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Modeling And Simulation of a Reliable Hybrid (Pv/Diesel) Power System with Energy Storage in Batteries for University Library, Bayero University, Kano State, Nigeria

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Abstract

Due to unreliability of power supply from national grid, high cost of diesel and maintenance of generators being an alternate for national grid, there is need to adopt a renewable energy source for efficient and reliable power supply. Savings associated with conversion of a stand-alone diesel generator powered system to a reliable PV/Diesel hybrid power system with energy storage in batteries for Bayero University Kano Library using HOMER software was presented in this study. The economic parameter of merit used in selecting an optimum energy system from set of configurations was total Net Present Cost (NPC) in billions of naira. Generator + PV + Battery system has a total NPC of (₦ 1.17B) and saves (₦ 0.9B), Generator + PV system has a total NPC of (₦ 1.68B) and saves (₦0.4B), Generator + Battery system has a total NPC of (₦ 2.05B) and saves (₦ 0.03B), PV + Battery system has a total NPC of (₦ 2.28B) and saves (₦ - 0.2B) when all compared with Generator-only system (₦ 2.08B). It can be seen that the best case is the PV + Gen + Battery system. Even though it has the highest capital cost, but it resulted to the least net present cost (NPC); as such, PV + Gen + Battery system is the optimized model to fulfill the load demands. Therefore, this research work shows that the integration of PV with battery storage into the existing diesel stand-alone system in the University library is more reliable at the lowest lifecycle cost.

Keywords: HOMER; Modeling Simulation; Hybrid System; Generator + PV + Battery Hybrid System; Net Present Cost

INTRODUCTION

Many Nigerian Universities augment greater proportion of their deficit to electricity due to mismatch between demand and supply from the national grid by supplies from diesel or gasoline powered generators, which can be noisy and have the disadvantage of increasing the greenhouse gas emission that has a negative environmental impact. Due to these environmental problems and high cost of running petrol or diesel generators, many universities are willing to shift from using these traditional generators to the use of renewable energy technologies to achieve their energy mix (Oloketuyi, 2013). The installation of a solar power system to offset or replace a portion of the diesel power system is an option to be considered; yet complete replacement of diesel power system with solar power generation system is usually not possible, due to intermittent nature of solar radiation especially during

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the rainy season (Sambo, 2013). However, a combination of solar and diesel system known as hybrid system is proving to be very reliable and cost effective. Applications of hybrid energy systems are of increasing interest, because a well-managed hybrid solar/diesel system can achieve lifetime fuel savings, whilst ensuring reliable electricity supply (Faruk, 2012).

Bayero University, Kano is located at Latitude 11^{o}57′56.27″ Longitude 8^{o}25′5.22″ having daily solar radiation raging from the least which is the month of August with 5.55 kWh/m^2/day to the highest period which is the month of March with 6.89 kWh/m^2/day (Kutama *et al*., 2012). Hybrid Power System (HPS) has been known to be among the popular cost-effective renewable energy systems, but little or no attention has been given to such system in Nigeria. In hybrid (PV/Diesel) powered system, a diesel generator can provide energy at any time, whereas energy from PV is greatly dependent on the availability of solar radiation. This makes the system (generator) more reliable and can be used for operation when the PV fails to satisfy the load and when the battery storage is depleted (Odhiambo, 2017). Modeling a hybrid power system requires proper components sizing and selection with effective operational strategy.

The software HOMER was developed by the National Renewable Energy Laboratory (NREL) in the United States, purposely to design and evaluate financially and technically the options for off-grid and on-grid power systems for various generation applications. The software was first developed in 1993 for internal Department of Energy to understand the tradeoffs between different energy production configurations. After some couple of years with the original version, NREL developed another version to serve the growing designers of renewable energy systems. To date, HOMER remains the software for modeling and simulation of both conventional and renewable energy technologies. It is user-friendly software that can be easily configured, and the managed information is complete, as well. This software is a computer modeling tool based on a genetic algorithm that can evaluate different situations to determine the system configuration that will provide acceptable reliability at the lowest lifecycle cost. The software performs three principal tasks: simulation, optimization and sensitivity analysis (Ani & Emetu, 2013).

