OPTIMISATION OF A HYBRID ENERGY SYSTEM FOR RELIABLE OPERATION OF AUTOMATED TELLER MACHINES

Michael S. Okundamiya, Vincent O. A. Akpaida, Benedict E. Omatahunde
Department of Electrical and Electronic Engineering,
Ambrose Alli University, P. M. B. 14, Ekpoma, Edo State, Nigeria
Corresponding Author: *Michael S. Okundamiya*

ABSTRACT

This study presents the optimum size of a hybrid energy system for reliable operation of automated teller machines (ATMs). The aim is to identify a configuration among a set of power generation options that can reliably satisfy the electrical power consumption requirements of a remote load at the lowest energy cost, taking into consideration the availability and dynamic nature of energy sources. Three primary energy sources (solar, wind and diesel) are considered. The optimum design configuration is determined by making energy balance calculations based on HOMER (hybrid optimization model for electric renewable) software. Simulations are carried out for a one-year period, using long-term meteorological data and load profile of a typical ATM installation for Ekpoma, located (latitude 6.75°N, longitude 6.13°E) in the southern part of Nigeria. Simulation results show that the optimum design configurations consist of 5 kW wind turbine generator, 12 kW photovoltaic arrays and 81 kWh battery bank for study location. A more reliable and less expensive operations of ATMs would not only improve the quality of banking services, but will also reduce emissions of CO_2 and other harmful gasses from ATM installation sites in Nigeria by approximately 95.7% thereby making the environment much more friendly and safe.

KEYWORDS: automated teller machine; energy optimization; hybrid energy system; photovoltaic system; wind energy.

INTRODUCTION

Since the introduction of automated teller machines (ATMs) in Nigeria, there has been a rapid increase in the deployment of these machines nationwide. Banks are investing heavily on the rollout of these ATMs. Investment in ATMs has seriously improved the quality of service delivery to customers, as it has taken the lid off official banking hours. The recent implementation of a “cashless policy” by the Nigerian government has resulted in the deployment of more ATMs at several locations nationwide, by various banks to ensure bank customers have access to their funds when needed, regardless of banking hours.

Power supply to these ATMs and other auxiliary equipment is often a key issue. The power consumption of a typical ATM is about 3 kW (i.e., 0.7kW for the ATM and 2.3 kW for other auxiliary equipment, such as the air conditioning, lighting etc.). The power consumption varies from one ATM site to another, depending on the type and number of installation device as well as on the mode of operation. The power demand of a typical ATM installation (including auxiliary equipment) for an off-site location in Nigeria is shown in Table 1.

Table 1 Power demand of a typical off-site ATM installation in Ekpoma, Nigeria

Equipment/facility	Quantity	Power (kW)	Electrical load (kW)
ATM	2	0.70	1.40
Air condition	1	1.60	1.60
Lightings	6	0.09	0.54
Hub	1	0.32	0.32

Lack of a reliable power supply in Nigeria hampers the effective operation of ATMs, and this significantly impacts the quality of services delivered by the Nigerian banking sector. This has made the banking sector resort to the use of fossil fuelled generators either as supplements to the national electricity grid or exclusively in remote locations. The use of diesel generator as a source of electricity is inadequate because the operations of diesel generators is characterized by a number of economic, logistic and environmental problems (Kovats *et al*., 2005; VandeWeghe and Kennedy, 2007; Okundamiya *et al*., 2014a).

The growing need for energy sustainability has made renewable energy technologies promising energy sources (Liu *et al*., 2012; Okundamiya *et al*., 2014a, b). The most common renewable energy sources are solar and wind (Zhou *et al*., 2010). Solar and wind are ubiquitous and freely available. They are clean energy sources that do not emit greenhouse gases. However, the initial cost of renewable (solar and wind) energy systems is significantly greater than that of the conventional (diesel) power generating systems. In addition, renewable sources are intermittent since they are highly dependent on weather conditions (Banos *et al*., 2011). The intermittent nature of renewable sources could lead to power supply instability. As a result, energy storage device such as battery, used in cancelling out unpredicted power fluctuations, stabilizing voltage and frequency, and for improving power quality forms an integral part of the renewable energy system.

