Original Research Article

Development of Software for Life Cycle Cost Analysis of Solar Photovoltaic (PV) and Diesel Generator Systems in Nigeria

ABSTRACT

The ability to harness energy for both human and economic development of any nation is dependent on adequate supply of electricity and reliable energy system. Nigeria's economic growth is undermined by the epileptic nature of its electricity supply system. This has presented electricity consumers with a conflict of choice between alternative ways of power generation. In this paper, a software computer program is developed to determine/compare life cycle cost (LCC) of solar photovoltaic (PV) and diesel generator systems as alternatives for electricity generation in Nigeria. The software is developed through an approach involving load determination, energy resources determination, system sizing and a typical residential building. The key methodology adopted is evolutionary prototyping which focuses on vertical dimension approach. Typical load description of a household located in Amawbia Awka of Anambra state in Nigeria was used to test the efficiency of the source code. The initial cost and life cycle cost for the two systems over a period of 30 years was ascertained. Results of the test show that solar PV system is cost effective compared to diesel generator based on total life cycle costs. The study recommends among others, the need to increase awareness of the long term benefits of solar energy systems as alternative source of electricity in Nigeria.

Keywords: Life cycle cost; software; solar; photovoltaic; diesel generator; renewable energy; alternative power generators.

1. INTRODUCTION

Access to clean and affordable modern energy is crucial to fostering social and economic development and to achieve the Sustainable Development Goals. Efficient electrification programs are required to ensure that people are electrified in a sustainable manner [1]. Nigeria's power generation system has not been one marked with significant success. Inadequacies characterize the system at all levels (generation, transmission and distribution), leaving a huge deficit of energy demand. At present, about twenty million households out of about one hundred and fifty million inhabitants lack access to grid electricity and for those who have access to grid electricity, the supply is very poor [2].

The erratic power supply and frequent outages in the country's electric power system has compelled a large percentage of the populace to rely on diesel powered generators [3,4], with a few subscribing to solar energy as alternative means of power generation. The advocacy for a clean source of energy (solar) and the large statistics of diesel generator being used as alternative for power generation by Nigerians led to the consideration of solar PV and diesel generators as alternatives for power source in this study. However, there exists a conflict of choice between these two alternatives of power generation systems. This conflict is instigated by cost of acquisition and efficiency of the system. Though life cycle cost analysis helps to make a cost effective choice, the complexity and time consuming nature of the techniques involved in life cycle cost analysis stands as a deterrent to an average Nigerian in making a choice of a cost effective alternative power generation system. It is in this light that a software for life cycle cost analysis (LCCA) of solar PV and diesel generator power systems is developed in this paper. Depending on the user's load requirements, selected location, material and criteria, the software developed in this paper shows cost difference between solar photovoltaic and diesel generator power systems as well as cost variation in different designers' specifications for either of the systems.

Research has been ongoing in the area of life cycle cost analysis of different renewable energy systems and conventional energy sources. Refs [5–10] affirmed the need for the adoption of solar energy as alternative source of energy for electricity generation. Software and different simulation tools have been developed and employed in life cycle cost analysis, of alternative power generation systems [11,12]. However, the software developed for life cycle cost analysis in this paper differs from others in the capacity of being developed considering sensitive input variables (like solar radiation, diesel fuel price) only in Nigeria. It also demonstrates for educational purpose, a practical approach to implement prototyping software development model.

2. MATERIAL AND METHODS

The cost of generating electricity for a household using solar PV and diesel generator system options have been ascertained. The household is situated in Amawbia, which is about 3km from Awka ((Longitude 7.07^0E, Latitude 6.21^0N) in Nigeria. The area receives 6 hours of peak sun daily, throughout the year, [13]. The life cycle cost methodology used is the present worth technique. The systems have been compared based on the service life they provide, rather than on the classical utility approach of cost per KWh.
This study used a process of requirements engineering (RE), to complement Object Oriented (OO) modeling using the Unified Modeling Language (UML). It incorporates case diagram and activity diagrams as the unified modeling language tool.

