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MODELLING AND TECHNO-ECONOMIC SIZING OF A DC NANO-GRID FOR OFF-GRID NOMADIC SETTLEMENTS IN NORTH CENTRAL NIGERIA

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Abstract: *This paper focuses on providing solution for the incessant farmer/herdsmen conflict, using modern technology. It centered on electrification of nomadic settlement, with case study of three nomadic locations in North-central Nigeria, using DC-Nano grid. Research revealed that frequent clashes of herdsmen with farmers are as a failure of the herdsmen to ranch their animal in a single or confined location. However, the herdsmen are willing to ranch in one location if facilities such as irrigated ranches and sprinkler pumps are provided. Thus, this called for electrification of their settlement to improve their socio-economic way of life. Meanwhile, owing to the distance of their settlement from the national grid, it is therefore better and more economical to supply these settlements from an off-grid system. The preliminary research revealed that the load requirements of these nomadic settlements can be serviced from DC source, thus the reason for proposing a DC-Nano grid from renewable energy source. The research is carried out with sizing of the DC-Nano grid from possible options of wind and solar energy using particle swarm optimization (PSO). Results obtained shows that solar energy will be more economical to power the nomadic settlement than wind energy. In addition, with the designed load management system on the proposed renewable energy source, 50% reduction in energy consumption was achieved, while with PSO, 63.41% reduction in cost of electricity was achieved.*

Keywords: *DC-Nano grid, Renewable energy, Off-grid, Nomadic settlement, Farmer-herdsmen conflict and Techno-economic*

1. INTRODUCTION

Energy is debatably an important element in developmental processes. It has been posited that without energy, it is almost impossible to attain sustainable development. "Since access to modern energy lies at the heart of human development, it is evident that in order to meet the Sustainable Development Goals (SDGs), substantial improvements are needed in the type of energy services that the poor have access to"[1]. Therefore, Energy is surely an important aspect of socio-economic development that touches almost every sphere of human life, and an essential requirement for human development. The 2016 World Energy Outlook reported that about 1.2 billion people in the world do not have access to modern energy services. Research has also revealed that around 55% of this population is in Sub-Sahara Africa, and the vast majority of this energy-poor population resides in the rural communities, including the nomadic settlements which are located far from the grid-connected areas, [2]. This reflects in the level of infrastructural development such as educational services, water supply, healthcare, and communications system. It is un-economical to extend the existing conventional grid to the rural communities because of their remoteness [3, 4].

However, when the prospects of being connected to the national grid are low, alternative solutions energy solutions, such as the solar Nano-grids (S_{ng}), solar/wind Nano-grids (S/W_{ng}), solar/diesel Nano-grids (S/D_{ng}), solar/wind/diesel Nano-grids ($S/W/D_{ng}$) and the diesel Nano-grids (D_{ng}) need to be assessed [5, 6]. The rural areas form a part of a nation's economy due to their huge natural resources and the potential for agricultural production such as farming, fishing, livestock, including the hub for raw materials for industrial processes, [7]. Therefore, given the worth and contributions of the rural sector of the economy, the development of the rural communities and villages is expected to be central to the government of developing countries, including Nigeria.

The intent of this study is to propose a Nano-grid system template for a group of nomadic settlements in three locations of the North Central part of

Nigeria. The locations are Niger, FCT and Kwara. At the end of this study, an option between solar Nano-grid and wind Nano-grid will be suggested based on their economic advantage. In particular, this study seeks to find possible solution to the incessant herdsmen/farmer clashes through application of modern technology and also serve as a reference point for considering new electrification systems for the energy-poor nomadic settlements in the future.

1.1 Case Studies and Renewable Energy Potentials

The settlements covered by this study are the Mai-Salati village which is located on latitude 9.569352N and longitude 6.684127E of Niger State according to NASA [8], Ogojo village in Oloru district of Kwara State located on latitude 8.661324N and longitude 4.598200E according to NASA, [9] and Kata village which is located at the outskirt of Bwari in the Federal Capital Territory on coordinate 9.260458N and 7.328374E according to NASA, [10]. These settlements are area purely semi-nomadic Fulani settlement with an average of 15 hut and mud houses. The dwellers of these villages engage in farming and livestock rearing. They go on grazing during the day and then return back home in the evening. The primary source of lighting and cooking in the village are kerosene and biomass. These energy sources often pose hazards to domestic health through smoke-related illnesses and also to the environment through widespread deforestation and greenhouse gas emissions. The people also travel to a nearby community to charge their phones and rechargeable lanterns. There are no social and economic infrastructures, and the national electricity grid is yet to be extended to the village.

