TELKOMNIKA Telecommunication, Computing, Electronics and Control
Vol. 18, No. 6, December 2020, pp. 3258~3265
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v18i6.13558

Cost implications analysis of grid supplied electricity and solar source of electricity in Nigeria

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Article Info

Article history:

Received Jul 10, 2019
Revised Feb 8, 2020
Accepted Jul 9, 2020

Keywords:

Cost implication
Energy
Power holding company of nigeria
Solar system

ABSTRACT

Energy is a key component in the overall growth of every nation. Insufficient energy delivery hinders political growth, restricts social growth, limits economic growth, and negatively affects the standard of living of citizens, both in urban and rural areas. Sufficient energy delivery increases food production, improves the standards of living of citizens, improves healthcare and enhancements in other human services, enhances industrial output, provides effective and efficient transportation not forgetting adequate shelter to the citizens of the nation. Currently, there is a significant level of deficiency in Nigeria's energy sector. This study seeks to address this issue by analysing cost implications of conventional energy source and solar energy source. This study brings to focus the payback period of a solar powered home and the return on investment that might accrue during this time to the residential homeowners. Furthermore, the best cost-effective load sharing option for residential owners considering two energy sources is also obtained.

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1. INTRODUCTION

Energy is a key component in the overall growth of every nation [1]. However, most of the developing nations are yet to combat the plague of inadequate supply of electricity. Nigeria with her population of about 200 million people making her the most populous nation in the Sub-Saharan region of Africa and positioned seventh in the world population rankings is still suffering from epileptic supply of electricity [2-4]. Yet, she has prospect of reaching over 300 million people by the year 2035 [2]. Currently, there is a significant level of deficiency in Nigeria's energy sector. This is because only 40% of the nation's total population have access to electricity[5]. This makes Nigeria the third largest country without access to electricity according to International Energy Agency (IEA). Nigeria is behind in this regard when compared with other developing countries of similar GDPs and load demands. Presently, she generates about 5,500 MW power of which only about 3,500 megawatt (MW) is transmittable [2, 6]. The nation has the ability to generate about 11,000 MW and more with its existing energy infrastructure but various factors ranging from weak transmission lines to inefficient government policies make the country to transmit only 3,500 MW [2, 5, 7]. Nigeria has abundant energy resources to tap from in order to meet her load demands. She is blessed with both renewable and non-renewable energy sources. Table 1 gives the comprehensive list of all the energy sources available in Nigeria which can be explored.

Table 1. Energy sources in Nigeria [4, 5, 7-9]

S/N	Renewable source	Non-renewable source
1	Hydro	Natural gas
2	Biomass	Crude oil
3	Solar	Coal
4	Wind	Tar sands
5	Wave and Tidal	

From the list of available energy sources for power generation in Nigeria, the crude oil contributes significantly while the hydro power generation ranks second [2]. From Table 1, non-renewable energy sources generate about 80% of the total power generated in Nigeria but contribute immensely to various environmental hazards [5, 10]. This calls for the need of power generation from clean energy sources. The Nigerian population has about 25% urban dwellers that are connected to the national grid. The challenges experienced by the urban dwellers are epileptic power supply, power unreliability, and poor power infrastructure among others [11-16]. The rural dwellers which represent majority of the Nigerian population live in darkness since they are not connected to the grid. From relevant literature works, it was gathered that energy generation level is directly proportional to the development of any nation [17-20]. This gives way for renewable energy to compensate and augment the conventional energy source (i.e. non-renewable energy) [21]. Solutions to energy deficiencies will increase the earnings and the standard of living of residents in rural regions. This will reduce the overwhelming number of rural urban migrants [21]. It is important to know that the demand for electricity is on the increase in every sector [22-27] including residential buildings which dominate energy consumption in Nigeria, thus putting stress on the national grid [4, 28]. If a portable clean energy can be generated from renewable energy sources to power most of the loads in the residential buildings, this will go a long way to relieve the national grid and also reduce the cost of electricity per day [29]. Hence, in this study, cost implication of generating electricity from solar powered system to argument the conventional power generation shall be considered and analysed in order to come up with a logical solution. The solution will aid proper planning as stated in reference [7].

