Design, Simulation And Optimization of A Hybrid Renewable Energy System For Bayero University Kano, Nigeria

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Abstract

Hybrid renewable energy system (HRES) combines two or more renewable energy sourcesto improves reliability on power generation. To complement the current powersupply received from Kano Electricity Distribution Company(KEDCO)in Bayero University Kano (BUK) Nigeria,renewable energy resources (RES) were exploited. In this study, wepropose and designa HRESfor BUKusing HOMER 3.4.3 simulationtool. BUK annual load profile, solar radiations, wind speed data and diesel hourly operational data were obtained and used as the inputs to the software with calculated and estimated sized components (Photovoltaic, wind turbine,inverter, diesel generator(s), battery and the loads) coupled together. Two different models wereconsidered to cover all possible states of the system and the outputs of the simulation helps to choose the optimal case for the system. The obtained simulation results, shows that the HRES comprising of diesel generators, PV, wind turbine, battery and inverter is the optimal in terms of economy, efficiency, reliability and environmental friendliness.

Keywords: *HOMER, DBS, HRES, BUK, COE.*

I. INTRODUCTION

Energy played a very significant role in the socio-economic growth of a nation. But, it's quite disturbing that Nigeria is among the 31% of sub-Saharan Africa population that enjoyed this energy [1]. However, regular power outages and insufficient supply, have impaired national economic growth and development [1], [2]. Conventional sources of energy like diesel, have been exploited by various organization to meet their daily load needs [3]. Nigeria tertiary institutions fall in this category, as they constantly run on diesel generators [19].The rise in demand for electrification, fuel prices inflation, hazardous emission and augmented depletion of conventional energy resources has necessitated the world's towards utilization of the viable source of energy called renewable energy (RE) [5],[18].

RE system covers all form of energy generated from natural resources which are consistent and inexhaustible such as sunlight, wind, hydro, tide, and forest resources. Their exploration has provided nations with a clean, secure, reliable and affordable energy accessed [6],[7].These rapid interests in RES have played a key role in addressing the current power epileptic problem. [2] has reported that Nigeria being above the equator with a land mass of $924 * 10^3 \text{km}^2$, is well suited for harnessing the sources of RE such as wind and solar. The efficient use of renewable energy resources would help Nigeria institutions to meet any future load demand without increasing its reliance on conventional resources. However, these energy sources are inherently stochastic and weather dependent. Combining two or more renewable energy sources (RES) to overcome these inherent defects are one of the novel applications of RE technology [19]. The Hybrid Renewable Energy Systems (HRES) combined one or more RES with at least a conventional source in either grid or stand-alone connected mode. RE will provide substantial amount of energy which can significantly meet the load demands, contribute to poverty alleviation and mitigate economy [6]. The aim of this paper is to design and simulate a diesel based with a HRES, in order to choose an optimized system that will produce the desired power needs for BUK new campus.

The rest of the paper is organized as follows. In Section II, we look into the literature review, section III gives the methodology adopted for the study. Section IV; discusses the simulation results. Section V; presents the Conclusions and recommendation for further study.

II. LITERATURE REVIEW

This section looks at some recent works that employed the HRES system for electricity supply. [8] had given hypothetical study for a1Mega standalone hybrid energy system for technical institute in eastern India. In their work, they proposed that hybrid system supplies the power to the Technical Institute throughout the year and had used four sensitivity variables (wind speed, solar irradiation, fuel cost and Battery cost) for their analysis and modelled system using HOMER software. The performance of a commercial scale of 1.2 MW capacity grid connected PV at the Colorado State University-Puebl USA was also investigated with the used of Excel and RETScreen software. It was found that there was a rise in economic feasibility and a substantial expense improvement between year 2008 to 2013[11].

In a similar report, [10] had proved that grid-connected HRES configurations in France is to seek the best combination of available RES to deliver electricity in a reliable and sustainable way to the study office building. He tested the built HRES and showcased a demonstrating ground on a large office building. [9] had also shows that multi-objective design of HRES that operates in both isolated-island and grid-connected modes is modelled and simulated via the use of multi-objective evolutionary algorithm based on decomposition (MOEA/D) and localized penalty-based boundary intersection (LPBI) method. [12] applied a hybrid solar 1.5kW wind/photovoltaic HRES for a Telecommunication Base Station in a rural area of Benin City of Nigeria. [13] had designed a PV/wind-battery and PV/wind/diesel-battery HRES with the goal of supplying electrical energy to remote locations in Malaysia. They also employed HOMER for the system optimization where annual climatic conditions and annual load variation were taken into account and concluded that, PV-wind-battery hybrid as a better option. [18],[20] has carried out a survey on green energy computing and had observed that the sustainability of a healthier environments lies on embracing RE which can cater for both thepresent and future needs with a negligible negative effect.