Wind and solar energy are two potential renewable energy sources in the areas. Though, potential vary from one region to another. The potential of wind and solar energy is summarized in the map shown in Figure 1 and 2 respectively.

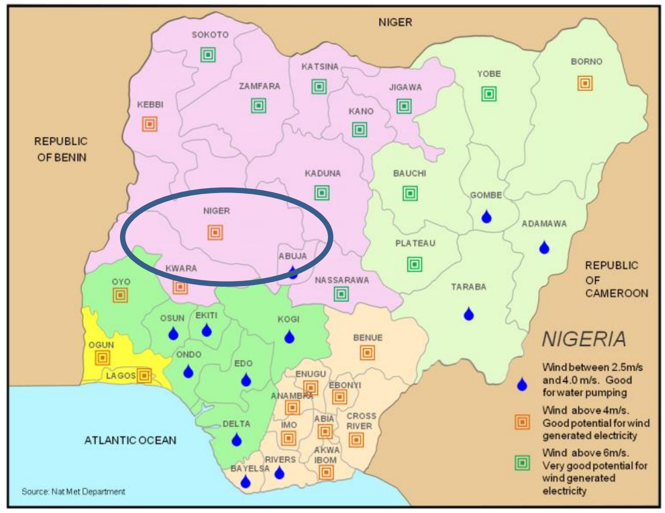

Figure 1: Wind energy potential of different location of Nigeria [11].

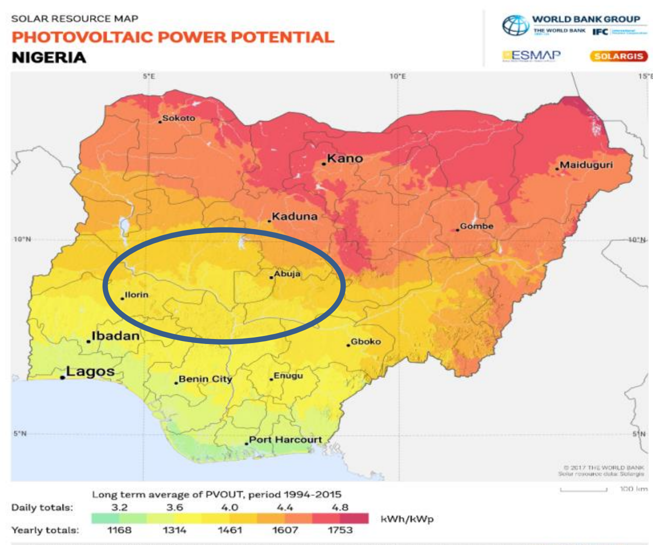

Figure 2: PV potential of the various region in Nigeria [12].

The annual photovoltaic power potential for the regions under study ranges between 1314kWh/kWp - 1607 kWh/kWp while the wind speed is between 2.5m/s - 4.0m/s.

2. METHODOLOGY

A popular member of metaheuristic algorithm known as particle swamp optimization (PSO) which is very effective and efficient in locating optimum result of an optimization problem was used to find what capacity of PV or wind Nano-grid will be sufficient to power the required load with least possible cost [13]. Another tool used was Simulink, developed by

MathsWorks, for modelling and simulation of the developed Nano-grid. The tools were utilized from MATLAB 2017a environment.
The implemented methodology in this research include detailed study of the nomadic settlement through questionnaire, study of electrical load demand of multiple nomadic settlements in the North Central states of Nigeria,, optimal sizing, techno-economic analysis of the required DC Nano-Grid System for a typical Nomadic settlement, modelling, design and simulation of the DC Nano-Grid and evaluation of the design model. The proposed system block diagram is as shown in Figure 3