2. RESEARCH METHOD

This study considers energy usage from Power Holding Company of Nigeria (PHCN) and or solar energy source for an average Nigerian to power his/her load. Figure 1 gives the relevant block diagram of the interconnection of PHCN and solar sources. Two case studies (self-contained apartment and 3-bedroom flat) are considered in this study for a typical average Nigerian with respect to three different energy sources scenarios (PHCN, solar and hybrid of PHCN and solar). All necessary data required for the case study were collected through physical load assessment over a period of six months and the average results are presented in Tables 2 and 3. For each case, three scenarios were considered as shown below.

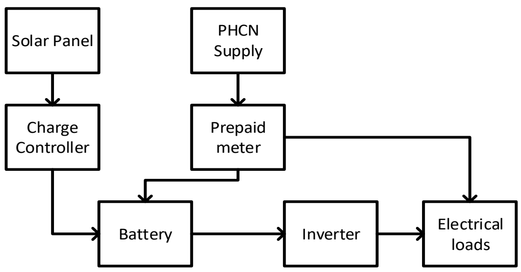

Figure 1. Block diagram

2.1. CASE 1: Self-contained apartment

2.1.1. Scenario 1

The first case study describes a self-contained apartment of an average Nigerian citizen. The electrical loads used for this case study are similar to the ones used by a self-contained home user in Nigeria. The electrical loads contained in the self-contained building are described in the Table 2. The total energy consumed in this building in a day is 1701.42 Whr and the energy tariff for residential users (R2) in Nigeria is 25 Naira/kWh as determined by National Energy Regulatory Council (NERC) for EKO distribution company users [28]. The unit cost of electricity for this building is calculated using (1) as follows:

The total cost of daily consumption = Total daily consumption (kWhr) × Tariff (1)

$$= \frac{1701.42 \text{ x } 25}{1000} = 1.7 \times 25 = 42.5\ Naira$$

Table 2. Load demand and energy usage of a typical consumer of electricity in a self-contained

S/N	Electrical/ Electronic Devices	Qty	Watt (W)	Total watt (W)	Operational hours			Energy use/week (Whr)	Energy use/day (Whr)
					weekdays	weekends	weekly		
1	LED TV	1	35	35	15	16	31	1,085	155
2	Ceiling fan	1	65	65	20	8	28	1,820	260
3	DVD player	1	15	15	2	5	7	105	15
4	Go tv	1	25	25	13	11	24	600	85.71
5	Led bulb (type 1)	5	13	65	30	12	42	2,730	390
6	Laptop	1	65	65	15	6	21	1,950	278.57
7	Phone charger	2	10	20	15	6	21	420	60
8	Blender	1	300	300	1	1	2	600	85.71
9	Fridge	1	150	150	6	8	14	2,100	300
10	Washing machine	1	500	500	–	1	1	500	71.43
				1,240				11,910	1,701.42

Table 3. Load demand and energy usage of a typical consumer of electricity in a 3-bedroom flat

S/N	Electrical/ Electronic Devices	Qty	Watt (W)	Total watt (W)	Operational hours			Energy use/week (Whr)	Energy use/day (Whr)
	Bedroom				weekdays	weekends	weekly		
1	Ceiling fan	3	65	195	25	10	35	6,825	975
2	Led bulb (type 1)	3	13	39	21	14	35	1,365	195
	Sitting room								
3	Led tv	1	35	35	40	16	56	1,960	280
4	Dvd player	1	15	15	5	6	11	165	23.57
5	Satellite dish	1	25	25	35	10	45	1,125	160.71
6	Led bulb (type 2)	4	10	40	10	4	14	560	80
7	Ceiling fan	2	65	130	25	10	35	4,550	650
8	Laptop	2	65	130	15	6	21	2,730	390
9	Phone charger	2	10	20	12.5	5	17.5	350	50
	Kitchen								
10	Blender	1	350	350	0	1	1	350	50
11	Led bulb (type 1)	1	13	13	10	4	14	182	26
12	Refrigerator	1	500	500	15	6	21	10,500	1,500
13	Freezer	1	250	250	15	6	21	5,250	750
	Other areas								
14	Led bulb (type 1)	6	13	78	10	4	14	1,092	156
15	Washing machine	1	500	500	0	1	1	500	71.43
				4,070				37,504	5,357.71

