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Demand Side Management Strategies for Solar-PV Penetration in Powering Rural Healthcare Centre in Africa

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ABSTRACT
This paper explored the possibility of applying Demand Side Management (DSM) strategies in meeting the energy demands of rural healthcare centres in Africa. Using an energy management system, it is possible to increase renewable energy penetration, optimize energy costs and reduces carbon emissions. DSM is a process of managing energy consumption to optimize available and planned resources for power generation. The DSM strategies employed in this study incorporates all activities that influence the rural healthcare facilities use of electricity, hence leading to manageable demand. The main focus of this study is on feasibility of increasing penetration of off-grid hybrid renewable energy in delivering basic healthcare services in rural areas with limited or no electricity access. Renewable energy resources (RES) such as solar is considered abundant in many rural places, it is also environmental friendly, hence suitable for providing electricity in rural healthcare facilities where there is no electricity access or limited supply. To meet the facility's energy need, an optimum PV-Gen-battery hybrid system was designed using HOMER (Hybrid Optimization of Multiple Electric Renewables), with COE of $0.224/kWh, Net Present Cost (NPC) of $61,917.6 and initial capital cost of $16,046.5. DSM measures were applied to reduce the peak and average demand. With this new load profile, an optimum hybrid system was obtained, producing a COE of $0.166/kWh, NPC of $18,614.7 and initial capital cost of $10,070.8 after the DSM. The cost saving realized for the considered rural healthcare center is $0.057/kWh, representing 25.8% reduction from the current COE and 70% reduction in Total NPC. The research provides novel insights which may be applicable worldwide. It has the potential to significantly advance the development of high-quality and timely evidence to underpin current and future developments in the rural energy sector and contribute to the implementation of SDG7..

Keywords
Demand side management, electricity demand, energy supply, healthcare services, renewable energy, reliable supply, Africa.

1. INTRODUCTION
Electricity is vital for the daily living of modern man. It provides illumination, energy for homes, schools, hospitals, offices, businesses and promotes industrialization [1]. In many developing countries in the world, the difference between electricity generated and the energy demand has caused gross energy dearth. Electrifying rural communities is a major challenge facing most developing countries of the world. There is need to develop a means of increasing access to electrical energy services for rural communities, since electricity is an essential component in the development of any community. Rural communities in most developing countries have limited access to all forms of basic services such as good health care delivery (since electricity is needed to preserve vaccines through refrigeration, power laboratory equipment, provide illumination for patients at night, pump water and power computer systems for easy access to information), pipe borne water, good communication and road/street networks [2]. Rural electrification often impacts greatly on the rural lives. Apart from improving the people's standard of living, it sparks overall rural development. It assists in reducing rural-urban migration which in turn helps alleviates urban congestion and its associated social vices such as poverty and crime[3]. It also helps to promote political stability and increase social virtues such as an improved health care delivery, creation of employment, improvement of the education system and the social cohesion and development in rural communities in the many countries [3].

In many of these places, the traditional approach to serve the communities is extension of the central grid. For example in Nigeria, many reforms on extension of grid supply to rural location has been proposed, such as National Energy Policy (NEP), the Electric Power Sector Reform Act (EPSR), which led to the establishment of the Nigerian Electricity Regulatory Commission (NERC) and the Rural Electrification Agency (REA). These reforms are expected to lead to the development of various independent power projects (IPPs), to complement the existing power infrastructure across the nation. Despite these reforms, the provision of electricity to the rural communities has not improved due to non-access to the grid, coupled with grid unreliability; other constraints include inaccessible terrain, and the high cost of grid extension to the communities. Since about 70% of the rural areas are still without any form of electricity, it is obvious that rural communities are not likely to benefit from power reforms, because extension of the national grid to most rural areas via thick jungles and difficult terrain is challenging and inefficient due to the associated high cost and loss of transmission from the grid to the load centre. Power generation in rural villages through the use of diesel generators may seem to be a reliable option if there is proper operation and regular maintenance. However, the noise and environmental pollution resulting from the emission of CO_2 and other harmful gasses have negative effects on the environment. So, when resources are harvested unsustainably and energy conversion technologies are inefficient, there are serious adverse consequences for health, environment and economic development. Given the fact that improvement of

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rural accessibility to electricity via connection the national grid seems impracticable in many rural locations at the moment, the establishment of a system that is autonomous and off-grid in such locations becomes imperative. A solution based on renewable energy (RE) technologies, could be a viable option due to the vast deposits of the resources, coupled with the associated environmental friendliness, cost effectiveness in operation as well as sustainability.