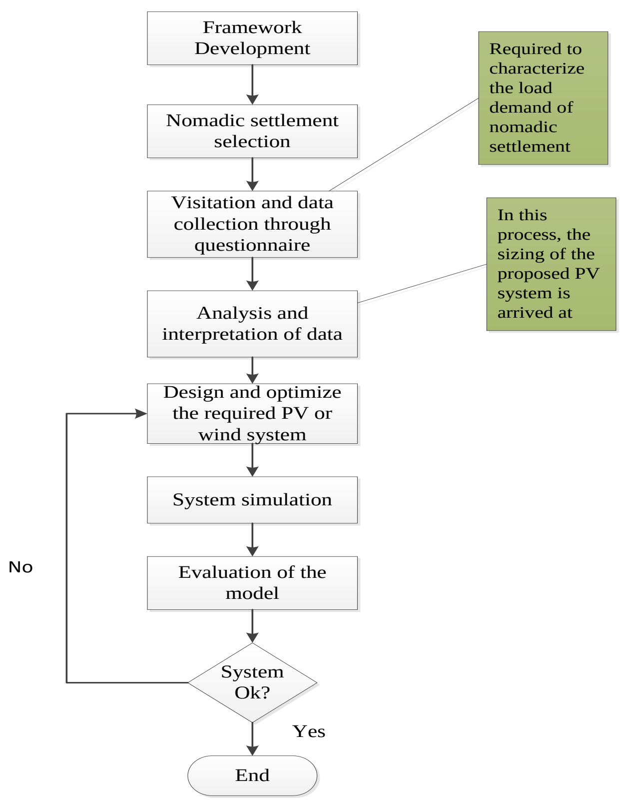

Figure 3: Block Diagram of Research Methodology

2.1. Electrical Load Study of Nomadic Settlement in North Central Area of Nigeria

Statistical study of the load pattern of the chosen settlements was carried out through issuing questionnaire to some settlers of the settlement. This was necessary to gather information on what they chose to do with energy based on their lifestyle. The questionnaire also helped to determine why the settlers move from one place to another, requirements for them to remain and ranch in one location, willingness to pay for electricity and host of other questions that could assist in this study. Table 1 below shows the average load demand of the settlements.

Table 1.Estimated load demand of the study area.

ELECTRICAL APPLIANCES	POWER RATING	UNITS	TOTAL POWER(W)
Lighting	5	43	215
Mobile Phone	6	25	150
Radio	30	10	300
Submersible and Sprinkler pressure Pump	211	1	211
TOTAL LOAD (W)			866

2.2 System Description

From preliminary study carried out on the selected Nomadic settlements, the settlers' load demand can be powered from a DC source, thus without requiring an inverter. This eliminates energy losses in converting from DC to AC. The system block diagram is as shown in Figure 4.

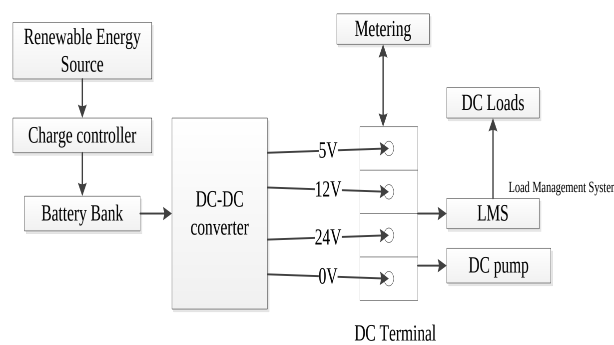

Figure 4: System block diagram showing their interconnectivity

The different modules of the proposed system as presented in Figure 4 are thus discussed as follows.

