchers the software was choosing because of its simplicity and ease of implementation for microgrid modeling. With HOMER software, the physical implementation of the microgrid system can be modelled, the life cycle cost including installing and operating costs can also be modelled and compared with other design options based on the technical and economic aspects. HOMER software can be used for simulation, optimization and sensitivity analysis. The software can simulates the microgrid system for long-term operation and variety of system configurations, after which the system configurations can then be subjected to an optimization process to obtain the system's most optimal configuration based on the cost and designer's decision variables. The decision variables include the size of the PV array and the number of wind turbines. Finally, the system's optimal configuration will be made to undergo a sensitivity analysis process in which multiple optimizations each with a different set of input assumption can be obtained. The purpose of the sensitivity analysis process is to know how sensitive the outputs are to the changes in the inputs. Details of how HOMER software work can be found in [15] and [28]. HOMER Grid is a tool that can help a developer or site owner outline different options for reducing a site's electricity bill. It compares the costs and savings for installing different combinations of batteries, solar panels, and generators. HOMER Grid uses a powerful optimization to find the system that will maximize your savings see fig 4. and 5. The billing system is in line with the latest standard tariff set by Nigeria electricity regulatory commission [27]

Hybrid system components: There are five major system components to be designed for the study of renewable energy-based systems as found in most literatures like[15]. These are the wind turbine, PV modules, diesel generators, power converters and battery banks. But in this study only four were considered in order to obtain a purely green energy as well as seeks to find the most optimal option of a suitable mix of these components. 8 wind turbines, each with a capacity of 30 kW In addition to as much as 100 kW of PV resources were considered during the optimization process of this simulation. Moreover, a battery system was added to the proposed model to act as a peak-solver for the times when wind and solar are not available see fig 1. In order to meet up with the AC load demand of the study area, the following system components were used;

Photovoltaic panel
Wind turbine
Converter
Storage Battery

The PV cells modelled in this study were obtained from the NREL website [22]. The PV modules capacity selected for this study is 100kw Generic flat plate PV. The generated power of the PV is dedicated to support the load and charge the batteries during low demand. The lifetime for this system is 25 years by default from NREL's data sheet. This is on the assumptions that temperature effect is negligible. On the practical site, the PV array is mostly installed with an inclination angle equal to the latitude

Wind turbines: XANT M-21 [100kW] wind turbine model selected from the HOMER Library was used for this study. The wind turbine characteristics data obtained from NASA were use as input resources into the

HOMER. Besides, the hub of this wind turbine is taken to be at a height of 20m and is estimated to serve for 25 years.

Power converter: A converter is required to convert AC to DC or DC to AC. Appropriate converters were choosing to match the capacity of power flow. An optimization sizeof range 24 kW to 48 kW in steps of 6 kW was considered in the optimization test of the converter. Conversions from AC to DC, and vice versa, are assumed to have efficiencies of 0.9 and 0.85, respectively. The converter is assumed to have a capacity of 100% relative to inverter and it can also operate simultaneously with a wind generator.

Batteries: The battery bank used in this hybrid system is the Generic 100kWh Li-Ion. The chosen battery has a 12V and 1900-Ah capacity. HOMER assumes that the properties of the battery remain constant throughout the battery's lifetime and are not affected by external factors such as temperature[25], the batteries were modelled as perfect storage devices with losses incurred only during charging and discharging [25][The round trip efficiency of the battery is modelled to have a constant efficiency of 0.8. It is noteworthy that HOMER specified the battery's minimum state of charge (SOC) of this battery type to be at 40 %.

Methods: Five possible systems were modelled and simulated by making different combinations as follows;
System Details:
System 1: Solar + Wind + REB
System 2: Solar + Wind + Storage: 100LI + REB
System 3: Solar + REB
System 4: Solar + Storage: 100LI + REB
System 5: Wind + Storage: 100LI + REB

The lowest net present cost system architecture is system1 (Solar + Wind + REB) withannual savings of ₦1,397,134,586.40 and the system capital cost is ₦409,178,596.29 with ₦34,931,049,665.23 as savingsOver the project lifetime of 25 years.IRR can be 3.4E+02% and a payback time can be 0.29 years. But this is on the assumption that the PV supply power during the day time and the wind supply mostly at night time and there is no need for storage sincethe morning load coincides with the availability of solar resource. And wind power is mostly available at night, in the evenings and early mornings. But to do so, a great deal of wind capacity is required. Therefore since the main objective of this study is to find a technically and economically feasible alternative to reduce the large dependence on diesel generators, therefore battery storage system is added to the proposed model in order for the system to have a peak-solver during the times when wind and solar not available. Therefore System 2(Solar + Wind + Storage: 100LI + REB) was found more appropriate and hence was chosen as the model for the study. See fig 1.

