OPTIMISATION OF INDEPENDENT HYBRID PV-DIESEL BATTERY SYSTEM FOR POWER GENERATION IN REMOTE VILLAGES

I. A. Bakura
College of Agriculture and Animal Science Bakura, Zamfara State.
ibromasud@gmail.com

ABSTRACT
This study investigates the feasibility of electricity production using standalone solar PV (Photovoltaic)/diesel (generator) hybrid systems suitable for remote areas.Hybrid Optimization Model for Electric Renewable (HOMER), software for optimization of renewable based hybrid systems has been used to determine the most optimal system configuration in terms of cost and renewable energy contribution. Twenty years solar radiation data (1991 to 2010) was obtained from NIMET and was subsequently analyzed using the software. In the Overall Optimization Results table, HOMER displays a list of the five system configurations that it found to be feasible according to their total net present cost (NPC). For the most feasible system configuration, the total NPC is $240, 032, the initial capital cost is $39, 760, the operating cost per year is $14,322 and the Levelized cost of energy (LCOE) was $0.403/kWh. It was found out that solar energy contributed 70% while diesel contributed 30%. Sensitivity analysis was also conducted, in which two sensitivity variables have been chosen into accounts. The chosen variables are amount of solar radiation of the site (6.4, 6.6, 6.8 & 7) and the price of diesel fuel (0.9, 1.0, 1.1 & 1.2) and it is found out that these two variables highly affect the cost of the system. The output of sensitivity analysis shown that PV/Gen/battery is optimal solution until the solar radiation as well as diesel price will reach 7.0 kWh/m2/day and 0.9$/L respectively.

Keywords: Optimization, Diesel, PV, Hybrid, Homer, Levelized cost of energy (LCOE).

INTRODUCTION

As opposed to the solar PV system only, the PV/Diesel hybrid system, containing of a photovoltaic system backed-up by an engine-generator set has greater reliability for electricity production, and it often represents the best solution for electrifying remote areas (Muselli *et al*., 1999).

The diesel generator reduces the photovoltaic component, while the photovoltaic system decreases the operating time of the generator, reducing the running costs of the diesel generator (Nfah, *et al*., 2007). The addition of battery storage reduces the number of start/stop cycles of diesel generator, thus minimizing fuel consumption considerably (Elhaady and Shaahid 1999).The hybrid energy systems have received much attention over the past decades. In particular, the integrated approach makes a hybrid system to be most appropriate for isolated communities. One of the most important aspects of hybrid energy system is to supply power to the customers economically (Ajai *et al*., 2011). A hybrid generation system is a system combing two or more energy sources, operated jointly, including (but not necessarily) a storage unit and connected to a local AC distribution network (Bakura and Mayyama 2017). In remote areas, far from the national grid of many countries, electricity is usually supplied by diesel generators or small hydroelectric plants. In most of these cases, the supply of diesel fuel becomes so expensive that hybrid diesel/photovoltaic generation becomes competitive with diesel-only generation (Bakura, 2016).

MATERIALS AND METHOD

To use HOMER optimization software to design PV/Diesel hybrid power system, one has to provide some inputs such as hourly load profile, monthly solar radiation value for a PV system, the initial cost of each component (renewable energy generators, diesel generators ,batteries and converters), cost of diesel fuel, annual real interest rate project lifetime, etc. Twenty years (1991 to 2010) solar radiation data was obtained from NIMET (Nigerian metrological agency) for the location. The capital costs of each components, was taken from solar Wholesalers which is available online.

Hybrid renewable energy systems

In this research the Hybrid System components consists of an electric Load, Renewable energy Source (Solar) and other system components such as PV, batteries, and Power conditioning units, such as converters, are also a part of the system. A schematic diagram of the standalone hybrid power systems is shown in figure 2.1 below.