2.2.1 PV Module

A possible option to supply the nomadic settlement is through solar Photovoltaic source. The most viable

source will be determined through techno-economic analysis of wind/PV source. The PV unit received the sun irradiation and converts it into electricity. Statistics obtained from NASA Surface meteorology and Solar Energy shows that the solar irradiation of the proposed cities of study is high, which make it suitable for PV generation.
The output of the PV array can be calculated using (2.1) [14].

$$P_{pv} = Y_{pv} f_{pv} \left(\frac{G_T}{G_{T,STC}} \right) [1 + \alpha_p (T_c - T_{c,STC})] \tag{2.1}$$

where Y_{pv} is the rated capacity of the PV array, f_{pv} is the PV derating factor (%), G_T is the solar radiation incident on the PV array in the current time stamp (kW/m^2), $G_{T,STC}$ is the incident radiation on standard test condition, α_p is the temperature coefficient of power, and $T_c, T_{c,STC}$ are the PV cell temperature in the current time stamp and under standard test condition respectively. The required size of Nano-Grid for the nomadic settlement will be optimized using Particle Swarm Optimization algorithm.

2.2.2 Wind Energy Source

Wind turbine (WT) helps to convert wind energy to electricity. The output of the WT is connected to a Pulse Width Modulator (PWM) voltage source converter. The output power generated by the WT is given as [14]:

$$\begin{aligned} P_{WT} &= 0, \quad V < V_{ci} \\ P_{WT} &= (aV^2 + bV + c)P_r, \quad V_{ci} < V < V_r \\ P_{WT} &= P_r, \quad V_r < V < V_{co} \\ P_{WT} &= 0, \quad V_{co} < V \end{aligned} \tag{2.2}$$

The wind speed at a given hub height is given as:

$$V = V_r \left(\frac{h}{h_r} \right)^{\alpha} \tag{2.3}$$

where V is the wind speed at the given hub height *h*, V_r is the wind speed at a reference height h_r, while α is the coefficient of ground surface friction ranging from less than 0.1 to greater than 0.25 depending on the terrain, V_{ci} is the cut-in speed, V_{co} is the cut-out speed, a, b, and c are constants. The electric power of a turbine at a given wind speed is computed using:

$$P_{wt} = 0.5 C_p \rho A V^3 \tag{2.4}$$

where C_p, ρ, A, V are the air density in kg/m^3, maximum power coefficient, the swept area of the wind turbine blades, and the wind speed respectively.

2.2.3 Energy Storage

Surplus energy will be stored in a battery bank which is usually of lead-acid type. Energy storage in battery is necessary to provide continuous supply of electricity when there is no renewable energy source. One important variable which determines the residual capacity state of the battery is the State of Charge (SOC). It can be calculated through battery voltage, current, and temperature. An optimum battery/PV or battery/wind sizing will be required to power the load demand shown in Table 1. The total battery capacity required daily can be obtained from (2.5) [15].

$$C_{req\_daily} = \frac{\varepsilon_{req\_daily}}{SystemVoltage} \tag{2.5}$$

where, ε_{req_daily} is the daily required total energy. The system voltages here are of three categories, 5, 12 and 24V. 5V is mainly for charging of mobile phones, 12V for the DC radio, 24V for lighting and DC pumps. Thus, the total battery capacity required will results from the summation of the battery capacity obtained from the three different voltage levels.

2.2.4 Charge Controller

The charge controller unit is needed to regulate the charging rate of the battery. Power intake will be restricted when battery has charged up to the required maximum voltage. Similarly, excessive discharge will be avoided by hindering batteries from discharging when battery voltage has dropped to a preset minimum value. Thus, this unit will protect the batteries from over charging and over discharging, while charging the battery with the required charging current.

2.2.5 Dc-Dc Converter

To handle the different loads, a DC-DC converter will be designed and simulated to supply three levels of voltages, 5, 12 and 24V. The three voltage levels will be made available to each household through a DC bus.

2.3 Optimization Using Particle Swarm Optimization (PSO)

To optimize the size of Nano-grid required, the cost of the grid is a good metric for this purpose. This involves analysis such as the net present cost (NPC), and levelized cost of electricity (LCOE). The net present cost also known as life-cycle cost of a component is the present value of all the costs of installing and operating the component over the project lifetime. This does not include the present value of all the revenues that it earns over the project lifetime. The goal of optimization here is to minimize the NPC and LCOE using particle swarm optimization while satisfying the load demand of the community. Two different optimizations will be carried out. Optimizing the NPC and LCOE for wind on one hand and that of solar energy on the other hand. Comparing the two, the one with the least NPC/LCOE will be of economic advantage. Figure 5 shows the flow chart of the optimization process.