The analysis of costs can be very detailed, but for comparison purposes and transparency, the approach used in this study is a simplified one. This allows greater scrutiny of the underlying data and assumptions, improved transparency and confidence in the analysis, as well as facilitating the comparison of costs by technology for the same community needs in order to identify the key drivers in any differences. Additionally, to provide a technology comparison of microgrid economics, an average cost estimate is an acceptable proxy among the researchers. In-line with this assumption, neither a ‘system fixed capital cost' nor a ‘system fixed O&M cost’ was specified in the HOMER simulation. Zero penalty charges for capacity shortage were also considered.

It is worth mentioning that HOMER assumes all prices inflate at the same rate over the project lifetime. According to the user support website [29] provided by HOMER Energy, this allows to factor inflation out of the analysis by using the real interest rate, and reporting all costs in constant dollars. Therefore, in order to model the effect of prices and charges over time, a conversion to the local currency was carried out.

III. Results and Discussion

Simulation results: Due to the assumption of the close proximity between the power supply and the customer load HOMER models a lossless Scenario[25]. The two types of load modelled for this study were simulated and was found that Average Electric Energy Consumption is 165.4 kWh/day and 5,374.6 kWh/month. TheAnnual Peak Electric Demand stand at 21.61 kW see fig 3.A base case scenario of diesel-based microgrid system was simulated by HOMER and then compared with the hybrid microgrid system with PV/Wind/ sources see Fig 6.

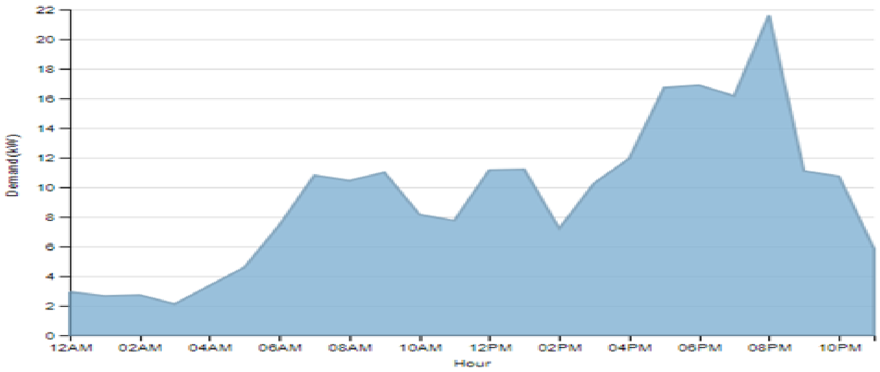

Figure 3: Load Profile for the Day on Which the Largest Demand Occurs 30/1/2018

Optimization results: The main objective of the simulation is to evaluate and compare the different models in terms of efficiency and capital cost and to predict the effect of the future price fluctuations. The optimization results of the different systems are shown in table2.

Table 2. Optimization results compared

System	Average annual energy bill savings	CAPEX	Payback time (simple/discounted):	Internal Rate of Return (IRR)	Project lifetime savings over 25 years:
1	₦1,397,267,599.01	₦409,122,438.77	0.3/0.3 years	341.39%	₦34,928,595,152.55
2	₦1,396,537,827.32	₦410,206,511.45	0.3/0.3 years	340.53%	₦34,927,459,749.00
3	₦1,211,743,073.65	₦409,189,981.73	0.3/0.4 years	296.20%	₦30,305,736,541.07
4	₦1,211,801,041.76	₦409,469,053.28N	0.3/0.4 years	295.94%	₦30,301,250,680.10
5	₦234,647,630.79	₦322,175.46	n/a	n/a	-₦16,276,695.08

Demand Charge Reduction and Calculation: A bill from an electric utility can comprised of different types of charges. The energy charge is for the quantity of energy in kilowatt-hours (kWh) used in total for a particular month. The demand charge is for the highest peak power drawn in kilowatts (kW) or megawatts (MW) for the month. Finally, the fixed charge is a charge that is the same every month and is not affected by your consumption or peak demand. January has the highest consumption/sales and the details of the month are as follows;

Fixed charges ₦4,000
Monthly Total ₦11,705,459.52
Demand Charges ₦ 25,593.19
Peak Demand 18 kW
Energy Charges, ₦13,173,159.82
Consumption 1,469 kWh
Sales 10,605 kWh
The annual total charge for one year is ₦74,279,004.27