In the case of rural health facilities, a solar/wind/battery hybrid system can be deployed to cater for the need of the un-electrified rural health centre and schools. It will enable power supply to certain medical equipment, critical lighting, and mobile communication devices in an off-grid area for timely delivery and critical medical care for the rural dwellers. Therefore, reliable energy access to health centres produces multiplier effects: improved community sanitation, health, gender empowerment, reduce rural-urban migration and prevent disasters. All these are highly recognized as key priorities by UN and GCRF through SDGs (SDG1-7, 10, 13). It is quite interesting to note that SDG 7 (affordable and clean energy) offers a series of interlinkages with other goals. For example, access to affordable and clean energy is needed to achieving SDG13 (reduce GHG emission), SDG3 (access to quality healthcare services) among others.

1.1 Related works

Solar, wind, small hydro and biomass make up the different renewable resources in Nigeria. These sources have severally been assessed in order to establish their potential and viability for electricity generation in the country [4]. Out of the various renewable energy resources in the country , wind and solar are the most favored for electricity generation. However, the investigation of wind power potential at different location in the country shows that viable wind speed are not evenly distributed, as such wind energy is not applicable at all locations in the country. Conversely, solar irradiation data indicates vast presence of solar energy potentials at almost every location within the country [5]. Moreover, photovoltaic (PV) modules which convert solar energy into electricity also have the advantage of being more suitable for residential buildings on small scale because of its modular structure, zero operating noise, ease of maintenance as well as the environmental friendliness [5]. The potentials of solar energy utilization for various activities in the country have been established by different authors in various studies [6, 7, 8, 9, 10]. Some of these areas of applications have been identified to include; agricultural, industrial, building (commercial and residential), operating pumping machines for water supply and purification, rural electrification, and heating applications [7]. A feasibility assessment of solar energy utilization for electricity generation in buildings has been conducted in Nigeria [8]. Eight hypothetical remotely located off-grid BTS sites at different geographical regions in Nigeria for solar PV application has been considered [9]. Another key area of application of solar and other renewable sources is in rural health clinics. The optimal configurations of hybrid renewable system for rural health clinic application in three grid-independent rural villages in Nigeria have also been assessed [10] However, the drawback of the utilization of solar PV system is its affordability, due to high initial cost of purchase and installation since there is no obvious or popular national policy that encourages increased RES penetration [5]. In order to encourage increased penetration of solar power systems in the country, the feasibility of utilizing standalone solar system on a scalable level using load partitioning with quality of life (QoL) as a constrain has been investigated [5]. Government intervention in the form of subsidy on the importation of Renewable Energy Technologies (RET), especially solar PV to bring down high costs, and the encouragement of private individuals and groups to invest in solar technologies would help tap the vast RES potential in Nigeria [11]. Additionally, the establishment of a policy for regulating the Renewable Energy industry and the development and maintenance of a Renewable Energy resource database have been recommended to increase RES penetration [12].

This research therefore aim to explores the use of Demand Side Management (DSM) strategy that ensures low cost of energy, reduction in CO_2 emission and reduced capital cost for a system that uses a mix of Solar PV, diesel generator and battery power bank to meet the power supply need of a typical rural health clinic.

1.2 Site Description

A rural health clinic in Karu Local Government Area of Nasarawa State in Nigeria (**Figure 1**) having similar characteristics of many rural healthcare centres in Nigeria and other sub-Sahara Africa countries been considered as a case study. The coordinate of Karu LGA is latitude 90 08'N and longitude 70 51'E; and covers an approximate land area of 704 sq. km. Karu LGA has two distinct seasons (wet and dry), typical of north-central Nigeria.