2.1.2. Scenario 2

The electrical loads contained in the self-contained building are described in the Table 2. The total energy consumed in the building in a day is 1701.42Whr, if solar source were to be used as a means of power supply, the components of a typical solar panel such as charge controller, battery and inverter have to be designed. The required components of the solar system are specified as follows:

Solar power system components

Specifications-

Battery loss factor = 0.9

Depth of Discharge = 50% or 0.5

Nominal battery voltage = 24 V

K = 1.3 (factor used to multiply the total energy consumption of loads to cover for losses from the solar modules) [28]. Panel generator factor = 3.41 (varying factor used to divide the energy consumption need from the solar modules which depends upon the climate of the site location and the global geographic location) [28].

Total energy consumption (kWh) $= \frac{1701.42}{1000} = 1.70\ kWhr/day$

Total wattage of load (kW) $= \frac{1240}{1000} = 1.24\ kW$

Actual energy consumption needs from the PV modules $= Total\ energy\ consumption x 1.3$

$= 1.7 x 1.3$

$= 2.21\ kWhr/day$

Total wattage of PV panel capacity needed $= \frac{\text{Energy consumption need from the PV modules}}{\text{Panel Generator Factor (NIGERIA)}}$

$= \frac{2.21}{3.41}$ kW

$= 0.6481\, kW \approx 648\, W$

Therefore,

Number of PV panels $= \frac{\text{Total wattage of PV panel capacity needed}}{Rated\ Output\ (Watt)\ of\ the\ PV\ module\ Available}$

$= \frac{648}{325}$

$= 1.99\ Modules \approx 2\ Modules$

- Inverter Sizing

Total wattage of load = 1.24 kW

Inverter should be between 25 and 30% bigger than the total watt of appliances to accommodate any slight increment in loading. Therefore,

Inverter size $= 1.24 + (1.24\, x \frac{25}{100})$

$= 1.24 + 0.31$

$= 1.55\, kW$

- Determining the ampacity of the battery bank

Battery Bank Capacity $= \frac{\text{Energy consumption need from the PV modules x Days of Autonomy}}{Battery\ loss\ factor\ x\ Depth\ Of\ Discharge\ x\ Nominal\ Battery\ Voltage}$

Battery Bank Capacity $= \frac{2.21\ \text{x}\ 1}{0.9\, x\, 0.5\, x\, 24}$

= 204.6 Ah

- Determining the capacity of the charge controller

The solar charge controller rating per string = $I_{SC} \times 1.3$

I_{SC} = Total short-circuit current of the PV array

Maximum power P_m = 325 W

Maximum power voltage V_m = 37.6 V (DC)

Maximum power current I_m = 8.66 A

Open-circuit voltage V_{oc} = 46.7 V

Short-circuit current I_{sc} = 9.10 A

Minimum rating of the single solar charge controller $= 9.10 \times 1.3$

$= 11.83\, A$

Note that any rating that is not available in the component data book will be substituted with the next available one of higher rating. Available ratings of the components needed for electric power generation using solar system design bill of engineering measurements and evaluation (for case 1 scenario 2) are given in Tables 4 and 5.

Table 4. Solar system components and rating (case 1 scenario 2)

S/N	Specifications	Rating
1	Total Energy Consumption (kWhr/day)	1.70
2	Total Wattage of Load (kW)	1.24
3	Energy Consumption from the Solar Panel Modules per day	2.21 kWhr
4	Total Wattage of Solar Panel Capacity Needed	648 W
5	Number of Solar Panel Modules	2
6	Inverter Size	2.0 kW
7	Battery Bank Capacity	250 Ah
8	Minimum Rating of the Single Solar Charge Controller	30 A
9	Nominal Voltage of the Battery	24 V

Table 5. Bill of engineering measurements and evaluation (case 1 scenario 2)

S/N	Component	Specification	Quantity	Estimated rate (N)	Amount
1	Battery	250 Ah, 24 V	1	80,000	80,000
2	Solar PV panel	325 W, 24 V	2	35,000	70,000
3	Charge controller	30 A, 24 V	1	18,000	18,000
4	Inverter	2,000W	1	90,000	90,000
5	Cables and accessories		1	7,000	7,000
				TOTAL	**265,000**

2.1.3. Scenario 3

Scenarioes 1 and 2 under case 1 considered electric power supply for self-contained and 3-bedroom flat from PHCN and solar source respectively. Under this section, both sources of electric power supply are combined to meet the required load demand based on different load sharing proportions as shown in Table 6. The load-sharing amount of the combined sources for case 1 scenario 3 is shown in Table 7.