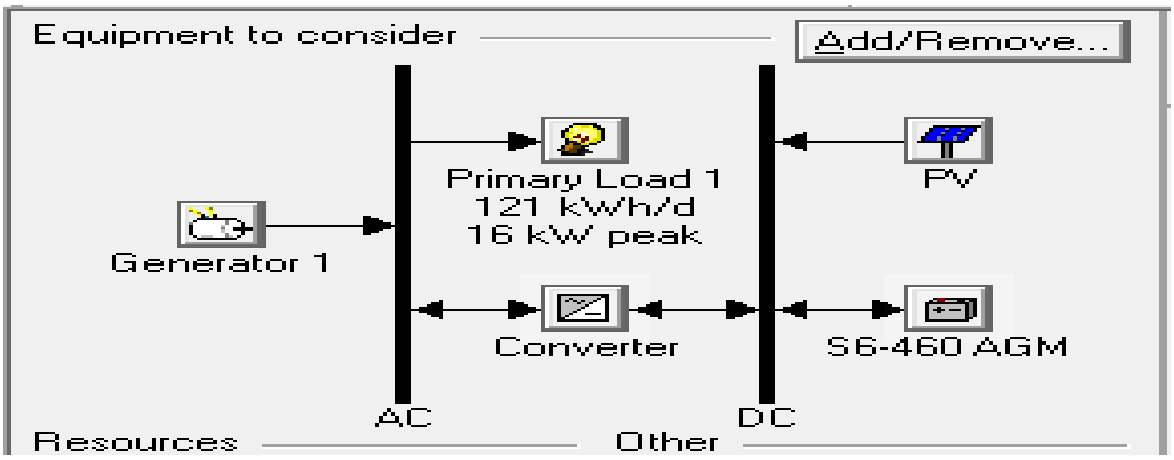

Figure 2.1: Schematic diagram for the standalone hybrid power supply system from the HOMER.

Load profile

Load profile study and determination are the first steps for the design of any electric power system. Nature and hours of operation of loads are the parameters that determine the load profile. In this research, The Gumburawa maternity clinic has been considered. The basic Load parameters quantities, capacity and operation hours has been calculated as shown in table 2.1. So the load data were synthesized by specifying typical daily profiles and then adding some provision for starting of 25% was added (Dabai *et al.*, 2012).

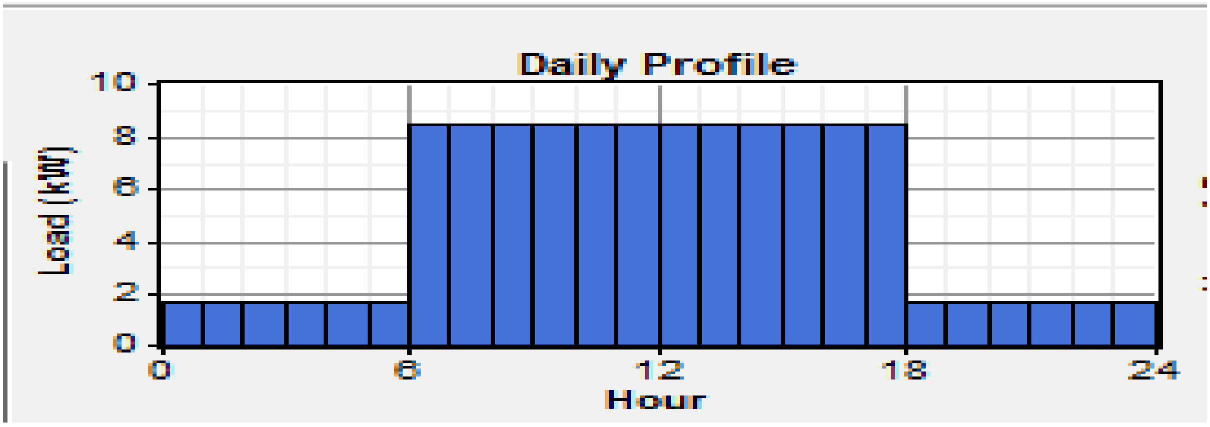

Figure 2.2: daily load profile

The daily load profile is represented by a sequence of powers and it is considered as constant over a time-step of 1 h. The used load profile (Figure 2.2) denotes the consumption of the maternity clinic. The system load is assume to be constant during the working hours from 6am-6pm which is peak due to the medical equipment that assumed to be all in used.

But after the working hours from 6pm-6am all the equipment will be off, so only bulbs and fans will remain at used; that what bring the load down to 2kW. This system is expected to be constant daily, monthly and annually.

Data in homer software for different component

The major components of hybrid energy system are PV panels, diesel generator, batteries and converters. For economic analysis, the number of units to be used, capital costs, replacement and O&M costs and operating hours must be defined in HOMER in order to simulate the system.