The hybrid energy system combines different energy sources to maximize each source's strengths, while compensating for the others' shortcomings. If properly designed, the hybrid energy system can be more reliable and less expensive than a single energy source. A reliable and cost effective energy solution could result in effective operation of ATM installations in

Nigeria. Nevertheless, potential investors should be aware of the optimum design specifications, capacity projections and the techno-economic implications of the hybrid systems, which include renewable technologies as these will enable investors, decide on the most suitable technology or combination. Moreover, studies (Koutroulis *et al*., 2006; Zogou and Stapountzis, 2011; Liu *et al*., 2012; Kim *et al*., 2014; Okundamiya *et al*., 2014a, b) have shown that the implementation of hybrid energy systems brings benefits of cost saving and emission reduction, but the range of financial benefits vary from one region to another, due to different technologies and climatic conditions.

In this paper, the optimum size of a hybrid energy system running under the Nigerian climatic condition is presented. The aim is to identify a configuration among a set of energy options that can reliably satisfy the electrical power consumption requirements of a remote load at the lowest energy cost, taking into consideration the availability and dynamic nature of energy sources.

METHODOLOGY

The simulation model used and the input data collected for a case study are discussed in this section under the following sub-headings.

Simulation model

The HOMER software was used to model the system's long-term implementation. HOMER is a computer-based optimization model developed by the National Renewable Energy Laboratory (NREL, 2013). It is a widely used simulation tool for the design of micro-power systems. It allows for comparison with different design options based on technical and economic merits, as a result, several studies (Nandi and Ghosh, 2010; Liu *et al*., 2010; Supriya and Siddarthan, 2011; Yousif, 2012; Fulzele and Dutt, 2012; Talebhagh and Kareghar, 2012; Teoh *et al*., 2012) have applied this tool for the design, management and sizing of various hybrid energy systems for different locations around the world.

The simulation model for the studied hybrid energy system is shown in Fig. 1. It consists of a photovoltaic (PV) array, wind turbine generator (WTG), diesel generator (DG) and battery bank, as well as power converter. The power converter is included because the energy from PV array, WTG and battery bank is DC type, which is different from the energy type of diesel generator and load. The power converter converts electricity between direct current (DC) and alternating current (AC).

HOMER performs the energy balance calculations for each system configuration and determines whether a configuration can meet the electric demand under the conditions specified, and simulates the cost of installing and operating the system over the lifetime of the project. A list of the possible configurations of energy system, which can reliably satisfy the electrical power consumption requirements, is presented. The list of feasible energy options is sorted according to their net present cost (NPC) as shown in Table 4.

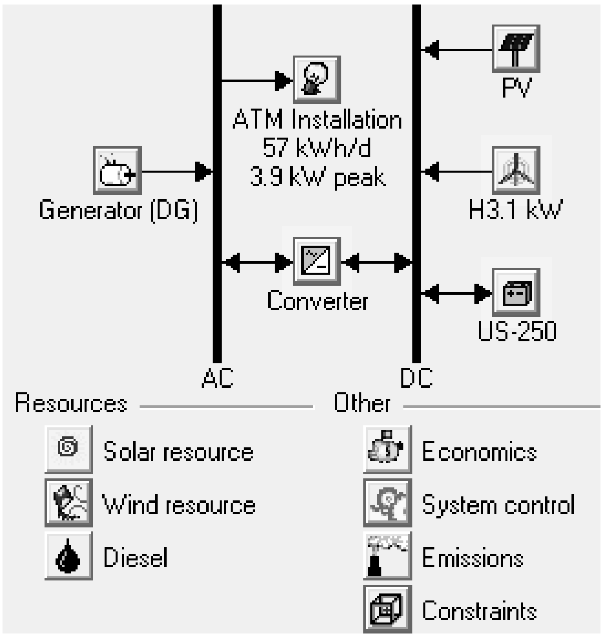
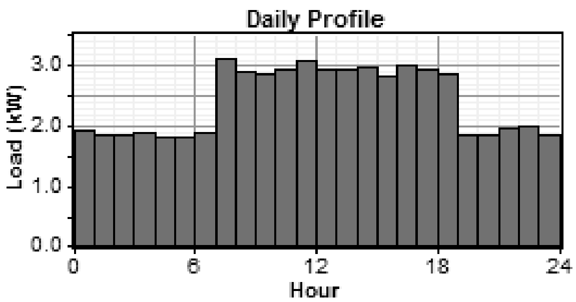