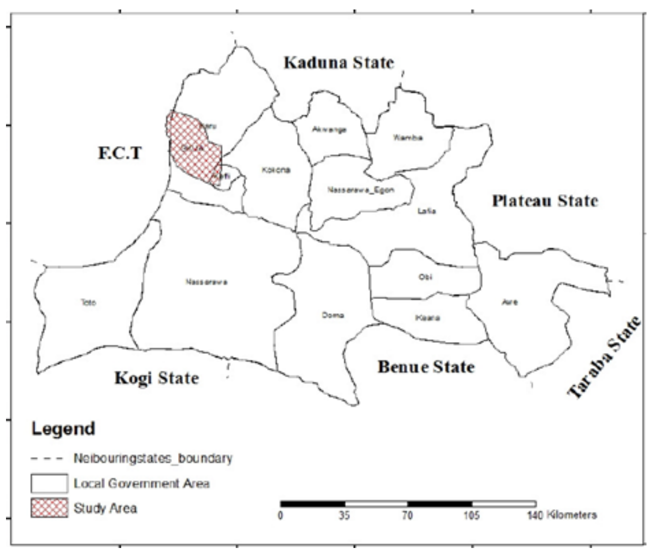

Figure 1. Map of the Study Area

The public health center has two blocks of building consisting a consulting room, injection room, card room, a pharmacy, male ward, female ward, a delivery room, and a laboratory. The entire village is off-grid. Therefore, the healthcare centre depends on two diesel generators for its power supply. The description of the generators, and their operation and maintenance (O&M) cost is shown in **Table 1**. Oral interview with the facility maintenance personnel, physical inspection and observation of energy consumption pattern were carried out to acertain the level of electricity availability and consumption in the clinic.

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Table 1. Current Power Source for the Clinic

Code	Name	Name Plate Details	Target Load	kWh/Day Supplied	O & M Cost
GEN.1	Tiger (TG 2700) Gasoline Generator	50Hz, 230V, Single Phase Rated Output: 2KVA	Submersible Pumping Machine	2.2	$0.86/day $0.39/kWh
GEN.2	SANDING (SD 3000) Gasoline Generator	50Hz, 230V, Single Phase Rated Output: 2.2KVA Maximum Output: 2.5KVA	Lighting, Medical Equipment, T.V, Phone Charging and Refrigeration	3.55	$0.86k/day $0.24/kWh
TOTAL				5.75	$1.73/day $0.64/kWh

2. METHODOLOGY

To achieve the objective of designing a low cost hybrid power system that uses a mix of Solar PV, diesel generator and battery power bank to meet the power supply need of a rural healthcare clinic, the methodology employed is shown **Figure 2.**

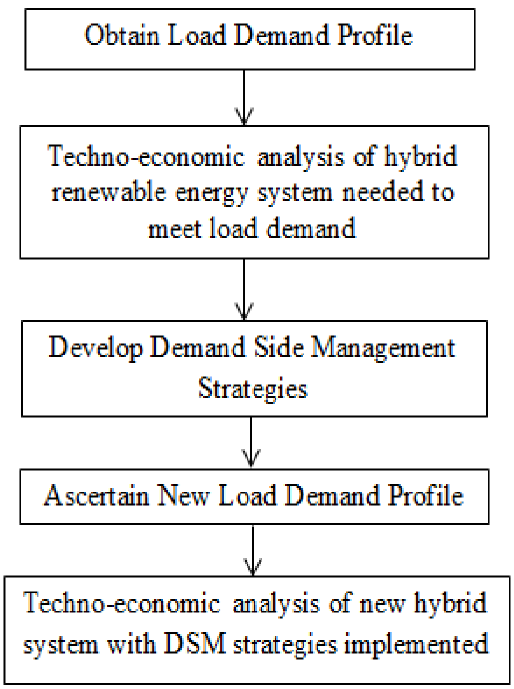

Figure 2. Block Diagram of Methodology

2.1 Current Load Profile at the Clinic

The current electricity consumption load profile of the clinic using power supplied by the generators is shown in **Figure 3**. The capacity in watts of each appliance, the quantity, daily run time in hours and peak load are noted. The total connected load is 3.2kW, with peak load as 1.5kW and average daily demand of 4.75kWh/day.

From the load profile, electricity consumption is shifted towards evening time when the generator is used for lighting purposes. Other uses of power have to be shifted to this time except for emergency situations. The healthcare center observes immunization only once in a month due to lack of power supply to maintain cold chain for vaccines. The lack of electric centrifuge also slows the process of laboratory tests, since separation of blood samples have to be done manually. The laboratory technician also has to resort to using the microscope manually at times when there is no power supply in the day time. Staffs in the healthcare facility are not fully motivated due to insufficient power supply.

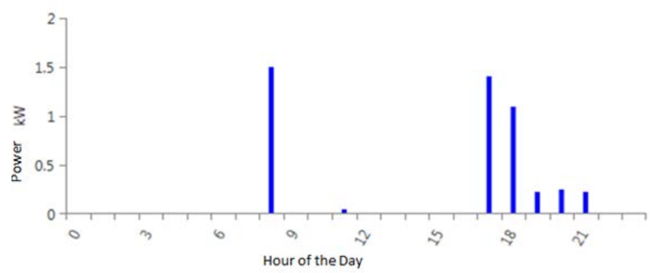

Figure 3. Current Load Profile of the Clinic

However, in order to motivate the clinic's staff to deliver quality healthcare, there is need for increase in the number of hours electricity is supplied to the health facility. A new load to meet the health center's current energy need with all appliances functional is presented in **Table 2**. The new load serves as input to the optimization software, HOMER with a day-to-day and hourly variability of 5% and 10% respectively, to avoid underestimating the peak load. The new load profile is shown in **Figure 4**. The clinic has total connected load of 4.64kW, with peak load of 2.67kW and average daily demand of 20.58kWh/day.