Solar Photovoltaic

The cost of PV module including installation has been considered as $0.92kW. Life time of the modules has been taken as 25 years. 250kW modules are considered. The parameters considered for the simulation solar PV are furnished in the table 2.1

Table 2.1: Solar PV array-technical parameters and cost assumption

Parameters	Value
Technology	Mono
Capita cost	$0.92/W
Replacement cost	$0.92/W
Operation and maintenance cost	0
Lifetime	25years
Derating factor	80%
Tracking system	No tracking system

Diesel Generators

The Fuel used in homer is modeled by a linear curve characterized by slope and intercept at no load. For a capacity range of 1kW to 100 kW, the slope and the intercept are 0.25 L/h/kW and 0.08 L/h/kW respectively. A diesel generator with its technical and economic parameters furnished in the table 2.2.

Table 2.2: Diesel generator-technical parameters and cost assumption

Parameter	Value
Size	1kW
Capital cost	$ 700
Replacement cost	$ 600
Operation and maintenance cost	$ 0.052/hr
Lifetime	15000 hours
Minimum ratio load	10%
Fuel curve slope	0.25L/hr/kW
Fuel curve intercept	0.08L/hr/kW
Fuel price	$ 1.2

Battery

The Surrette S6-460 AGM storage batteries are used in the hybrid system. The specifications like life time, efficiency, rectifier capacity and efficiency, capital and replacement cost are shown in the table 2.3.

Table 2.3: Battery-technical parameters and cost assumption

Parameter	Value
Technology	Surrette S6-460 AGM
Capacity	3kW
Nominal capacity	500Ah
Voltage	6v
Minimum state of discharge	40%
Capital cost	$385
Replacement cost	$380
Operation and maintenance cost	$100/year
Efficiency	80%
Lifetime	10years

Power Converter

The power converter is used to maintain the flow of energy between AC and DC components. The technical and economic parameter for the converter is given in table 2.4.

Table 2.4: Power Converter-technical parameters and cost assumption

Parameters	Value
Technology	Magnum energy inverter
Capital cost	$590/Kw
Replacement	$590/kW
Operation and maintenance cost	40$/year
Efficiency	90%
Lifetime	15years

HYBRID SYSTEM SIMULATION SOFTWARE AND COMPONENTS

Simulation software

A software program HOMER was developed to simulate the hybrid system behavior. An hourly time step is used throughout the simulation. By using computer simulation, the optimum system configuration can be found by comparing the performances and energy production costs of different system configurations. The first step to be considered when starting simulations is to formulate tasks in form of problems that the software is expected to address. In this case, the following questions were formulated which formed the basis of the simulations similar to research hypotheses to be proved or disproved.

i. Is solar/diesel based hybrid arrangement feasible?
ii. Will the system meet growing electric demand?
iii. What is the most feasible system configuration?

Thereafter, the components that make up the system were selected after an extensive market survey to determine their durability, availability in the market as well as cost among other considerations.

The simulation process determines how a particular system configuration, a combination of system components of specific sizes, and an operating strategy that defines how those components work together, would behave in a given setting over a long period of time. HOMER can simulate a wide variety of micro power system configurations, comprising any combination of a PV array, wind turbines, and up to three generators, a battery bank, and a dc-ac converter.

Optimization

The simulation process models a particular system configuration, whereas the optimization process determines the best possible system configuration. The best possible, or optimal, system configuration is the one that satisfies the researcher's specified constraints at the lowest total net present cost. Finding the optimal system configuration may involve deciding on the mix of components that the system should contain, the size or quantity of each component, and the dispatch strategy the system should use. In the optimization process, many different system configurations are simulated; the infeasible ones are discarded, the feasible ones are ranked according to total net present cost, and the feasible one is presented with the lowest total net present cost as the optimal system configuration.

Components considered for standalone solar/Diesel hybrid power system.

The PV panel selected has a rated power of 250 kW DC, slope of 13^0, and life time of 25years. Also, the panel has a derating factor of 80%, an azimuth of 0^0 and ground reflectance of 20%. The battery chosen was the Surrette S6-460 AGM type with nominal capacity of 500Ah, nominal voltage of 6V and lifetime of 10years. It is a deep cycle battery commonly used for renewable energy applications. Because it has thicker plates and is designed to be discharged as low as 80% and recharged over and over again. While, the converter selected has 14kW rated capacity, a lifetime of 15years and it can work in parallel with an AC generator.