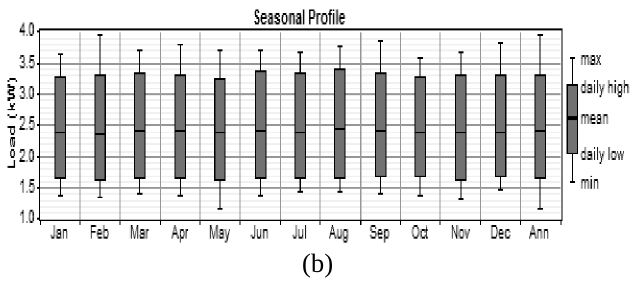
Fig. 1 HOMER simulation model for studied hybrid energy system

Data collection

Sample of one week (March 27 – April 3, 2014) daily average hourly load data, shown in Fig. 2a, were collected for an offsite ATM installation within the campus area of Ambrose Alli University, Ekpoma, located (latitude 6.75ºN and longitude 6.13ºE) in the southern part of Nigeria. The seasonal load profile, shown in Fig. 2b, was deduced from the daily average hourly load profile, by taken the hourly and daily variations of 5% and 7% respectively. The electrical load of 57 kWh per day, with a simulated daily peak load of 3.9 kW is considered for the typical ATM site (see Table 1) discussed in this study.



(a)



(b)

Fig. 2 Load profile of studied ATM installation (a) daily (b) seasonal

The meteorological data used in this study were collected from two data sources for Ekpoma. The first part collected from the archives of the National Aeronautics and Space Administration (NASA) consists of the monthly average daily global solar radiation on a horizontal surface for a period of 22-years (1984–2005). NASA derives these datasets from a variety of earth-observing satellites and reanalysis research programs, which provide reliable meteorological resource data over regions where surface measurements are scarce or nonexistent (NASA, 2013). The second data set, which consists of 22-years (1991–2012) monthly average daily wind speed (measured at a height of 10 m above sea level), were collected from the archives of the Nigerian Meteorological agency (NIMET) for same location. It is worth mentioning that the data collected from NIMET consists of some missing (unrecorded or unmeasured) values. Hence, these data are checked to eliminate faulty and/or incomplete measurements.

The main characteristic of datasets collected from NIMET is shown in Table 2, while Figs. 3 and 4 show the meteorological data used as inputs to the simulation model. The economic specifications of components that constitute inputs of the studied hybrid system are shown in Table 3. The project life span is assumed to be the same as that of the photovoltaic module which has a longer lifetime of 25 years. Details of the technical specifications of hybrid system components are available in Okundamiya (2014).

Table 2 Main characteristic of meteorological station (NIMET)

Instrument	Measurement range	Recording resolution	Accuracy
Wind vane (for direction)	$0 – 360^0$	$\leq 1^0$	$\pm 2^0$
Anemometer (for speed)	$0.3 – 50$ m s^{-1}	≤ 0.1 m s^{-1}	± 0.3 m s^{-1}

RESULTS AND DISCUSSION

The overall optimum sizing results of possible configurations of the studied hybrid energy system is shown in Table 4. As shown, it is clear that the photovoltaic-wind-battery hybrid energy system gives the lowest costs.

The cost of energy of the photovoltaic-wind-battery hybrid systems is US$ 0.238 per kWh (₦38.56 per kWh), whereas the initial capital required and the net present cost are US$ 39,900.0 and US$52,701.0 (₦ 6,463,800.0 and ₦ 8,537,562.0), respectively. The optimum size consists of 12 kW PV arrays, 5 kW (5 × 1 kW) wind turbine generators, 4 kW converter and 81 kWh (60 × 225 Ah × 6 V) battery bank.

The electrical characteristics of proposed (photovoltaic-wind-battery) hybrid system for studied ATM installation are given in Table 5 and Fig. 5, while the economic characteristics (total annualized and net present costs) are shown in Table 6. The environmental implication on the use of various feasible options is shown in Table 7.