The RE process, supported by the UML, generated structured layers of textual requirements at each level of development. The key methodology adopted for providing a structured approach to the UML is evolutionary prototyping which focused on vertical dimension approach. With this, the study presents a logical detail of the data processing function of the software to be developed.

2.1 Mapping prototype and requirements engineering

Evolutionary prototyping used for this design, provides flexibility in the prototype when the requirements that are fully understood are added.

Fig.1. shows the interrelationship between the prototype segments and the requirement engineering development process. It also reveals the separation of problem and solution domains within the RE layers. As displayed by the representation, the associations made, are between the work product models generated through the evolutionary prototyping requirements gathering, analysis and prototype construction segments and the various input models at each RE layer.

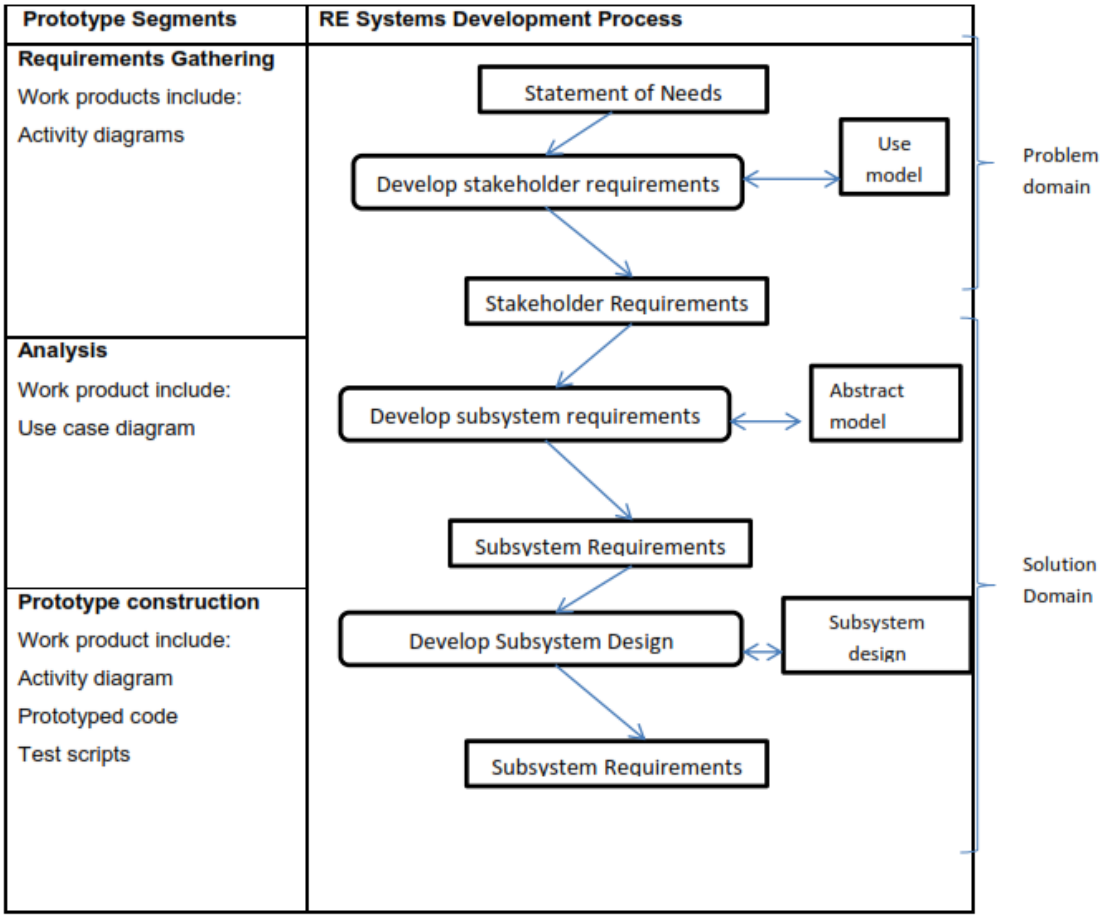

Fig.1. Mapping Prototype segments to requirement engineering process. It shows the interrelationship between the prototype segments and the requirement engineering development process