Hybrid system comprises of multiple technologies each mature in their own right, but it is their combination that allows for significant reduction in the cost of electricity to communities currently far from the grid. Hybrid power systems are flexible platforms that can provide cheaper electricity than systems using only one energy source (Shaahid & El-Hadidy, 2004). An optimum design carried out usually minimizes the Net Present Cost (NPC), which is the investment costs plus the discounted present values of all future costs during the lifetime of the system. It also considers the residual value of system components after the project ends (salvage costs). An alternative to the NPC in comparing the economics of various system configurations is the levelized COE, which is defined as the average cost for every kWh of electricity produced by the system. The economic figure of merit chosen by HOMER is NPC (Hoque *et al*., 2012).

HOMER software has been successfully used by a vast number of energy system designers. They include that of Modu *et al.* (2018) whom proposed PV-diesel-battery Hybrid Power System (HPS) as the focus for an area after considering the Net present costs of $0.434/kW in a research carried out on techno-economic evaluation of a hybrid PV-diesel-Battery system of some houses at Barhim Quarters of Katsina state in Nigeria. Detailed techno-economic analysis of hybrid PV-diesel-Battery system using HOMER simulation and Optimization software performed by Hrayshat (2009) to meet the load demand of off grid houses located in some remote settlement clearly revealed that such a system is economically viable as it reduced about 19.3 % diesel generator operating hour alongside with about 18.5 % diesel consumption when compared with the diesel only solution. Another research on technical feasibility and economic assessment of PV/diesel/battery hybrid off-grid energy system for some remote villages was carried out by Bukar *et al.* (2017) using HOMER. The result obtained from the study shows that a hybrid PV/diesel with a backup battery has the potential of replacing diesel powered generator used by individual households independently due to the fact that it has less net present cost as well as less level of greenhouse gas emissions. Detailed simulations and financial analysis were performed with HOMER by Alayan (2016) to study the viability of integrating photovoltaic generators into an existing diesel unreliable grid connected system at the Lebanese village of Khiam. The simulated PV-diesel-battery hybrid system was modeled with an existing diesel capacity of 200 kVA, PV capacity of 270 kWp, battery bank nominal capacity of 1872 kWh and inverter output of 115 kW. The project life cycle of 25 years and the system renewable fraction of 53% provide further justification for PV installation in a commercial PV-diesel hybrid system. Riasat *et al*. (2013) designed and conducted an experimental analysis on a PV-diesel hybrid power system to meet the residential loads in Dhaka city. Their findings revealed that the use of PV-diesel hybrid system with battery significantly reduced the dependence on available diesel source as it gave a total net present cost (NPC) of 164106 USD and a renewable fraction of 25 percent. But for all that, the remaining challenge is the high capital cost involved in PV-diesel-battery Hybrid Power System (HPS). This is in line with the experience acquired by Ani (2013) in his research on photovoltaic (PV) hybrid system for a residential home located in Southern Nigeria. The simulation was run to compare PV/diesel/battery with diesel/battery system using HOMER. His findings had brought to light that the capital cost of a hybrid (PV/diesel) solution with batteries is virtually three times higher than that of a diesel generator and battery option, while the net present cost (cost representing cost across the lifetime of a system) is less than one-half of the diesel generator and battery option. This economic comparison clearly shows that such a system could pay back its investment cost within two years and saves a huge amount of money.

This research work involves identifying and measuring or taking readings of the load of all equipment or appliances used in the University library of Bayero University Kano, Nigeria, identifying the generator capacity attached to the library and use HOMER software to model and simulate in order to achieve an optimized hybrid energy system that will produce the desired power needs of the University library while minimizing the financial expenditure, since no such study has been carried out for the University.