Table 6. How the loads are shared between the grid and solar source

S/N	Combination	
	Grid to supply	Solar to supply
1	All the load	No load
2	¾ of all the load	¼ of all the load
3	½ of all the load	½ of all the load
4	¼ of all the load	¾ of all the load
5	No load	All the load

Table 7. Load sharing of hybrid energy sources (case 1 scenario 3)

S/N	Combination		Total (kWhr)
	Grid (kWhr)	Solar (kWhr)	
1	1.701	−	1.701
2	1.276	0.425	1.701
3	0.8505	0.8505	1.701
4	0.425	1.276	1.701
5	−	1.701	1.701

2.2. Case 2: Three-bedroom flat

2.2.1. Scenario 1

The electrical loads computed and energy usage in the three-bedroom flat are already described in Table 3. The total energy consumed in the building in a day is 5,357.71 Whr. However, according to the National Energy Regulatory Council (NERC) for EKO distribution company as at 2019, the energy tariff for residential users (referred to as R2) in Nigeria is 25 Naira/kWhr. Hence, the unit cost of electricity paid by residential user of this building will be ₦133.95 daily according to (1).

2.2.2. Scenario 2

Following the same approach employed in case 1 scenario 2 i.e. when electric power supply is solely from solar source. The available ratings of the components needed for electric power generation using solar system design for case 2 scenario 2 is given in Table 8. The bill of engineering measurements and evaluation (BEME) for case 2 scenario 2 is given in Table 9.

2.2.3. Scenario 3

Under this section, both electric power supply from PHCN and Solar system are combined to meet the required load demand. The sharing ratio for this scenario employs the same one given under case 1 scenario 3 as shown in Table 6. The load sharing amount for this hybrid scenario is shown in Table 10.

Table 8. Solar system components and rating (case 2 scenario 2)

S/N	Specifications	Rating
1	Total energy consumption (kwhr/day)	5.358 kWhr
2	Total wattage of load (kw)	2.320 kW
3	Energy consumption from the solar panel modules per day	6.965 kWhr
4	Total wattage of solar panel capacity needed	2.043 kW
5	Number of solar panel modules	7
6	Inverter size	2.9 kW
7	Battery bank capacity	700 Ah
8	Minimum rating of the single solar charge controller	50 A
9	Nominal voltage of the battery	24 V

Table 9. Bill of engineering measurements and evaluation (case 2 scenario 2)

S/N	Component	Specification	Quantity	Estimated rate	Amount
1	Battery	350 Ah, 24 V	2	150,000	300,000
2	Solar PV panel	325 W, 24 V	7	35,000	245,000
3	Charge controller	100A, 24 V	2	25,000	50,000
4	Inverter	1500W	2	100,000	200,000
5	Cables and accessories		4	7,000	28,000
					823,000

Table 10. Load sharing of hybrid energy sources (case 2 scenario 3)

S/N	Combination		Total (kWhr)
	Grid (kWhr)	Solar (kWhr)	
1	5.358	−	5.358
2	4.0185	1.3395	5.358
3	2.679	2.679	5.358
4	1.3395	4.0185	5.358
5	−	5.358	5.358

3. RESULTS AND ANALYSIS

From the design, it is obvious that it is quite expensive for an individual to generate electricity for his/her consumption because it requires huge capital. However, since some of the major components required to setup solar system can last for a period of 25 years or more, the cost of the solar system can therefore be compared with the cost of energy usage from PHCN over a period of 25 years. Taking 5 years interval, the analysis is carried out for case 1 scenario 1 as follows:

- For 5 years

There is one leap year in 5 years.
The number of days = $(4x365) + (1x366)$
= $1{,}460 + 366$
= $1{,}826$ days
The total cost of energy consumption for 1826 days is $1{,}826\ x\ 42.5 = N77{,}605$

- For 10 years

There are 2 leap years in 10 years.
The number of days = $(8x365) + (2x366)$
= $(2{,}920 + 732)$
= $3{,}652$ days
The total cost of energy consumption for 3652 days is $3{,}652x42.5 = N\ 155{,}210$