2.2 Problem Analysis

All sizing of the PV system components and the present worth calculations were done using standard design procedures [14,15]. All sizing of the diesel generator and the present worth calculations were done using [11,14,15].
This paper uses 5 % of the generator capital cost as single routine service cost. The life replacement cost of top cylinder is obtained by first finding the cost of top cylinder overhaul. 2.5% of the capital cost of generator is used as the cost of a single top cylinder overhaul. Overhaul of the generator top cylinder is done six times a year based on the maintenance specification of the selected generator. Hence the annual cost of top cylinder overhaul is obtained by multiplying the number of overhauls per year by the single cost of an overhaul. The life replacement cost of engine is obtained by first finding the cost of a complete engine overhaul. 6% of the capital cost of a generator is used as the cost of a single engine overhaul. The operation of engine overhaul is done seven times before each replacement based on the maintenance specification of the selected generator. The percentage of the generator capital cost used for single routine service cost, single top cylinder cost and single engine overhaul cost were estimated based on the local market of generator service and overhaul cost in Nigeria. The salvage cost used is 20% of the original equipment-price.

The efficiency factors to take care of losses in the wiring and battery were estimated to be 0.98 and 0.9 respectively, based on realistic assumption. The battery was selected such that its nominal voltage does not exceed the selected system voltage. Considering the peak sun hour/ day of Amawbia, the work assumed five days of autonomy.

Maximum depth of discharge of 0.7 and temperature derate factor of 1.0 were used for the selected battery type.

The module was selected such that its nominal voltage does not exceed the selected system voltage. The controller for this solar PV design was selected such that the controller voltage is compatible with the nominal system voltage. It is also capable of handling the maximum current produced by the PV array.

The local costs of PV systems and diesel generators were deduced from quotations of local suppliers. The diesel generator costs #200,000, module costs #30,000, inverter costs #80,000, charge controller costs #5,000, battery costs #30,000 per unit. The study uses estimates of general inflation rate of 11.61%, fuel inflation rate of 14.77% and investment rate of 14% [16,17].
The activity diagram for LCCA of solar PV and diesel generator system is shown in Fig.2. and Fig.3. respectively.