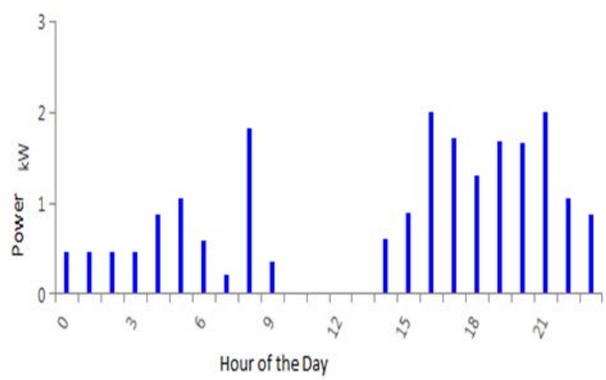

Figure 4. Proposed Clinic Load Profile without DSM

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Table 2. A new load description with all the basic medical appliances functioning

Application	Detail	Quantity	Capacity (watts)	Run time (hours/day)	Peak load(W)
Lighting	Bulb (Incand.)	2	100	12	200
	Bulb(Fluorc.)	10	40	8	160
	Bulb (CFL)	15	18	12	270
	Bulb (CFL)	17	11	8	187
Ventilation	Ceiling fan	8	75	8	600
Medical Equipment	Sterilizer	1	1,500	1	1500
	Microscope	1	20	1	20
ICT and Audio Visual	LCD T.V	1	45	1	45
	Mobile Phones	5	3.68	2	18.4
Water Supply	Submersible Pump	1	1,100	1	1100
Other	Refrigerator(Non-Med)	1	300	1	300

2.2 Hybrid system optimal sizing

Hybrid Optimization of Multiple Electric Renewables (HOMER), software designed by US's National Renewable Energy Laboratory (NREL) was used to design and size an optimal hybrid power supply to meet clinic load demand. It is an optimization model for micro-power [13]. It makes easier the job of appraising power system designs for onn-gird and off-grid applications. The inbuilt algorithm HOMER uses for its optimization and sensitivity analysis allows the user to gauge the technical and economic possibility of a variety of electricity generation technology options that can serve a particular load. It also helps to give justification for changes in technology costs and the availability of energy resource.

Six different types of data are required by HOMER for simulation and optimization. These include meteorological data, load profile, equipment characteristics, search space, economic and technical data.

2.2.1 Resources Data

The monthly average daily solar irradiance data used for the study site is shown in **Table 3**. These data are obtained from Nigeria Meteorological Agency (NiMET).

Table 3. Monthy average global solar radiation and clearness index for the study site

Month	Solar Insolation	Clearness Index
Jan	5.88	0.65
Feb	6.09	0.63
Mar	6.27	0.61
Apr	6.06	0.58
May	5.58	0.54
Jun	5.06	0.49
Jul	4.42	0.43
Aug	4.18	0.40
Sep	4.73	0.46
Oct	5.30	0.54
Nov	5.97	0.66
Dec	5.87	0.67
Annual	5.45	0.56

2.2.2 System components data

The information regarding components pricing and sizing as adopted in the proposed hybrid system, are expressed **Table 4** Present market values were used for the prices of each component per kW. The battery sizing was selected from sizing options provided by HOMER using battery autonomy of five (5) days to calculate the amp-hour rating.

Table 4. Economic and Technical Specifications

Component Parameter	Values
PV Module	
Capital Cost ($/kW):	2,500
Replacement Cost ($/kW):	2,500
O&M Cost ($/year):	10
Lifetime (years):	25
De-rating Factor (%):	80
Search Space (kW):	0,1,2,3 & 4
Converter	
Capital Cost ($/kW):	250
Replacement Cost ($/kW):	250
O&M Cost ($/year):	10
Lifetime (years):	15
Efficiency (%):	9
Search Space(kW):	0,1,2,3 & 4
Battery	
Model:	Trojan J200-RE
Rating:	2.71kWh, 226Ah
Capital Cost ($/Unit):	167
Replacement Cost ($/Unit):	167
O&M Cost (₦/year):	10
Lifetime (years):	7
Search Space (Unit):	0, 8, 16, 24 & 32
Battery String:	1
Generator	
Type:	Generic Auto-size
Capital Cost ($/kW):	418
Replacement Cost ($/kW):	418
O&M Cost ($/hr):	8
Diesel Price ($ /litre):	0.54
System/Economic Constraints	
Maximum Capacity Shortage	20%
Minimum Renewable Fraction	55%
*Inflation Rate:	17.26%
*Interest Rate:	14.00%