Most literatures focus on HRES implementation using different simulation tool with consideration on economical and feasibility analysis, with HOMER yielding an ultimate result for stand-alone system.

Hence, this paper proposed to design, simulate and choose an optimize HRES for Bayero University Kano (BUK) new Campus using HOMER 3.4.3 software. Two different case scenarios were investigated. Hybrid of wind and solar integrated with battery, inverter and generators to form a stand-alone power plant. The battery is used as a backup to provide power in the absent of the wind and solar, moreover the backup (battery) can work simultaneously with the wind and solar to supply the load in a synchronized way.

III. METHODOLOGY

For this research, two different models were implemented with their various techno-economic feasibility determined to see whether the load demand is met or not. As part of the design, some parameters within the project lifetime such as; components model, numbers, costs, efficiency, lifespan were calculated, estimated, sized and inputted into HOMER as required [14]. Others were obtained from Geography, Works &Maintenance Department of BUK with wind and solar data downloaded from NASA satellite at approximately Gwarzo location.

A. BUK Data Analysis

a) Wind, Solar Data Energy Resources

The daily radiation and clearness index of Gwarzo road BUK was obtained from HOMER, which uses NASA satellite at approximately this location via National Renewable Energy Laboratory (NREL) website. The data was imported online through HOMER software by entering respective Gwarzo latitude and longitude ($11°59.0'N, 8°28.0'E$) resources information [15], [16].

b) BUK Load Data

The electrical load for BUK New Campus was obtained for year 2015; from the substations catalogue (data book) [17]. These substations were divided into two which are substation A and B. These substations are responsible for supplying electrical power as well as keeping track of all the electrical demand of the New Campus, this catalogue contains all the information with regard to the power consumption, fuel consumption and running hours of the generators. Substation A has a 725Kva (G1) set of generators which is used to serve the Staff Quarters and the student hostels. Substation B has a set of two 500Kva (G2 & G3) generators synchronized together supplying offices and teaching buildings. Both generators supply was in three phase and are set to supply 80 percent of their rated power.

c) Components Cost and Description

The research work is aimed at modeling three diesel generators. One in the medium capacity range with a rated power of 725KW (G1) and the other two are of the small capacity with a power of 500KW (G2 &G3) each[17]. For the purpose of supplying the base and peak load, the scenario of the power operation and the generating capacities of these gen sets were investigated. Hence, the medium 725KW generator is used to carry the base load demand, while the smaller 500KW generators are to supply the peak load demand. The three generators under consideration were produced by caterpillar labeled as CAT. The peak demand of power obtained from BUK sampled data was 1576.04KW as indicated in fig. 3.1.and 3.2 respectively and the genset were then sized to meet the peak load.

For the design and simulation analysis, three generic generators were considered in the course of modeling along with wind turbine, battery, power inverter and PV. The essential parameters of the components were calculated and approximately estimated [4], [14],[19]. Other required data were obtained from the manufacturer’s data sheet. The table below gives the details of the components.