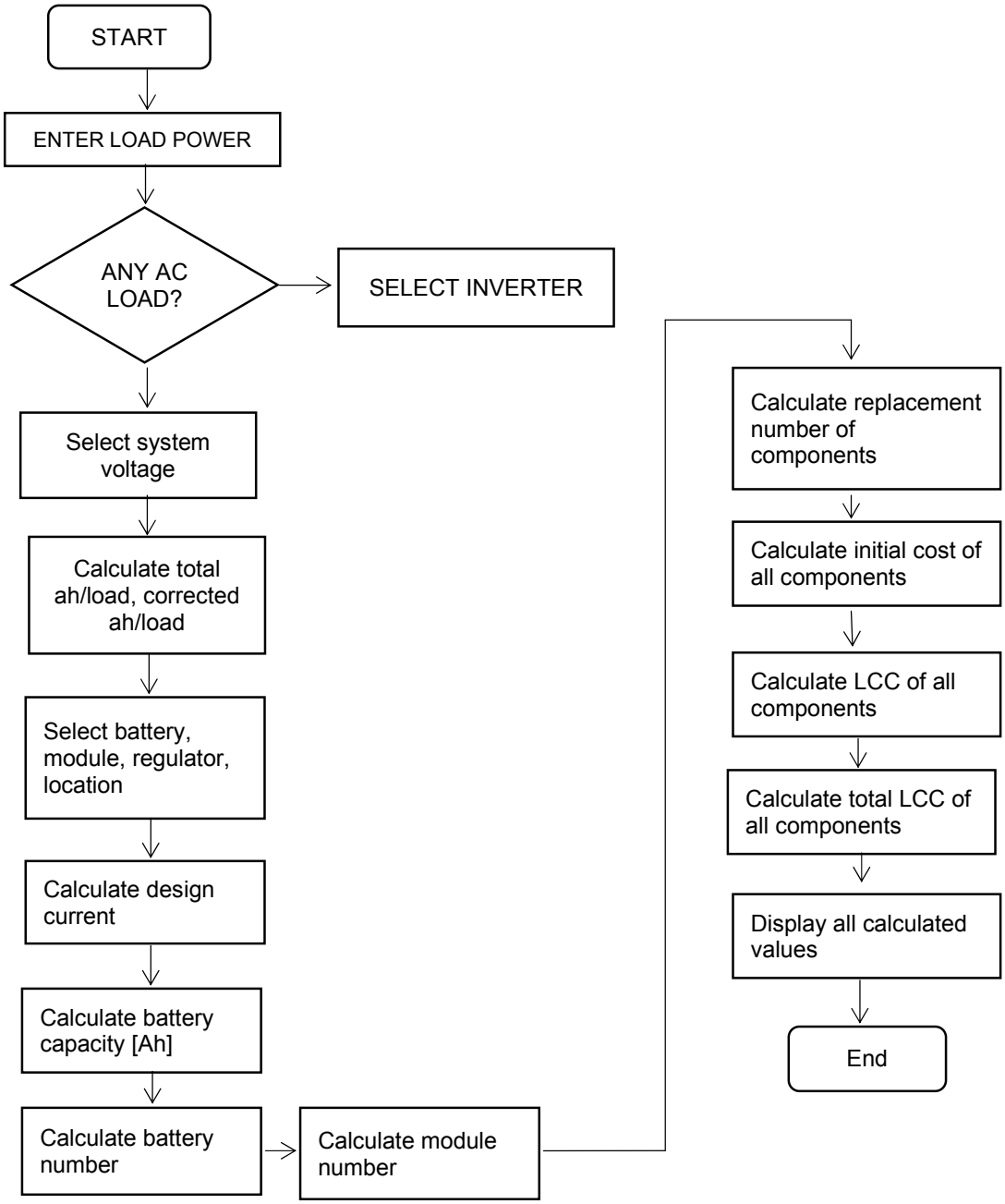

Fig.2. Activity diagram for LCC of Solar PV system. It illustrates laid down steps taken to obtain the life cycle cost of a solar PV system

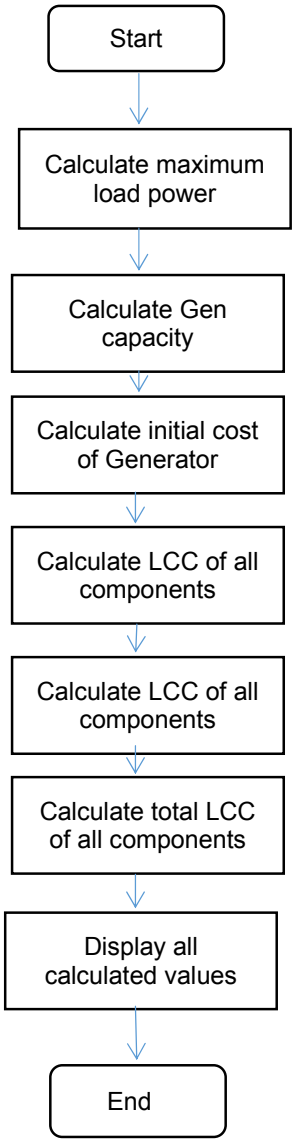

Fig.3. Activity diagram for LCC of diesel generator system. It illustrates laid down steps taken to obtain the life cycle cost of a solar PV system.