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2.3 Demand Side Management

Demand side management (DSM) can be defined as the process of managing energy consumption to optimize available and planned resources for power generation [14]. Using DSM, it is possible to increase renewable energy penetration, optimize energy costs and reduces carbon emissions. DSM incorporates all activities that influence consumer use of electricity and results in the reduction of the electricity demand, which are mutually beneficial to the consumer and the utility. There are two primary indices used in assessing both the economic and technical benefits of DSM. They are the demand side management quality index (DSMQI) for measuring the technical effects, and the demand side management appreciation index (DSMAI) for weighing economic results. These indices will help all the parties involved in the DSM program to appreciate the justification for the DSM program.

2.3.1 DSM Quality Index (DSMQI)

Demand side management quality index (DSMQI) evaluates the technical gains of a particular DSM program [14].

$$DSMQI = \frac{KW_{WODSM}}{KW_{WDSM}} \quad (1)$$

Where KW_{WDSM} and KW_{WODSM} are the kW rating with and without DSM, respectively. A $DSMQI > 1$ is good; the higher the ratio, the higher the benefit of the DSM program.

2.3.2 DSM Appreciation Index (DSMAI)

Demand side management appreciation index (DSMAI) is an index that reveals the economic benefits of DSM programs DSMAI is expressed as[14]:

$$DSMAI = \frac{CKWh_{WODSM}}{CKWh_{WDSM}} \quad (2)$$

$CKWh_{WDSM}$ and $CKWh_{WODSM}$ are the cost of electricity per kWh with and without DSM, respectively.

2.3.3 Proposed Demand Side Strategies

In order to reduce energy consumption by the healthcare facility, some DSM strategies were considered based on the energy audit conducted. Smart appliance, energy efficiency programs and load partitioning are techniques considered to achieve consumption reduction, thereby reducing the cost of the hybrid renewable energy system in the rural clinic.

2.3.3.1 Smart appliance

From the list of appliances used in the health centre presented in **Table 2**, the following appliances were observed to be inefficient and energy consuming: (i) Two (2) 100W incandescent light bulbs(ii) Ten (10) 40W fluorescent tubes fittings and (iii) non-medical refrigerator used for preserving vaccines.

Therefore, It is proposed that the incandescent bulbs and fluorescent fitting be changed to Compact Fluorescent Lamps (CFLs). A solar vaccine refrigerator will also reduce energy consumption and improve the healthcare service delivery of the health center to the community. To ensure each room in the healthcare center is lighted according to standard, calculations were also done for the number of fixtures required for internal lighting.

2.3.3.2 Energy Efficient Water pumping

To ensure the water pumping machine is not used for longer than necessary, the water requirement of the healthcare centre was estimated. According to World Health Organization standard, water required per person, per day is 20 litres [15]. For In-patient (admitted patients) and Out-patient (non-admitted patients), it is 60litres and 5litres respectively. Laboratory water requirement is estimated at 75litres per day. A 20% miscellaneous is added for other use. The healthcare center usually has an average of five (5) staff on duty daily, with a total of seven (7) bed space for admitted patients.

2.3.3.3 Load partitioning

Loads in the healthcare centre were classified in order of priority as primary (critical) and deferrable (Important and Non-Critical). The load classification is shown in **Table 5**.

Table 5. Classification of loads

Category	**Detail**	**Priority**
Lighting	All Light Fixtures	Primary
Ventilation	Ceiling fan	Primary
Medical Equipment	Sterilizer	Deferrable
	Microscope	Primary
ICT and Audio Visual	LCD T.V	Primary
	Mobile Phones	Deferrable
Water Supply	Submersible Pump	Deferrable
Other	Refrigerator (Non-Med)	Primary

Deferrable loads are electrical load that must be met within some time period, but the exact timing is not important. Loads are normally classified as deferrable because they have some storage associated with them. Water pumping is a common example - there is some flexibility as to when the pump actually operates, provided the water tank does not run dry. Other examples include ice making and storage charging. The deferrable loads identified and their analysis are as follows:

(1) Submersible pump

The clinic pumps water for two (2) hours daily. The pump has a pumping rate of 2000litres/hr. The water requirement of the health centre is 714litres per day (approximately 1000litres per day). It would take pump 0.5hours to pump the daily water required.