Table 1: Components Description for Modelling

Components	System Description		Cost(₦)
1. **Generator(s)**	Model	Generic (G1, G2 & G3)	Capital G1=18.3M G2=G3=7.37M Replacement G1=18.3M, G2=G3=7.37M O&M G1=252K G2=G3=172K
	Life Time (operating hours)	15000	
	Rated Capacity (KW)	G1=725, G2= G3=500	
	Fuel(L)	diesel	
	Full Load	G1=200; G2=117	
	75% Load (L/h)	G1=160; G2=90.3	
	50% Load (L/h)	G2=115; G2=65.3	
2. Wind turbine	Model	(wind flow 45-500)	Capital = Replacement 1.1M O&M 92K
	Type	3-bladed horizontal axis	
	Life Time (years)	15	
	Rated Capacity (KW)	2.7	
	Hub Height (m)	30	
	Size (quantity)	18	
3. Battery	**Model**	Trojan-IND9-6V	Capital = Replacement 32K O&M=0
	Life time (kwh)	4575/battery	
	Nominal Voltage (V)	6	
	Capacity (Ah)	602	
	Batteries/String	55	
	Min. State of Charge (%)	20	
	Float Charge (C)	6.75	
4. Power Converter	Capacity (KW)	300	Capital = 50,000/kw Replacement=O&M=0
	Life Time (years)	15	
	Inverter Efficiency (%)	90	
	Rectifier Efficiency (%)	70	
	Relative Capacity (%)	100	
5. PV	Model	Generic flat plate	Capital=420K
	Size (KW)	150	

Key: O&M-operation and maintenance, M-Million, K-Thousand

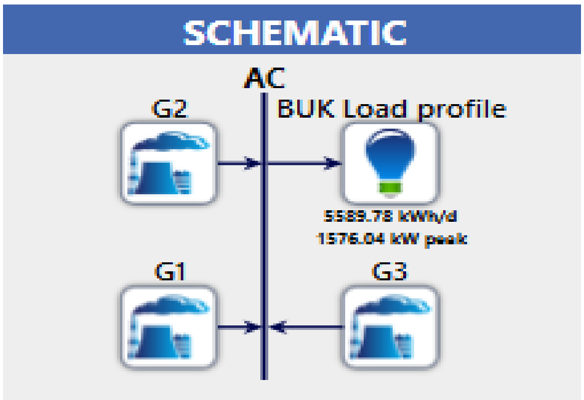
d) Design Models

1. Diesel-based system (DBS)

This is a baseline case which was optimized for providing all power from diesel generators with no energy storage, RES or any other sources of electricity [9]. The operational hourswas coveredfor annual with the diesel generators used in a year. The model included all the capital cost and other design assumptions[14], [19]. The first model is shown below in Fig.1.

2.Hybrid Renewable Energy System (HRES)

The HREScomprises of two RE sources (solar and wind) and two diesel generators (G2 and G3) with a capacity storage using battery banks as modelled by HOMER. The model is shown in Fig.2.



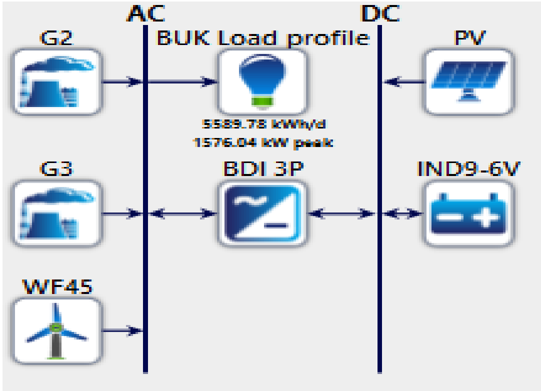


Fig1: Model1(DBS) Fig2: Model2(HRES)

IV.RESULT AND DISCUSSION

A. Simulation and Optimization Results

The simulation is done to evaluate and compare the two different modelsin order to determine the best configuration from the possible combinations in each model [1]-[3]. All the possibleconfigurations are listed in terms of their architectures and costs. The technical and economical details of theobtained optimized configurations for the two modelswerepresented along with other combinations.

The two different scenarios have been considered with the fuel price of ₦202/Land the costs for HRES have also been taken into account.

The highlighted section shows an optimized combination.

a) The first model (DBS).

From the optimization results shown in Fig 3, the sampled annual operational performance of G1, G2 and G3 are presented. This set-up appears to have a total NPC of ₦679Mand COE of ₦34.01.Though, the operating cost, initial capital, fuel cost and O&M are averagely optimized as compared to other tested possibilities in the search space as presented in fig.3.