Considering the costs of components as part of the economics of the system, an annual interest rate of 6.0% was adopted as maximum in the lifetime of the project. Also, components operation and maintenance cost was taken into consideration after the initial capital cost.Summary of components data supplied to the software is presented in table 2.7, below

Table 2.5 input data to HOMER

Components	PV	Generator	Battery	Converter
Size	250kW	1kW	500Ah	1kW
Capital ($)	$910	$700	$385	$590
Replacement($)	$910	$600	$380	$590
O &M ($)	0	0.05$/yrs	$100	40$/yr
Quantities considered (kW)	10,16,18,20	6,8,10,12,15	8,10,12,14,16,20	4,10,12,14
Size considered	16kW	8kW	20	14kW
Lifetime	25yrs	15000hrs		15yr

RESULTS AND DISCUSSION

This chapter presents the results and discussion about the findings of our analysis. First, the optimisation results are presented, which is followed by the outcomes of our sensitivity analysis.

Optimization results

In this simulation the optimized results are presented categorically for particular sets of sensitivity parameters like solar radiation, diesel price, maximum capacity shortage and renewable fraction. HOMER performs difference hourly simulations over and over in order to design an optimal hybrid system. Simulations have been conducted considering different values for solar radiation, minimum renewable fraction, and diesel price providing more flexibility in the experiment. It is seen that a PV, Diesel generator and battery hybrid system is economically more feasible with a minimum (Cost of energy) COE of 0.403$/kWh and a minimum Net present cost (NPC) of $204,032. The hybrid system comprised of 20 kW PV array, a diesel generator with a rated power of 8 kW and 20 storage batteries in addition to 14 kW converters is found to be most feasible system.

Table 3.1: Categorized optimization results

PV (kW)	Label (kW)	S6-460 ...	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Label (hrs)
20	8	20	14	$ 39,760	14,322	$ 204,032	0.403	0.62	5,553	2,172
20	8	20	12	$ 38,580	14,458	$ 204,410	0.404	0.62	5,701	2,320
20	8	24	14	$ 41,300	14,327	$ 205,632	0.406	0.64	5,292	2,061
20	6	28	12	$ 40,260	14,450	$ 206,001	0.407	0.66	5,073	2,640
20	10	8	14	$ 36,540	14,776	$ 206,024	0.407	0.55	6,861	2,316

In the Overall Optimization Results table, HOMER displays a list of the five system configurations that it found to be feasible. They are listed in order (from top to bottom) of most cost-effective to least cost-effective. The cost-effectiveness of a system configuration is based on its net present cost, displayed under the heading "Total NPC" in the results tables.

Table 3.2: Cost summary

Total net present cost	$ 204,032
Levelized cost of energy	$ 0.403/kWh
Operating cost	$ 14,322/yr

The total NPC is $240,032, the initial capital cost is $39,760, while the operating cost per year is $14,322. In this system, the cost of energy is $0.403/kWh (N78.988). Therefore the cost may appear high initially especially when compared with the cost of energy provided by the electric power production company (PHCN) which is about 30NGN/kWh. However, in the long run the cost shall be reducing due to low operation and maintenance cost, improved management of the system, less logistical costs and the lifetime of the system.

Thus, this being the most feasible and optimal system (among many others) can be an attractive solution for implementation.

Table 3.3: Component (resource) contribution

Component	**Production** (kWh/yr)	**Fraction**
PV array	38,872	70%
Generator 1	16,653	30%
Total	55,524	100%

The table above shows the percentage contribution by each renewable component. With PV array produced 38,872kWh/yr while the generator produced 16,653kWh/yr of the total electrical production. This represents 70% solar and 30% generator respectively.

CONCLUSION

Renewable energy technologies, such as photovoltaic hybrid systems can provide an economical option, greater reliability and it often represents the best solution for electrifying remote areas. In this researchthe total NPC is $240,032, the initial capital cost is $39,760, while the operating cost per year is $14,322, and the cost of energy is $0.403/kWh (N78.988). Therefore the cost may appear high initially especially when compared with the cost of energy provided by the electric power production company (PHCN) which is about 30NGN/kWh. Thus, this being the most feasible and optimal system (among many others) can be an attractive solution for implementation.

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