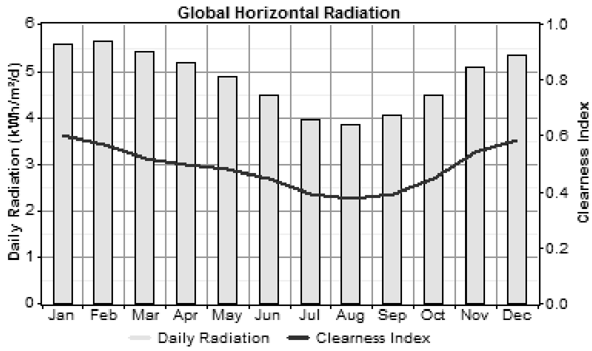


Fig. 3 Long-term (22-years) monthly average daily solar resources (radiation and clearance index) for Ekpoma (NASA, 2013)

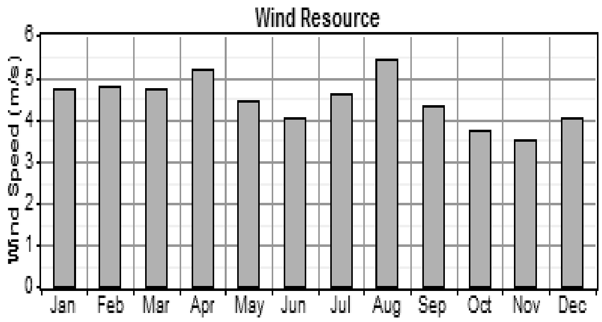


Fig. 4 Long-term (22-years) monthly average daily wind speed (measured at a height of 10 m above sea level) for Ekpoma (NIMET, 2013).

Table 3 Economic specifications of components for sizing of hybrid power system (Okundamiya, 2014; SunForte, 2014)

Components	Specifications				
	Model	Life time	Capital cost	Replacement cost	Operation and maintenance cost
Wind turbine	Hummer H3.1-1 kW	15 yr	1400 US$ per WTG	1200 US$ per WTG	14 US$ yr^{-1} per WTG
PV module	SunForte PM318B00 Mono-crystalline	25 yr	1500 US$ per kW	-	1 US$ yr^{-1} per kW
Battery	USB US-250	Float life: 10 yr Lifetime throughput: 845 kWh	225 US$ per battery	225 US$ per battery	1 US$ yr^{-1} per battery
Converter	Typical	15 yr	350 US$ per kW	300 US$ per kW	2 US$ yr^{-1} per kW
Diesel generator	Typical	15,000 h	700 US$ per kW	600 US$ per kW	0.1 US$ h^{-1} per kW

Table 4 Overall optimization results based on the net present cost

PV (kW)	H3.1	DG (kW)	US-250	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	DG (hrs)
12.0	5		60	4	$ 39,900	1,199	$ 52,701	0.238	1.00	0.01		
9.0	5	4	48	4	$ 35,500	1,734	$ 54,013	0.242	0.97	0.00	343	509
16.0		4	92	4	$ 48,900	3,543	$ 86,725	0.388	0.93	0.00	850	1,073
9.5	5	4		4	$ 25,450	6,936	$ 99,486	0.445	0.80	0.00	3,501	5,472
	5	4	40	4	$ 20,200	8,315	$ 108,962	0.487	0.61	0.00	4,046	6,004
15.0		4		4	$ 26,700	8,352	$ 115,860	0.518	0.68	0.00	4,768	6,042
	5	4		4	$ 11,200	10,698	$ 125,398	0.561	0.54	0.00	5,550	8,423
		4			$ 2,800	13,197	$ 143,679	0.642	0.00	0.00	8,041	8,760
		4	40	2	$ 12,500	13,740	$ 159,176	0.712	0.00	0.00	8,027	8,741

Table 5 Electrical characteristics of proposed (photovoltaic-wind-battery) hybrid system

Components	Annual electric energy production		Annual electric energy consumption	
	kWh yr^{-1}	(%)	kWh yr^{-1}	(%)
PV array	18,930	59	-	-
Wind turbines	13,339	41	-	-
ATM installation (load)	-	-	20,764	100
Total	**32,270**	**100**	**20,764**	**100**

Table 6 Summary of total net present cost of the proposed hybrid system components

Components	Capital (US$)	Replacement (US$)	O&M (US$)	Salvage (US$)	Total (US$)
PV	18,000	0	512	0	18,512
H3.1 1kW	7,000	2,207	747	-341	9,613
USB US-250	13,500	9,452	640	-822	22,770
Converter	1,400	378	85	-58	1,805
System	**39,900**	**12,037**	**1,986**	**-1,222**	**52,701**