- For 15 years

There are 3 leap years in 15 years.
The number of days = $(12x365) + (3x366)$
= $(4{,}380 + 1{,}098)$
= $5{,}478$ days
The total cost of energy consumption for 5,478 days is $5{,}478x42.5 =$ ₦ $232{,}815$

- For 20 years

There are 5 leap years in 20 years.
The number of days = $(15x365) + (5x366)$
= $(5{,}475 + 1{,}830)$
= $7{,}305$ days
The total cost of energy consumption for 7305 days is $7{,}305x42.5 =$ ₦ $310{,}462.5$

- For 25 years

For 25 years, we have 6 leap years in 25 years.
The number of days = $(19x365) + (6x366)$
= $6{,}935 + 2{,}196$
= $9{,}131$ days
The total cost of energy consumption for 9,131 days is $9{,}131\ days\ x\ 42.5 =$ ₦ $388{,}067.5$

The same analysis is carried out for case 2 scenario 1 and the result is tabulated as shown in Table 11. From Table 11, it is clear that return on investment (ROI) will not be possible before 15 years of investment in both cases. This is not economical at all for an average citizen. This is why another approach (hybridisation of both scenarios 1 and 2) is considered. The comparative load sharing process for the two energy sources is done based on the cost of electricity from PHCN and solar system over a period of 10 years. This is because most companies give 10 years warranty on most of their solar products. The battery is assumed to last for 10 years or replaced under warranty if it gets spoilt under 10 years. Hybridisation of both scenarios 1 and 2 gives rise to scenario 3 in case 1 and case 2. Hence, Tables 12 and 13 give a tabular representation for cost of energy over a period of 10 years based on load sharings in Table 6 for cases 1 and 2 respectively. From Tables 12 and 13, it can be deduced that 100% supply from PHCN without considering installation of solar system is the most cost-effective approach at the moment followed by 75 to 25% in that order of proportion. However, it is important to note that in a developing country like Nigeria where PHCN supply of electricity is epileptic, 75% to 25% hybrid combination can be adopted to cater for indispensable loads that must always be powered or any other hybrid combination based on financial strength of the individual.

Table 11. Cost of electricity over a period of 25 years

Year	Case 1 scenario 1 (₦)	Case 1 Scenario 2 (₦)	Case 2 scenario 1 (₦)	Case 2 Scenario 2 (₦)
5	77,605	265,000	244,592.7	823,000
10	155,210	265,000	489,185.4	823,000
15	232,815	265,000	733,778.1	823,000
20	310,462.5	265,000	978,504.75	823,000
25	388,067.5	265,000	1,223,097.45	823,000

Table 12. Cost of power consumption from the energy sources (case 1 scenario 3)

S/N	Hybrid		Total cost (₦)
	PHCN (₦)	Solar (₦)	
1	155,210	No load	155,210
2	116,407.5	66,250	182,657.5
3	77,605	132,500	210,105
4	38,802.5	198,750	237,552.5
5	No load	265,000	265,000

Table 13. Cost of power consumption from the energy sources (case 2 scenario 3)

S/N	Hybrid		Total cost (₦)
	PHCN (₦)	Solar (₦)	
1	489,185.4	No load	489,185.4
2	366,889.05	205,750	572,639.05
3	244,592.7	411,500	656,092.7
4	122,296.35	617,250	739,546.35
5	No load	823,000	823,000

4. CONCLUSION

In this study, two case studies were looked into: the self-contained apartment and three-bedroom flat. These two case studies were further explored individually with three different scenarios namely; electricity supply from only PHCN, electricity supply from only solar system and electricity supply from the combination of PHCN and solar system. Based on the results of data analysis, the following conclusions were drawn: The supply of electricity from PHCN is still the most cost-effective means of energy usage. This is due to the high cost of setting up solar system, The best cost-effective way for having access to constant supply of electricity in a country like Nigeria at the moment is to adopt the load sharing combination PHCN and the solar system based on individual financial strength, and With the load sharing approach, the payback period for solar system is within 10 years range

ACKNOWLEDGEMENTS

The authors would like to express special thanks and gratitude to Covenant University for her finanicial support.

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