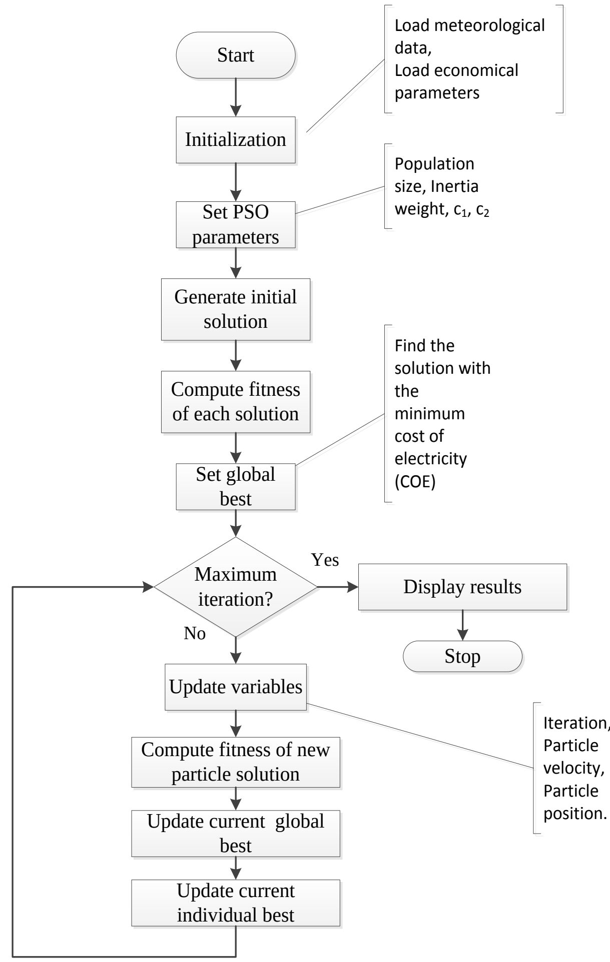

Figure 5: Flowchart of the optimization process using PSO.

2.4 Automatic Load Management System

Considering the illiteracy level of the nomadic settlers, an automatic load management system is suggested to control power usage and avoid wastage. To achieve this, a human detection sensor (HDS) was employed to detect human presence/absence and switch on/off the room light accordingly. A programmable chip was used to monitor the sensor to take decision such as switching off the lights whenever the user is absence and switching it on in the presence of the user. The circuit diagram used to achieve this is as shown in Figure 6.

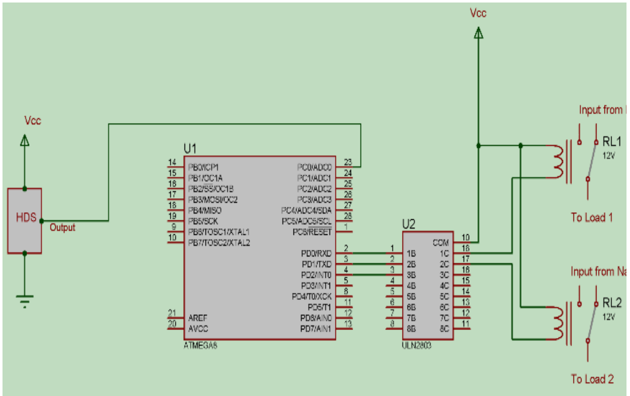

Figure 6: Schematic diagram of the load management system

2.5 A Simulink Model of the Nano-grid

The Nano-grid obtained from simulation is simulated from Simulink to investigate the operability of the grid. Figure 7 shows the Simulink block of the Nano-grid for the case of PV whose size will be determine by using the optimization tool previously discussed. It shows the DC-DC converter connected to the PV array with different input of temperature and irradiance. The wind energy model was not considered for simulation since it was not a viable option based on the results obtained.