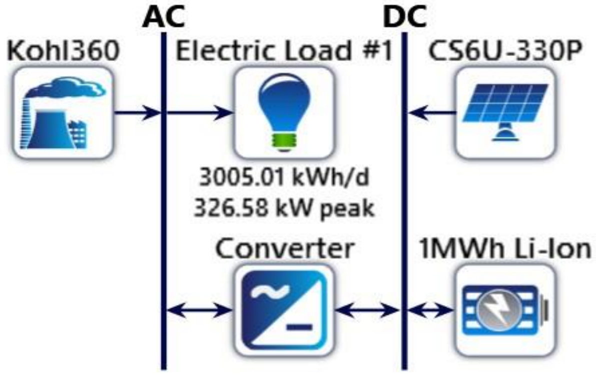

Figure 1: Generator + PV + Battery System Schematic (HOMER)

Methodology

Hybrid Optimization Model for Electric Renewable (HOMER) was the computer modeling software used to model and simulate this PV/diesel/battery hybrid system. The power system model was defined by clicking the Add/Remove button. Through the Add/Remove window the power system components (Primary Load, PV, Converter, Generator and Battery) were selected. At the bottom of the window "do Not Model Grid" was selected. Daily average power load profile was determined from data provided by equipment vendors using Microsoft excel. The primary load defines the power profile for the AC and DC equipment; as such the hourly load profile of each load was entered into primary load by clicking on the Primary load icon according to the setup defined in the schematic model shown in figure 1. Solar resources (monthly, annual and average radiation) were imported directly by HOMER from the NASA Surface meteorology and Solar Energy database by entering the GPS coordinates. Diesel price has a significant impact on the running costs of a system equipped with a diesel generator; as such diesel price was added by clicking the Diesel icon in HOMER. The system economic factors such as: Project lifetime, Annual Interest Rate, System Fixed Capital Cost, Capacity Shortage Penalty and System Fixed O&M Cost were determined by clicking on the Economics icon in HOMER. Equipment were defined by clicking on the icon of each component of the power system. The key parameters considered when defining each component were: Size, Cost, Replacement Cost, Efficiency, Operating Lifetime and O&M expenditure. HOMER calculated the different permutations of possible designs based on the inputs provided and simulated the power system after clicking the Calculate button. The optimized results panel displayed the list of configurations available and ordered by the total NPC (Net Present Cost). A comprehensive set of data providing high level of detail on each system component were accessed by clicking on each of the displayed solution (Kassam, 2010).

Results and Discussion

Sequel to the dimensioned modeling and simulation configuration, results of Net Present Cost (NPC) for the respective configurations are presented in Table 1. To make reading easy, only the key results are presented in this section while an example of a detailed system report can be found in HOMER – System Report of this study.

Table 1: Net Present Costs for Generator + PV + Battery System

System	Capital	Operating	Replacement	Salvage	Resources	Total NPC
Generator + PV + Battery	₦762M	₦63.3M	₦172M	-₦61.0M	₦232M	₦1.17B
Generator + Battery	₦462M	₦46.1M	₦135M	-₦35.3M	₦1.44B	₦2.05B
Generator + PV	₦144M	₦66.7M	₦58.8M	-₦10.00M	₦1.42B	₦1.68B
Generator only	₦14.1M	₦55.6M	₦54.0M	-₦4.50M	₦1.96B	₦2.08B
PV + Battery	₦1.97B	₦189M	₦178M	-₦48.7M	₦0.00	₦2.28B

Generator + PV + Battery System has total Net Present Cost (NPC) of ₦ 1.17B, Generator + PV System has ₦ 1.68B, Generator + Battery System has ₦ 2.05B, generator system has ₦ 2.08B and PV + Battery has ₦ 2.28B.