2.3 Analysis in the Solution Domain: Functional specification

An illustration of the functional specification for LCC analysis of solar PV and diesel generator systems is depicted in Fig.4.

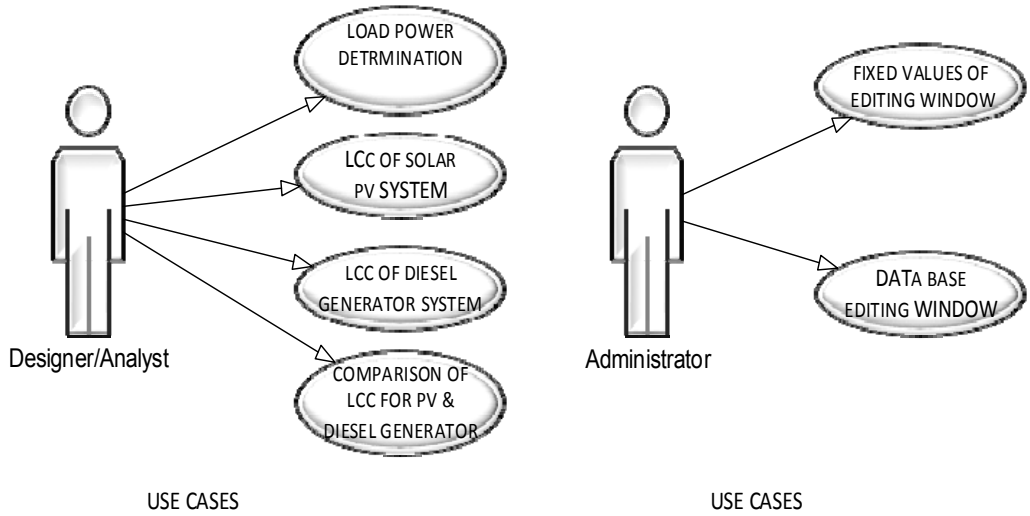

Fig.4. Use case diagram for LCC analysis of solar PV and diesel generator software. It shows the functional specifications of the developed life cycle cost analysis software.

The software at default will provide options for the user to obtain any of the following; the life cycle cost analysis of a solar PV system, obtain the life cycle cost of a diesel generator, compare the life cycle cost of a diesel generator to that of a solar PV system.

Based on the methodology adopted by this paper, the software developed is done on a command line interface. Hence, the values that are meant to be in the database and fixed value editing window, are inputted by the user in the command line.

3. RESULTS AND DISCUSSION

The results discussed in this paper were obtained from the load, inverter, module, battery, controller and generator specifications as shown in Tables 1-6 respectively.

From Table 1, the total energy to be used by the household is 2,074W in a day. Considering loss factor,

Daily Load (watt-hour) = 2,074 X 1.2 = 2,488.8 (watt-hour)

With the value of daily load obtained to be 2,488.8 (watt-hour), a 2500W inverter that would operate at 24 volts was selected.

Table 1: Load description for a household in Amawbia, Awka, Anambra state

Load description	Quantity	Dc load Power(W)	Ac load Power(W)	Daily duty Cycle (Hours/day)	Weekly Duty Cycle (Days/wk)
Lights [DC]	5	24	N/A	4.0	7
Incandescent Light [DC]	1	100	N/A	1.0	7
Ceiling fan [DC]	2	15		4.0	7
Radio [DC]	1	24		1.0	7
Pressing Iron [AC]	1	N/A	1000	0.25	7
Television[AC]	1	N/A	150	3.0	7

Refrigerator[AC]	1	N/A	350	4.0	7
Lights [AC]	3	N/A	100	0.20	1

The LCC of solar PV system and the LCC of the diesel generator system for the household used as case study is shown in Table 7 and Table 8 respectively.