- Peak power (pump rated power) = 1.1kW
- Storage capacity = 2 (hours) × 1.1 (kW) = 2.2kWh
- Average deferrable load = 0.5×1.1=0.55kWh/day

(2) Medical equipment Sterilization

It takes between 25 to 30 minutes (0.5hours) to complete one sterilization cycle.

- Sterilizer peak power = 1.5kW
- Storage capacity = 1 (hour) × 1.5 (kW) = 1.5kWh
- Average deferrable load = 0.5 × 1.5 = 0.75kWh/day

(3) Mobile phones charging

It takes an average 2hours to fully charge a mobile phone. However, to reduce power consumption, 1hour has been allotted per staff on duty to charge their mobile phones when necessary.

- Peak power = 0.0184kW
- Storage capacity = 0.0184 × 2 = 0.0368kWh
- Average deferrable load = 1×0.0184= 0.0184kWh/day

(4) De-lamping fixtures

There are loads that are important in a healthcare facility but not critical. This is because there may be alternatives or the facility

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could function in its core objective without powering such loads. Some loads that were cut down to reduce energy consumption include: (i) External lighting: reduced to eight (8) points (4 for each block of building). (ii) Ceiling fan: reduced to four (4) points for entrance/card room, labour recovery ward, male and female wards.

2.3.4 New Load Profile with DSM Implemented

The schematic for the hybrid system designed with DSM strategies in view is shown in **Figure 5**. This schematic shows the two classes of loads namely, primary and deferrable loads. The new primary load profile is shown in **Figure 6** with total connected primary load of 1.15kW, peak load of 1.08kW and a daily average load of 7.01kW/day.

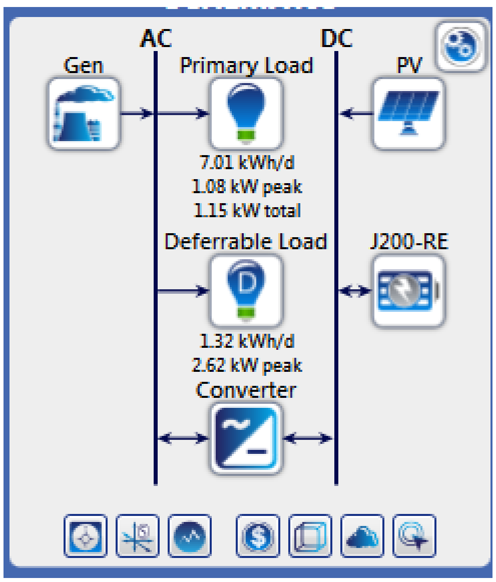

Figure 5. Schematic hybid energy system with DSM strategies implemented

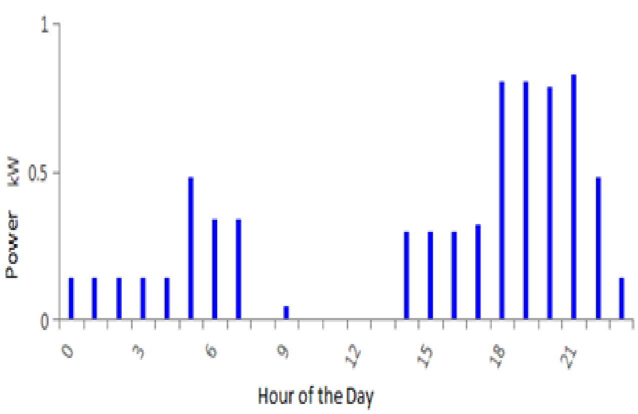

Figure 6. Primary load profile with DSM strategies implemented

3. RESULT AND DISCUSSION

The details optimization results for the selected hybrid system configuration for the considered Primary Healthcare centre are presented in this section. Input variables were introduced into HOMER to carry out the optimization and give the feasible and optimum system configuration. Results are displayed in categorized form showing the most feasible power system architecture which meets the load and the input constraints.

3.1 Optimization before DSM Strategies

With the load profile shown in **Figure 4** and system constraints of **Table 4**, an optimum hybrid system configuration was designed for the clinic using HOMER. The optimization result for various system configurations are shown in **Table 6**. The table shows optimization result for different system configurations that can meet the facility's current energy consumption need. Based on the total net present cost (NPC), the optimum configuration is found to be PV-Gen-Battery system. This configuration has a PV size of 4kW, with a generator capacity of 3kW, 24 units of 12V batteries and a 3kW converter. The Total NPC is $61,917.6 while cost of energy (COE) is $0.224kWh. Meeting the facility's energy need with generator alone will cost $1,253.6 as initial capital but a total lifetime cost (NPC) of $114,940. It is worth noting that a PV-Battery system is not feasible with a 20% maximum annual capacity shortage constraint as indicated in **Table 4**. The PV-Battery configuration is only feasible when the maximum annual capacity shortage is increased to 34%.