Architecture				Cost					
Gen500 (kW)	Gen725 (kW)	Gen500 (1) (kW)	Dispatch	COE (₦)	NPC (₦)	Operating cost (₦)	Initial capital (₦)	Fuel cost (₦)	O&M (₦)
500		500	CC	₦33.46	₦668M	₦66.7M	₦14.7M	₦61.8M	₦1.51M
	725	500	CC	₦33.97	₦678M	₦66.6M	₦26.1M	₦62.0M	₦1.51M
500	725	500	CC	₦34.01	₦679M	₦66.0M	₦33.4M	₦61.9M	₦1.51M
500	725		CC	₦34.31	₦685M	₦67.3M	₦26.1M	₦62.7M	₦1.51M
	725		CC	₦48.89	₦976M	₦97.8M	₦18.7M	₦85.7M	₦2.21M

KEY: Gen725-G1, Gen500-G2 and Gen500(1)-G3

Fig3: DBS Optimization Result

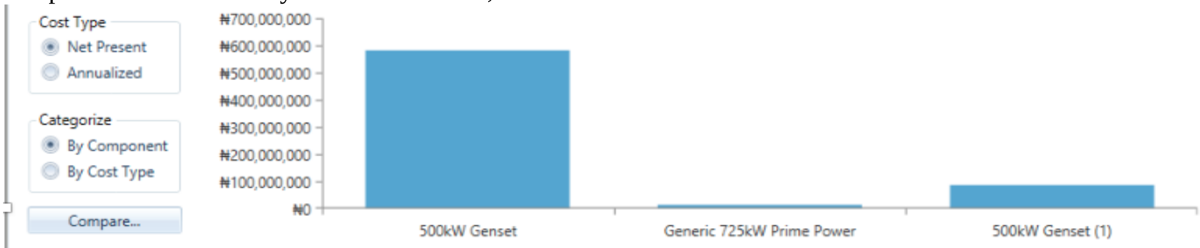
b) The second model (HRES)

As shown in Fig4., the HRES optimized result, have a higher NPC and initial capital with a reduction in the levelized cost of energy (COE) at ₦31.15/kWh as compared to the ₦34.04/kWh of the diesel-based system. In addition, there is reduction in O&M cost, operating cost and fuel cost.The lower NPC of the hybrid system is due the reduction in operation cost despite the rapid increase in the initial capital cost of the system. The lower cost of operation in the hybrid system is due to the lower electricity production of the cumulative energy contribution of the diesel generators in the hybrid system as compared to the diesel only system.

Architecture							Cost			
PV (kW)	WF45	G2 (kW)	G3 (kW)	IND9-6V	BDI 3P (kW)	Dispatch	COE (₦)	NPC (₦)	Operating cost (₦)	Initial capital (₦)
0.0300	21		500	10,000	500	CC	₦30.86	₦616M	₦24.7M	₦375M
0.0300	21	500		10,000	500	CC	₦30.98	₦618M	₦24.9M	₦375M
0.0300	21	500	500	10,000	500	CC	₦31.15	₦622M	₦24.5M	₦382M

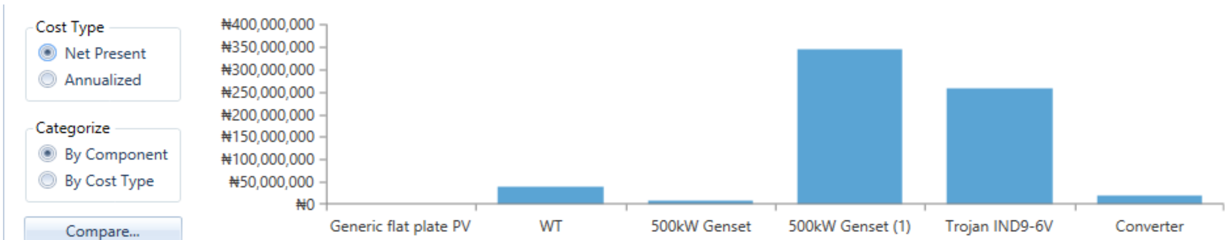
Fig4: HRESOptimization Result

The Cost Summary illustrating the Capital, replacement, O&M, fuel, salvage, and total are shown in fig5 and fig6 respectively for both diesel-based system and HRES [19]. The contribution of each generators is graphically indicated. When compared diesel-based system with HRES, it was observed that there is drastic reduction in the obtained costs and fuel consumption of HRES. Hence, this makes HRES a preferred model of recommendation for BUK New campus.