Table 7: Summary of solar PV system life cycle cost

ITEM	Naira Amount	Present Worth	Percent Total LCC (%)
Capital Cost	1,885,000	1,885,000	42.276
Operation & Maintenance	20,000	516,154	11.576
Replacement cost	425,000	2,074,104	46.517
Salvage	377,000	16,468	0.369
Total Life Cycle Cost		4,458,791	100.00

Table 8: Summary of diesel generator life cycle cost

ITEM	Naira Amount	Present Worth	Percent Total LCC (%)
Capital Cost	213,000	213,000	0.88
Annual fuel cost	525,600	18,495,797	75.97
Annual service cost	180,000	4,645,387	19.08
Replacement cost	1,151,045	993,290	4.08
Salvage	42,600	1,860	0.01
Total Life Cycle Cost		24,345,614	100.000

The values of LCC quoted in Table 7 and Table 8 highlight that using a Solar PV system as an alternative for electricity generation is cost effective compared to the diesel generator option. Though the capital cost for the PV system is high (42.276% of total LCC) as compared to the capital cost of the diesel generator (0.88% of LCC), the cost of diesel over the period of the lifetime of the system used in this study is 75% of the total LCC of a diesel generator, which is very high compared to the PV system with zero cost of energy. Furthermore, it is observed from Table 7 and Table 8 that it costs more to maintain a diesel generator over a long period of time than to maintain a PV system while it costs more to replace the components of a PV system compared to that of a diesel generator system.

In a country like Nigeria, where the growth of solar PV system is hindered by perceived high cost of system components, the result of the study discloses that, it is not wise to use procurement costs as the primary criteria to make a choice of an alternative power generation system. Rather, other important factors like fuel and maintenance cost, battery replacement cost, time value of money, as well as system life span should be taken into account This provides an analytical study and estimate of total costs of which a choice of a cost effective power generation system depends on.
Every power supply owner wants a cost effective and efficient system. The biggest overriding factor is that all systems, regardless of the power source, should make energy conservation a top priority. The less power needed, the lesser the amount that must be produced and stored. This can reduce the size, cost and weight of the power generation system. There is need for individuals and government to start massive investment in solar PV system as an alternative for generating electrical energy in residential buildings so as to minimize cost and maximize the free solar energy.

4. CONCLUSION

This paper presents a software for analyzing life cycle cost of two alternatives of power supply – diesel generator and PV systems. The use of this software enables the user to understand the lifetime costs of each of the alternatives. Thus the user is empowered to make better cost-effective choices for alternative energy solutions. The paper also presents a test case result from the software. We recommend that software for life cycle cost analysis of electricity generation alternatives be made readily available to Nigerians, to enable them carry out life cycle cost analysis at their convenience. Thus, the individual may become fully aware of the long term benefits or otherwise of the power alternative - solar PV generation systems or diesel generators- they intend to acquire.

APPENDIX

INVERTER, BATTERY, MODULE, CONTROLLER, AND GENERATOR SPECIFICATIONS

Table 2: Selected inverter Specification

Inverter Specifications
Make Photocomm: (2500W)
Model: 24/48
Wave form: Sine wave
Input Voltage (DC): 24 (V)
Output voltage (AC): 120/240 (V)
Surge capacity: 14,400 (W)

Table 3: Selected battery specification

BATTERY INFORMATION	
Make	Trojan
Model	L-16
Type	Lead Antimony
Nominal Voltage (V)	6
Rated Capacity (AH)	420

Table 4: Selected module specification

PV MODULE INFORMATION							
Make/Model	Siemens M75			Nominal volts		12	
Length	48	width	13	Thickness		1.5	
Weight	12lbs.			Bypass diode		Y	N
Voltage (V)	At STC	Open circuit		At highest expected temperature			
	15.9	19.8		14.4			
Current (A)	At STC	Short circuit					
	3.0	3.4					

Table 5: Selected controller Specification

CONTROLLER
Make/model: Bobier Electronics NDR-30
Rated Voltage: 24V option
Rated controller value: 30A