3.2 Optimization for Hybrid System with DSM Implemented

The result of the optimization for the power system that meet the energy needs of the clinic, with proposed DSM implemented is shown in **Table 7**. The optimization result shows that with DSM strategies implemented, the optimum configuration to meet the electrical energy need of the healthcare center is PV-Gen-battery system. This system has a PV size of 3.0kW, a 1.7kW generator, 8 units of 12V batteries and a 1kW converter. The Total net present cost (NPC) is $18,614.7 while cost of energy (COE) is $0.166/kWh. Meeting the facility's energy need with generator alone system after implementing DSM strategies will costs $710.3 as initial capital and a total lifetime cost (NPC) of $57.972.9.

3.2.1 Comparison Based on Initial Capital Cost

The initial cost of the optimum system configuration before DSM is $16,046.5 as compared to $10,070.8 after DSM as shown in **Table 6 and 7**. It is worth noting that in both load scenarios (before and after DSM implementation), the initial capital for 'Generator. only' system configuration is the lowest. This is one of the major reasons for the wide use of diesel/petrol generators in the country for residential, commercial loads.

3.2.2 Comparison Based on Total NPC

The net present cost of a component is the present value of all the costs of installing and operating the component over the project lifetime, minus the present value of all the revenues that it earns. The net present cost of the configurations in both load scenarios are earlier presented in **Tables 6 and 7**. For the optimum configuration before applying DSM measures, the total net present cost is $61,917.6, while the NPC for optimum system configuration with DSM measures is $18,614.7, representing a percentage reduction of 70%.

3.2.3 Cost of Energy (COE) Considerations

The Cost of Energy (COE), measured in $/kWh, is a convenient metric to measure the cost effective of the systems, even though HOMER does not rank systems based on COE. **Table 6 and 7** compares the cost of energy in both load scenarios.

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Table 6. Optimization result for hybrid power system before DSM strategies

System Configuration	PV (kW)	DG (kW)	Bat. (Units)	Con. (kW)	COE ($/kWh)	NPC ($)	Capital Cost ($)
PV-DG-Bat	4	3	24	3	0.224	61,917.6	16,046.5
DG-Bat	-	3	8	1	0.310	85,687.3	2,841.6
Gen. Only	-	3	-	-	0.415	114,940.3	1,253.6
*PV-Bat	4	-	32	3	0.166	32,501.6	16,046.5

*Maximum Capacity Shortage =34% (Not feasible for Maximum Capacity Shortage < 34%)

Table 7. Optimization result for hybrid power system after DSM strategies

System Configuration	PV (kW)	DG (kW)	Bat. (Units)	Con. (kW)	COE ($/kWh)	NPC ($)	Capital Cost ($)
PV-Gen-Bat	3	1.7	8	2	0.166	18,614,7	10, 070.8
PV-Bat	4	-	16	2	0.202	22,628.9	13,204.9
Gen-Bat	-	1.7	8	2	0.364	40,629.3	2,549.1
Gen. Only	-	1.7	-	-	0.518	57,972.9	710.3

It is interesting to note that for each load scenario, the cost of energy with optimum system configuration is lower compared to other system configurations. After the DSM measures, the PV-Gen-Battery system has the lowest cost of energy of $0.166/kWh, followed by the PV-Battery system under same load scenario with cost of energy of $0.202/kWh. The configuration with the highest COE is the generator only system, with $0.518/kWh. In general, the COE of the optimum system configuration after DSM measures brings 25.8% reduction when compared with the COE of the current system without DSM measures.

3.2.4 Environmental Friendliness of System Configurations

Table 8 present the summary of emission from the optimum system configuration. The optimization results show that optimum system configurations after implementation of DSM measures are more environment-friendly, with lower CO_2 emissions than without DSM measure. That is 2,579kg/year CO_2 emission without DSM and 88kg/year CO_2 emission after DSM, representing 96.6 % reduction emission. In both load scenarios, generator only systems also give the highest CO_2 emissions when compared with other system configuration.