Component	Capital (₦)	Replacement (₦)	O&M (₦)	Fuel (₦)	Salvage (₦)	Total (₦)
500kW Genset	₦7,370,000.00	₦32,945,386.00	₦12,110,543.00	₦530,531,968.00	(₦2,520,277.00)	₦580,437,632.00
Generic 725kW Prime Power	₦18,700,000.00	₦0.00	₦9,865.60	₦603,474.00	(₦7,902,179.00)	₦11,411,162.00
500kW Genset (1)	₦7,370,000.00	₦4,267,250.00	₦2,641,290.00	₦74,389,320.00	(₦1,347,692.00)	₦87,320,160.00
System	₦33,440,000.00	₦37,212,636.00	₦14,761,701.00	₦605,524,800.00	(₦11,770,147.00)	₦679,169,024.00

Fig5:Cost Summary of the DBS



Component	Capital (₦)	Replacement (₦)	O&M (₦)	Fuel (₦)	Salvage (₦)	Total (₦)
Generic flat plate PV	₦137,830.00	₦0.00	₦0.0326	₦0.00	₦0.00	₦137,830.00
WT	₦22,000,000.00	₦0.00	₦18,107,678.00	₦0.00	₦0.00	₦40,107,672.00
500kW Genset	₦7,370,000.00	₦0.00	₦43,769.00	₦2,919,112.00	(₦3,045,596.00)	₦7,287,285.00
500kW Genset (1)	₦6,370,000.00	₦11,675,931.00	₦3,913,371.00	₦325,108,768.00	(₦1,805,351.00)	₦345,262,688.00
Trojan IND9-6V	₦287,100,000.00	₦0.00	₦0.00	₦0.00	(₦30,452,230.00)	₦256,647,776.00
Converter	₦15,000,000.00	₦8,469,450.00	₦0.00	₦0.00	(₦3,182,051.00)	₦20,287,398.00
System	₦337,977,824.00	₦20,145,382.00	₦22,064,814.00	₦328,027,872.00	(₦38,485,228.00)	₦669,730,752.00

Fig6: Cost summary of HRES

c) Techno-Economic Analysis Result

The operational characteristics and techno-economic result of G1, G2 and G3 are shown in table 2.0. and Table 2.1. It describes the techno-economic operation as well as the system parameters such as; (excess electricity, unmet electric load and capacity shortage)for both the diesel-based system and HRES.

In a DBS, HOMER indicated that it is economically unwise to operate G1 (725KVA) in this operational consideration. Moreover, G2 produce most of the load requirement amounting to 88.31% of the load while G3 produce almost the rest of the load requirement of 11.6% with least of 0.09% contribution from G1. Also, with the availability of 100% of AC loads, it was noted that there was no reserved excess electricity to meet the future demand.

Similarly, it was observed in HRES, that two components contributed maximally to the total generation. The wind technology happened to be the favourite source of electricity contributing about 79.2% while G2 contributed 20.53%. G3 contribution is just 0.19% of the total generation.

There is much increase in excess energy of 52.1% of the total production when compared to the diesel only plant. This excess energy production will adequately cater for future load demand and variation in the current load requirement.

Table 2: Optimized Techno-Economic result of the DBS

	Output				Total
		G1	G2	G3	
Output (kwh/yr.)		1885	1813215	238168	2053268
% Output		0.09	88. 31	11.60	100
	Parameters				
	AC Load	Excess Electricity	Unmet electricity	Unmet electric load	Capacity Shortage
Output kWh/yr.)	2040276	12997.22	0	0	8.64
% (Output)	100	0.6	0	0	0

Table 3:HRES Techno-economic result

Output (kwh/yr.)	G2	G3	Wind turbine	PV	Battery annual throughput	Total generation
-	1104014	10366	4409163	53	7218.30	5403635
-	20.53%	0.19%	79.28%	0.00	-	100%
Parameters (kwh/yr.)						
AC Loads	Excess electricity	Unmet electric load	Capacity shortage			
2040000	2897217	276.0	553.0			
47.7%	52.1%	0.10	0.10			

c.GHG gas emission

As part of the obtained simulations result, the greenhouse gas (GHG) emission of both the DBS and HRES are illustrated by table 4. It shows that, there is a detrimental effect on the environment due to the emission of higher quantityof hazardous gas substances.Moreover, when compared with proposed HRES system, the GHG emission is negligible.HRES have a minimal emission detrimental effect and become more environmentallyattractive.