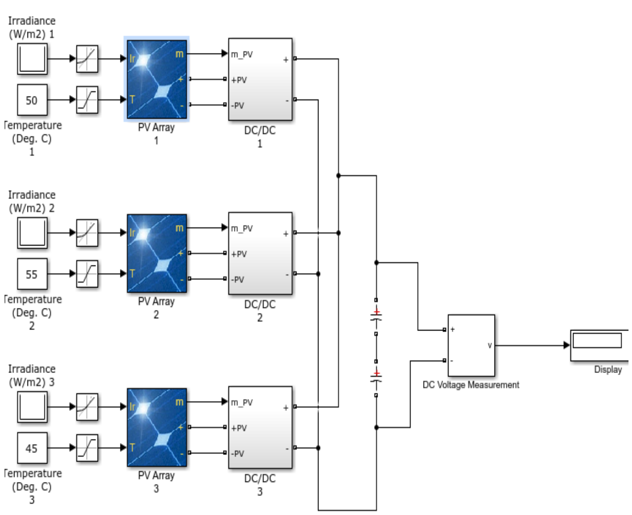

Figure 7: PV Nano-grid showing DC-DC converters connected to different PV array

3. RESULT

3.1 Techno-Economic Analysis

The essence of this analysis is to identify the most viable source of renewable energy for provision of electricity. Listed in Table 2 are specifications of the system components used.

Table 2. Technical and Economic Specifications of the system components

Components	Parameter	Value
WIND TURBINE	Model No of Blade Swept Area Efficiency Rated voltage Cut-in Speed Rated Speed Rated Power Maximum Output Power Life time Cost	HY-1000 5 3m^2 95% 24V DC 2.5m 12m/s 1.0kW 1.2kW 15 Years ₦427,305
BATTERY	Battery State of Charge Efficiency Life Time Rated Power Initial Cost	20% 85% 3 Years 200AH N90,000
PV	Rated Power Initial Cost Life Time Efficiency	0.3kW ₦27,000 24 years 95%

The aforementioned parameters were used in simulation where the wind/battery and PV/battery contributions are computed. Results obtained showed that PV gave a better contribution than wind with the cost of electricity being ₦62.72kWh and ₦64.06/kWh at 5kW capacity respectively.

The optimization result using PSO showed that the wind turbine requirement is estimated at a total sum of Two Million, One Hundred and Thirty-Six Thousand, Five hundred and Twenty-Five Naira, (₦ 2,136,525) while the PV requirement is estimated at a total sum of One Million, Six Hundred and Twenty Thousand Naira (₦ 1,620,000). A final reduction in cost of electricity to ₦23.44/kWh was achieved.

The load management system used also reduces the average daily consumption of energy by 50% as evident in the graph in figure 9.

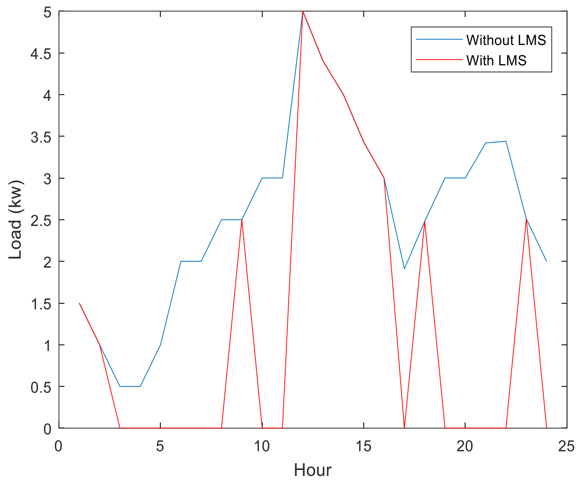

Figure 9: Result showing reduced energy consumption as a result of load management strategy.

4. CONCLUSION

In this work, a technological approach to curb the serial deadly conflicts between herdsmen and farmers was addressed. This old long conflict is as a result of inability of the nomads to provide greener pasture and water for their animals in a confined location. Result from survey conducted showed that the nomads are willing to adopt ranching in a location if government will provide them irrigated ranches. This calls for provision of electricity, from renewable energy source, to power their basic DC loads as well as to power pumps for irrigated ranches. A PV/battery DC Nano grid was found to be the most viable and economical option for the nomadic settlements.

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