Table 8. Comparison of emission for optimum system configuration after and before DSM

Quantity	Before DSM (kg/year)	After DSM (kg/year)
Carbon Dioxide	2,579	88.22
Carbon Monoxide	10.05	0.56
Unburned Hydrocarbons	0.50	0.02
Particulate Matter	0.05	0.00
Sulfur Dioxide	0.80	0.22
Nitrogen Oxide	1.05	0.52

3.3 Analysis of Optimal System Configuration for the Healthcare Centre after the DSM

Based on the aim of finding a low cost system that meets the healthcare facility's energy need in the most cost-effective and environment-friendly way, the optimum top ranked system of PV-Gen-Battery configuration after DSM measures is selected for the health center.

3.3.1 Cost summary for optimum system components

The NPC summary of the optimum system is shown in **Table 9**. The component with the highest NPC is the generic solar plate PV with NPC of $8,444.5, closely followed by the battery with NPC of $8,117.7. The cash flow summary for the optimum system is also considered. The capital cost includes the cost for each system component. Replacement cost is as a result of replacing the converter and battery during the project lifetime of twenty-five (25) years. The battery which has a lifetime of about seven (7) years, will be replaced three (3) times during the project lifetime, while the converter will be replaced once, after a period of about fifteen (15) years. At the end of the project lifetime, its salvage value is $3,372.3

3.3.2 Electrical power output production

The electrical power output of the generator set is observed. The maximum power output of the generator is 1.7kW, with a yearly electrical production of 72kWh. The average total fuel consumed yearly is 33.8L, while the daily and hourly average fuel consumption is 0.0927L/day and 0.00386L/hour respectively. The optimum system relies majorly on the PV panel for electrical power production. The PV panel runs for 4,471 hours yearly, on an average of 8 to 9 hours daily. The average electrical power output of the selected optimum hybrid system is shown in **Figure 7**. The PV panel supplies most of the electrical power and is complemented by the generator in the months of June, July, August and September when the daily hours of sunlight reduce due to the rainy season. The renewable energy fraction is about 98%.

3.3.3. Evaluation of DSM Measures

The DSM strategies applied was tested using two indices- the Demand Side Management Quality Index (DSMQI) which give the value of 1.23 and the Demand Side Management Appreciation Index (DSMAI), which gives1.35 based on computation with equations (1) and (2) respectively. It can be observed that both DSMQI and DSMAI are above one (1), which is desirable to show that the DSM measures applied were productive in reducing connected load and the cost per kWh of electricity. DSMQI is only a little bit above 1, because the connected load after DSM is almost the same except for the load reduction measures in de-lamping external lighting points and taking out some ceiling fan loads.

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Table 9. Cost Summary of optimum system components

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Genset	712.06	0.00	224.40	676.96	1094.93	516.82
Flat Plate PV	7521.78	0.00	923.13	0.00	0.00	8444.91
Converter	501.45	765.43	615.41	0.00	338.24	1544.05
Battery	1337.20	6258.03	2461.69	0.00	1939.25	8117.68
System	10070.8	7022.63	7567.66	676.96	3372.44	18623.46

Figure 7. Electrical power output of optimum system after DSM

DSMAI on the other hand is little bit higher because of the demand response measures applied, leading to load partitioning namely primary and deferrable.

4. CONCLUSION

This study identified a lack of modern electricity supply as a major impediment to proper functioning of the healthcare centers in the rural areas. An energy audit was conducted at rural clinic located in Nigeria with the aim of developing DSM measures to increase renewable energy penetration at the healthcare center. The current load profile generated showed power supply shortage at the healthcare center. To improve healthcare service delivery, a new load profile was designed to meet the expected energy need. This resulted in peak load, total connected load and average daily demand of 2.67kW, 4.64kW and 20.58kWh/day respectively. The optimum system to meet this load was found to be PV-Gen-Battery system with NPC of $61,917.6. The COE, initial capital cost and CO2 emission of the system were $0.224/kWh, $16,046 and 2,579kg/year respectively.

To reduce both NPC and initial capital cost, DSM measures were proposed. The DSM measures included de-lamping external lighting fixtures, reducing ceiling fan points and load partitioning into primary and deferrable loads. With the implementation of DSM, the new load profile was simulated with the required power supply resource. The optimum system configuration was found to be PV-Gen-Battery system, with initial capital cost of $10,070.8, NPC of $18,614.7, total COE of $0.166/kWh and a renewable fraction of 98%.

With DSM strategies implemented in the considered clinic, a cost savings of $0.06kWh was achieved, representing a 25.8% cost reduction from the present cost of energy per kWh, and 70% reduction in the total net present cost. The optimum system also has about 96% reduction in CO_2 emission. The research has shown that DSM measures could also be used to reduce the initial cost of installing renewable energy systems for off-grid locations..

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