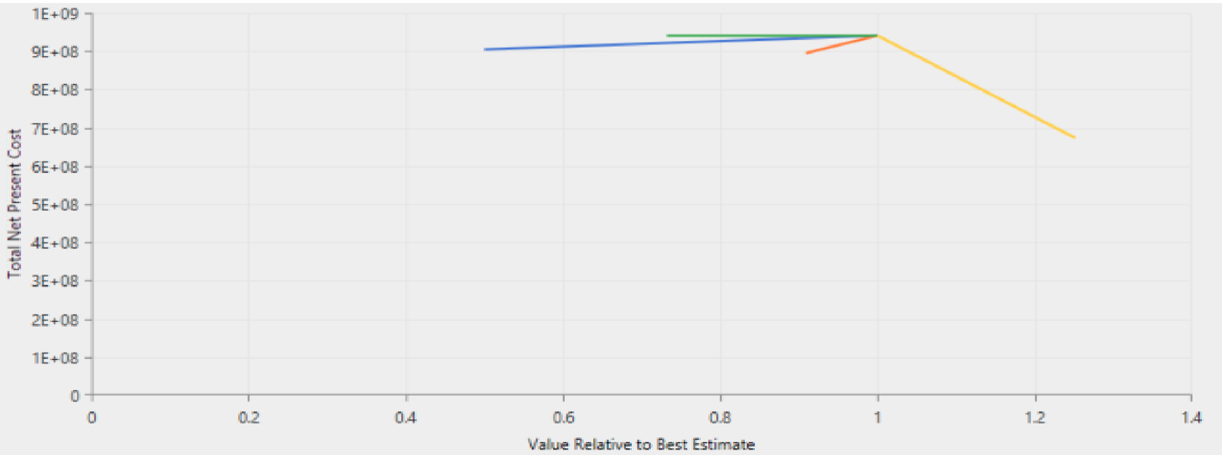
Table 4: DBS and HRES GHG gas emission

Quantity	DBS Value Kg/yr.	HRES Value Kg/yr.
Carbon Dioxide	1481079.00	802340.00
Carbon Monoxide	3658.40	1980.00
Unburned Hydrocarbons	405.26	219.37
Particulate matter	275.50	149.30
Sulphur Dioxide	2974.30	1611.00
Nitrogen Oxides	32595.00	17672.00

KEY: GHG-Green House Gas

d.Sensitivity Analysis

A sensitivity analysis was also carried out todetermine the sensitivity of the system's total net present cost to the four uncertain variables (wind turbineO&M, Diesel fuel price and scaled average of PV and Wind) []. The range of uncertainty was covered by inputting multiple values for each variable. The spider graph shown in figure 3.7 belowshows that NPC is most sensitive to the diesel fuel price and wind speed as their lines appeared to be steep. It is an indication that, a significant increase in diesel price and wind speed will tend to potentially reduce the NPC. The fuel prize was increased from ₦202/L to ₦205/L and subsequently decreased to ₦195/L. A 20% increase or decrease in solar radiation (PV) as well as a maximum of four times increase of the O&M cost estimated for the wind turbines indicates an almost negligible effect on the NPC as shown in the spider graph. Therefore, these two parameters should not be given much emphasis for any future investment [4].



kEY: Blue-Wind turbine O&M, Orange: Diesel fuel price, Green: Solar radiation (PV) and Yellow: Wind speed

Fig7: Spider plot showing the result of the sensitivity variables used.

V. CONCLUSIONS

This study explored the application of hybrid renewable energy system to supply the load of Bayero University Kano, Nigeria. Two case studies were designed and simulated. The output of the simulation helps to choose the optimal case for the system. It is shown that the optimal case is the solar-wind-diesel hybrid system (HRES). The chosen percentage of Minimum Renewable Fraction, considering cost and emissions, was 44%. Resource assessments and demand calculations have been carried out and the COE per kWh has been ascertained for different possible configurations. It has also been shown that, HRES is feasible with a considerable amount of COE as cheap as 31.15/kWh.

However, the main drawback of hybrid energy systems is especially on a larger scale which has high initial capital cost and the unreliability of RES. These obstacles can be expected to be removed by technological progress. Thus, the use of hybrid systems will become even more attractive, especially since they are environmentally friendly, reliable and can be operated continuously. For future analysis, micro-grid case is highly recommended for implementation, as full exploration has been made to stand-alone, like in this case.