Table 7 Comparison of pollutant emissions from conventional (diesel) energy source with various hybrid system options

Pollutants	Annual emissions (kg yr^{-1})				
	Diesel-only	Wind/Diesel/ Battery	PV/Diesel/ Battery	PV/Wind/Diesel/ Battery	PV/Wind/Battery
Carbon dioxide	21,175	10,655	2,237	904	-
Carbon monoxide	52.3	26.3	5.52	2.23	-
Unburned hydrocarbons	5.79	2.91	0.612	0.247	-
Particulate matter	3.94	1.98	0.416	0.168	-
Sulphur dioxide	42.5	21.4	4.49	1.81	-
Nitrogen oxides	466	235	49.3	19.9	-

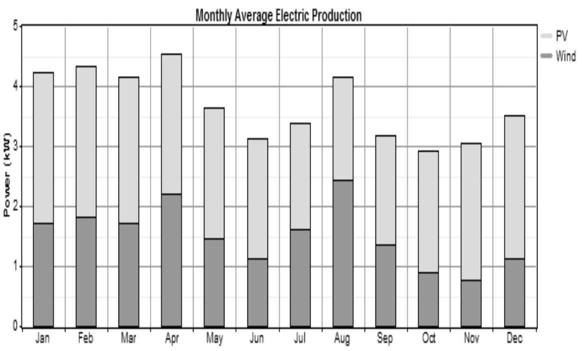


Fig. 5 Average monthly electrical production of the proposed hybrid system

The conventional (diesel generator) power supply option has the highest COE of US$ 0.642 per kWh (₦ 104.00 per kWh), which requires 8,041 litres of diesel for reliable operation of the ATM installation. This translates to the release of pollutant emissions into the atmosphere, with carbon dioxide having the largest share of 21.18 tCO_2 yr^{-1} as shown in Table 7.

The inclusion of a 5 kW wind turbine and 40kWh battery system to the existing diesel generator leads to a cost reduction of 24.1% (from US$ 0.642 to US$ 0.487 per kWh or ₦ 104.00 to ₦ 78.89 per kWh), with wind contributing 39% of the total energy requirement. This reduces the annual diesel consumption from 8,041–4,046 litres (i.e., by 49.7%) with a corresponding deduction in pollutant emissions released into the environment. Compared to the wind-diesel-battery system, the implementation of a photovoltaic-diesel-battery system, gives a reduction in both the energy cost and diesel combustion by 39.6% and 89.4% respectively. The higher percentage reduction in both energy cost and pollutant emissions is a clear indication that the applications of solar energy systems are more viable compared to wind energy systems for Ekpoma (Nigeria). The implementation of the photovoltaic-wind-diesel-battery system gives the highest percentage reductions in both the energy cost and diesel combustion of 62.3% and 95.7 % respectively, compared to diesel-only system.

CONCLUSION

This paper describes the optimum sizing of a hybrid energy system for a reliable and cost effective operation of a remote load under Nigerian climatic conditions. A hybrid system consisting of three primary energy sources (solar, wind, diesel), incorporating battery storage and power converter was considered. Simulations are carried out for one-year period, by making energy balance calculations based on HOMER software using long-term meteorological data and the load profile of a typical ATM installation for Ekpoma.

Simulation results clearly shows that the optimized photovoltaic-wind-battery hybrid system, which consists of 12 kW PV arrays, 5 kW (5 × 1 kW) wind turbine generators, 4 kW converter and 81 kWh battery bank, gives the lowest cost of US$ 0.238 (₦38.56) per kWh of energy consumed compared to diesel-alone (US$ 0.642 or ₦ 104.00 per kWh), wind-diesel-battery (US$ 0.487 or ₦ 78.89 per kWh), photovoltaic-diesel-battery (US$ 0.388 or ₦ 62.86 per kWh), and photovoltaic-wind-diesel-battery hybrid systems (US$ 0. 242 or ₦ 39.20 per kWh), but with 1% annual capacity shortage. In addition, the annual diesel consumption of the ATM installation site could be reduced by 7,698 L yr^{-1} per site. Analysis indicates that not only would the quality of banking services be improved, by making the operations of ATMs more reliable and less expensive, but also emission of CO_2 and other harmful gasses from ATM installation sites in Nigeria would reduce by approximately 95.7% thereby making the environment much more friendly and safe.

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