HOMER software was used to model a hybrid system consisting of PV and a lithium-ion battery for storage with a backup diesel generator. Simulations with different combination of resources were implemented to find the most optimal configuration of the hybrid model. Optimal system configuration refers to the systems with least Net Present Cost (NPC), which is the metric HOMER uses to rank systems. Findings from current study revealed that Generator + PV + Battery system has a total NPC of (₦ 1.17B) and saves (₦0.9B) when compared with the Generator-only system (₦ 2.08B). Generator + PV system has a total NPC of (₦ 1.68B) and saves (₦0.4B) when compared with the Generator-only system (₦ 2.08B). Generator + Battery system has a total NPC of (₦ 2.05B) and saves (₦0.03B) when compared with the Generator-only system (₦ 2.08B). PV + Battery system has a total NPC of (₦ 2.28B) and saves (₦ - 0.2B) when compared with the Generator-only system (₦ 2.08B). The PV + Battery system needs both high solar PV generation capacity and high storage capacity to meet the load demand. Reducing the generation and/or storage capacity in order to save costs made the system infeasible, and increasing the generation and/or storage capacity made the system too expensive together with very high excess electricity. For systems without battery storage the size of the PV system is constrained by the intermittent nature of solar energy and its effects on grid stability. The maximum RE fraction in terms of RE electricity production to total electricity production achieved without battery storage was 5-6%, while PV/Diesel systems with battery storage achieve RE fractions of up to 67% and save considerable amounts of fuel at a lower total NPC than the diesel stand-alone systems.

Findings from current study shows agreement with the conclusion drawn by Bataineh *et al.* (2014), that hybrid PV/diesel system has good application potential in remote areas especially in replacing or upgrading existing standalone diesel systems. The results are also in line with the decision reached by Zelalem (2013) that PV/diesel/ battery system has economic as well as technical advantages over a standalone diesel system following his study on feasible configuration of diesel generator with solar PV system as back up in Ethiopia for hypothetical rural school electrification. This conclusion drawn on the technical and economic advantage of PV/diesel/ battery system over standalone diesel system shows consistency with the one drawn by Modu *et al.* (2018) in his study. Findings from current study is also in agreement with that of Alayan (2016) at the Lebanese village of Khiam, who disclose the viability of integrating photovoltaic generators into an existing diesel unreliable grid connected system. Sensitivity analysis revealed that the effect of primary load and fuel price have a vast impact on the total Net Present Cost. By increasing the power load alongside with the diesel price, the installation and operation costs of the system rise accordingly. However, one technical issue that was not incorporated in the simulations was system control devices which provide grid stability and control different components of the system. Prices for control systems are difficult to obtain, as they must be designed individually according to the particular system configuration.

CONCLUSION

Detailed system model and simulation configuration within five different scenarios were achieved using HOMER. The summary of configuration result clearly revealed that the worst case from the five models is the PV + Battery system which has ridiculously high net present cost. It can also be seen that the best case is the PV + Gen + Battery system as it resulted to has the least net present cost with optimized sized components of 924 kW PV, 360 kW diesel Generator, 1MWh Li-Ion battery and 750 kW converter size. Therefore, this paper has revalidated the use of HOMER as software to model and simulate a reliable hybrid energy system for libraries, and verified the predictions that PV/diesel hybrid system is superior to the diesel-only system for desired power generation in the University library.

References

Abam, F. I., Nwankwojike, B. N., Ohunakin, O. S., and Ojomu, S. A. (2014). Energy Resource Structure and On-Going Sustainable Development Policy in Nigerian: A Review. *International Journal of Energy And Environmental Engineering*, 5(2): 1-16.

Akin, I. (2008). Nigeria's Dual Energy Problems: Policy Issues and Challenges. In the Proceeding of the International Association for Energy Economics Conference, pp: 17-21.

Alayan, S. (2016). Design of a PV-Diesel Hybrid System with Unreliable Grid Connection in Lebanon. (Master's Dissertation). European Solar Engineering School, Dalarna University, Dalarna.

Ani, V. A. (2013). Energy Optimization of Power Station for a Small Research Institute. *International Journal of Energy Optimization and Engineering (IJEOE)*, 2(2): 15-31.