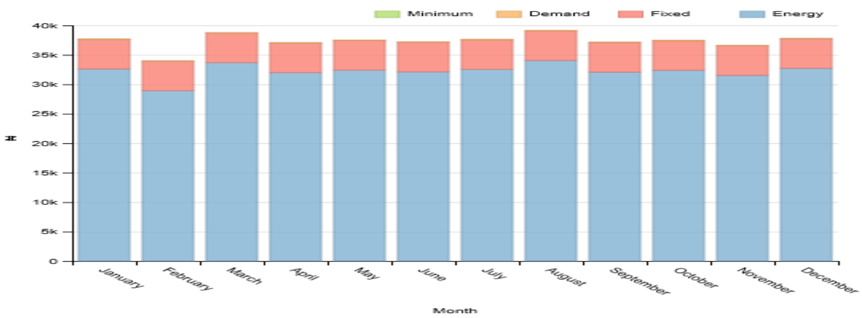

Fig 4. Monthly Electrical Bill Breakdown

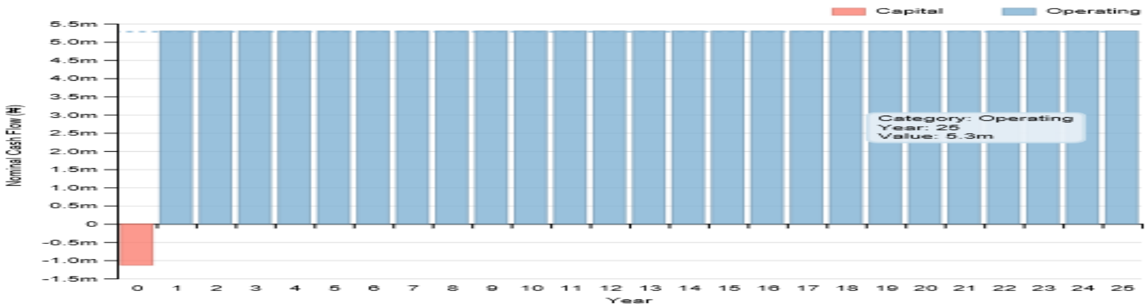

Fig 5. Cash Flow for the choosen System

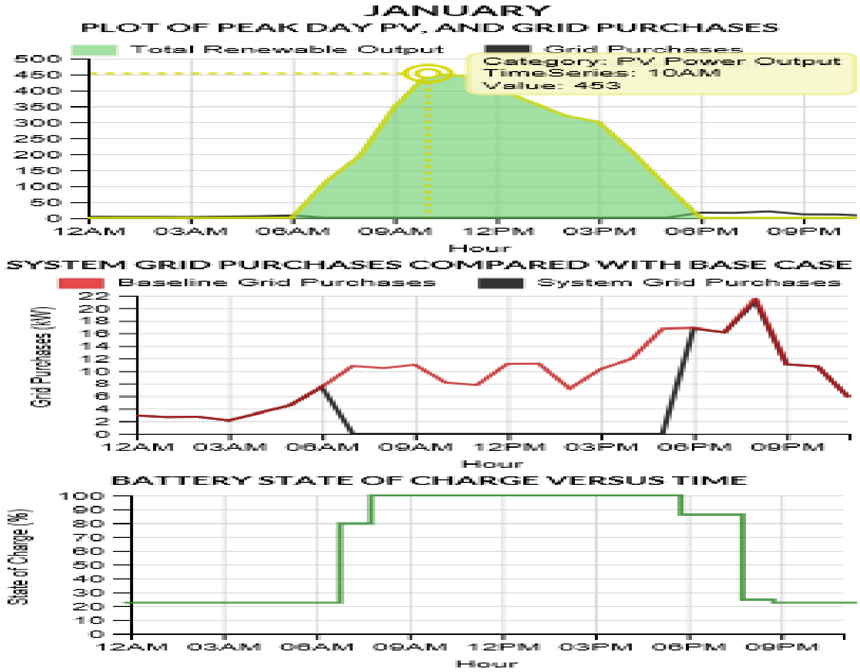

Fig 6: Performance Summary for January

IV. Conclusion

A techno-economic study of a hybrid (PV/Wind) Microgrid has been carried out using HOMER simulation software, the possibility of using RE resources for the generation of power was investigated. Optimization modeling plus sensitivity analyses were also conducted to compare technically as well as economically the benefit of either a diesel generator only power as the base case or a renewable energy based microgrid solution is best and also various combinations of RE resources were analysed and the best was chosen. The economies of power generation were analyse and the tariff system of billing was also predicted. The cost-effectiveness of the proposed system and the possibility of reducing diesel dependence for electricity generation was demonstrated. Finally, this study is expected to contribute to the knowledge of RE potentiality of the study area. And provide a scholarly contribution that could be used by the government to invest in RE based power rather than the unending spending on transmission lines each year

This model when actualized will solve the problem of power shortage in those areas and create businesses which at a long run will reduce unemployment among youths. The results of the techno-economic analysis indicate the economic prospect of achieving a 100% renewable energy (RE) power in the study area.

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