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REFERENCES

[1] Richard Ileberi, G. (2015). Feasibility of Harnessing Renewable Energy at an Off-grid Community in Nigeria. International Journal of Scientific & Engineering Research, 6(4).

[2] Anayochukwu, A. (2013). Simulation of photovoltaic/diesel hybrid power generation system with energy storage and supervisory control. International Journal of Renewable Energy Research, 3(3), 605-614.

[3] Aboudou, K., & El Ganaoui, M. (2017). Feasibility study for the production of electricity using a hybrid PV-wind-generator system in a remote area in comoros. International Journal of Recent Research and Applied Studies, 33(2), 23-36.

[4] Sagbansua, L. and Balo, F. (2016). Evaluatıon of the Solar Panels in Terms of Energy Effıcıency. International Journal of Computer Trends and Technology, 42(1), pp.59-65

[5] Kajela, D., & Manshahia, M. (2017). Optimization of Renewable Energy Systems: Review. International Journal of Scientific Research in Science and Technology (www.Ijsrst. Com), 3(8), 769-794

[6] Murugaperumal, K., & Ajay D Vimal Raj, P. (2019). Feasibility design and techno-economic analysis of hybrid renewable energy system for rural electrification. Solar Energy, 188, 1068-1083. doi: 10.1016/j.solener.2019.07.008

[7] Kour, O. (2018). Technical and economic Analysis of a Hybrid Power System: A Case Study for a Village in India. International Journal for Research in Applied Science and Engineering Technology, 6(5), 2043-2049. doi: 10.22214/ijraset.2018.5334

[8] Nema, P., & Dutta, S. (2012). Feasibility Study of 1 MW Standalone Hybrid Energy System: For Technical Institutes. Low Carbon Economy, 03(03), 63-68. doi: 10.4236/lce.2012.33009

[9] Ming, M., Wang, R., Zha, Y., & Zhang, T. (2017). Multi-Objective Optimization of Hybrid Renewable Energy System Using an Enhanced Multi-Objective Evolutionary Algorithm. Energies, 10(5), 674. doi: 10.3390/en10050674

[10] Islam, M. (2018). A techno-economic feasibility analysis of hybrid renewable energy supply options for a grid-connected large office building in southeastern part of France. Sustainable Cities and Society, 38, 492-508. doi: 10.1016/j.scs.2018.01.022

[11] Paudel, A., & Sarper, H. (2013). Economic analysis of a grid-connected commercial photovoltaic system at Colorado State University-Pueblo. Energy, 52, 289-296. doi: 10.1016/j.energy.2013.01.052

[12] Somkene N. Mbakwe, M. T. Iqbal, and Amy Hsiao "Design of a 1.5kW Hybrid Wind / Photovoltaic Power System for a Telecoms Base Station in Remote Location of Benin City, Nigeria".

[13] Fadaeenejad, M., Radzi, M. A. M., AbKadir, M. Z. A., and Hizam, H., "Assessment of Hybrid Renewable Power Sources for Rural Electrification in Malaysia," Renewable and Sustainable Energy Reviews, Vol. 30, pp. 299-305, 2014.

[14] ALTESTORE. (n.d.). altestore.com. (Alternative Energy Store Inc) Retrieved 05 08, 2019, from https://www.altestore.com/store/

[15] NASA surface meteorology and solar energy website, https://eosweb.larc.nasa.gov/cgi-bin/sse/grid.cgi/

[16] The HOMER energy website, http://www.homerenergy.com

[17] BUK Maintenance Service Department. (2017). Central Maine Diesel. (n.d.). centralmainediesel.com. (Central Maine Diesel Inc) Retrieved 08 08, 2017, fromhttp://www.centralmainediesel.com/order/09152.asp?page=9152.

[18] Saha,B.(2014).GreenComputing. International Journal of Computer Trends and Technology, 14(2), pp.46-50.

[19] Abubakar B., Abubakar A. and Bello S. M., (2016) Feasibility studies of a hybrid renewable energy for Electrical Engineering Department of Bayero University, Kano.

[20] Abid, A. and Hussein Ali, A. (2017). Smart Monitoring of the Consumption of Home Electrical Energy. International Journal of Computer Trends and Technology, 47(2), pp.142-148