Ani, V. A., and Emetu, A. N. (2013,) Simulation and Optimization of Photovoltaic/Diesel Hybrid System for Health Service Facilities in Rural Environments. *Electronic Journal of Energy & Environment*, 1(1): 57-70

Bataineh, A., Alqudah, A., and Athamneh, A. (2014). Optimal Design of Hybrid Power Generation System to Ensure Reliable Power Supply to the Health Center at Umm Jamal, Mafraq, Jordan. *Energy and Environment Research,* 4(3): 9-27

Bukar, A. L., Modu, B., Gwoma, Z. M., Mustapha, M., Buji, A. B., Lawan M. B., Tijjani, I., Benisheik, U. A., Bukar, A., and Mai, K. B. (2017). Economic Assessment of PV/Diesel/Battery Hybrid Energy System for a Non-Electrified Remote Village in Nigeria. *European Journal of Engineering and Technology*, 2(1): 21-31.

Faruk, N., Ayeni, A. A., Muhammad, M.Y., Abdulkarnim, A. and Moses, O. (2012). Hybrid power systems For Cell Sites in Mobile Cellular Networks. J*ournal of Selected Areas in Renewable and Sustainable Energy (JRSE)*, pp: 8-12.

Hoque, M. M., Bhuiyan, I. K. A., Ahmed, R., Farooque, A. A., and Aditya, S. K. (2012). Design, Analysis and Performance Study of a Hybrid PV/Diesel - Wind System for a Village Gopal Nagar in Comill. *Global Journal of Science Frontier Research Physics and Space Science*, 12(5): 1-6

Hrayshat, E. S. (2009). Techno-Economic Analysis of Autonomous Hybrid Photovoltaic-Diesel- Battery System. *Energy for Sustainable Development,* 13(3): 143-150.

Kassam, A. (2010). HOMER Software Training Guide for Renewable Energy Base Station Design. *Green Power for Mobile Resources*, retrieved from https://www.gsmworld.com/ourwork/mobile_planet/green_power_for_mobile/resources.htm

Kutama, A. S., Saratu, A. O., and Asma'u A. U., (2012). Occuranace of Wood-and Root-Rot Basidiomycetes on Trees in Bayero University, Kano, Nigeria. *Bayero University Journal of Pure and Applied Sciences,* 5(2): 26-30.

Modu, B., Aliyu, A. K., Bukar, A. L., Abdukadir, M., Gwoma, Z. M., and Mustapha, M. (2018). Techno-Economic Analysis of Off-Grid Hybrid PV-Diesel-Battery System In Katsina State, Nigeria. *Arid Zone Journal of Engineering, Technology and Environment,* 14(2): 317-324.

Odhiambo, O. P., (2017). Evaluation of the viability of solar and wind power system hybridization for safaricom off-grid GSM base station sites, Nairobi, Kenya. Master's Dissertation, School of Engineering, University of Nairobi, Kenya.

Oloketuyi, S. I., Oyewola, O. M., and Odesola, I. F. (2013). Determination of Optimum Tilt Angles for Solar Collectors In Lo-Latitude Tropical Region. *International Journal of Energy and Environmental Engineering,* 2(4): 2-9.

Riasat, M. T., Muntasir, A. A., Samirah, T., Atlamis, N., and Salmin, A. (2013). Design and performance analysis for hybrid PV-Diesel-Battery power system for residential area in Dhaka city. *2013 IEEE 39th Photovoltaic Specialists Conference (PVSC),* pp. 1515 - 1520.

Sambo, A. S., (2013). Renewable Energy Development in Nigeria. World's Future Council and Strategy Workshop on Renewable Energy, Accra, Ghana.

Shaahid S. M., and El-Hadidy M. A. (2004). Opportunities for Utilization of Stand-Alone Hybrid (Photovoltaic+Diesel+Battery) Power Systems in Hot Climates. *Renewable Energy,* 28(11): 1741-1753.

Umoh, F. O., Essien, O. A, Ijah, C. J., and Sunday, A. E. (2021). Determination of Phosphorous Fixation Capacity on Aluminum, Sandstone and Shale Soils Of Akwa Ibom State, Nigeria. *International Journal Of Sustainable Agricultural Research,* 8(2): 105-113.

Zelalem, G. (2013). Technical and Economic Assessment of Solar PV/Diesel Hybrid Power System for Rural School Electrification in Ethiopia. *International Journal of Renewable Energy Research*, 3(3): 735-744.