Table 6: Selected Generator Specification

Three phase 5KVA Diesel generator
Make/model: AD5800DSEA
Power Output: 4-7kw, 50/60HZ
Full tank capacity:16litres
Operating hour of 1 tank:15hours
Fuel consumption:2litre/hour
Hours of generator operation before servicing: 250hours

Hours of engine operation before overhaul: 600hours
Hours of cylinder operation before overhaul:150hours

REFERENCES

1. Mentis D, Andersson M, Howells M, Rogner H, Siyal S, Broad O, et al. The benefits of geospatial planning in energy access – A case study on Ethiopia. Appl Geogr. 2016;72:1–13.
2. Otasowie PO. Analysis of Life Cycle Cost and Determination of Economic Viability of Solar Photovoitaic System , Diesel Generator Set and National Grid Supply in Nigeria. In: 4th International Symposium on Energy Challenges & Mechanics-working on small scales. Aberdeen; 2015. p. 1.
3. Kennedy-Darling J, Hoyt N, Murao K, Allison R. The Energy Crisis of Nigeria: An Overview and Implications for the Future. Univ Chicago. 2008;1–28. Accessed: 05-01-2016. Available: http://humanities.uchicago.edu/orgs/institute/bigproblems/Energy/BP-Energy-Nigeria.pdf
4. Tyler G. Nigeria - Public and Private Electricity Provision as a Barrier to Manufacturing Competitiveness [Internet]. Washington, DC.; 2002. Accessed: 03-03-2015. Available: http://www.openknowledge.worldbank.org/handle/10986/9746
5. Oparaku OU. Photovoltaic systems for distributed power supply in Nigeria. Renew Energy [Internet]. 2002;25(1):31–40.
6. Oparaku OU. Assessment of the cost-effectiveness of photovoltaic systems for telecommunications in Nigeria. Int J Sol Energy. 2002 Jan 1;22(3–4):123–9.
7. Mahmoud MM, Ibrik IH. Techno-economic feasibility of energy supply of remote villages in Palestine by PV-systems, diesel generators and electric grid. Renew Sustain Energy Rev. 2006;10(2):128–38.
8. Zarma I, Bala EJ. Assessment of Diesel Generator and Solar PV for use in the Global System Mobile (GSM) phone industry in Nigeria. Niger J Sol Energy ,. 2008 Oct 13;Vol. 19.
9. El-Shafy A, Nafeh A. Design and Economic Analysis of a Stand-Alone PV System to Electrify a Remote Area Household in Egypt. Open Renew Energy J. 2009;2:33–7.
10. Otasowie P, Ezomo P. Life Cycle Cost Analysis of Diesel Generator Set and National Grid in Nigeria. J Emerg Trends Eng Appl Sci. 2014;5(5):363–7.
11. Ebenezer NK, Brew-Hammond A. Design and Analysis of a 1MW Grid-Connected Solar PV System in Ghana. 2013. (African Technology Policy Studies Network Working Paper Series). Report No.: 78. Accessed: 17-08-17. Available:https://www.africaportal.org/documents/13719/wps78.pdf
12. GUNEY İ, ONAT N, KOÇYİĞİT G. Cost Calculation Algorithm for Stand-Alone Photovoltaic Systems Vocational School of Technical Studies Electrical Programme. WSEAS Trans Syst. 2009;8(7):10.
13. Ike CU. Global Solar Radiation in Awka , South East , Nigeria Using Weather Station. ARPN J Sci Technol. 2014;4(11):678–83.
14. Sandia National Laboratories. Standalone photovoltaic systems: A Handbook of Recommended Design Practice. 1995. 200-203 p. Accessed: 10-11-2016. Available: http://educypedia.karadimov.info/library/sand87_7023.pdf
15. The University of Chicago. Life Cycle Cost Calculation 11-01-2011. Accessed: 10-03-2017. Available: https://d3qi0qp55mx5f5.cloudfront.net/facilities/pdfs/fs2/FS2_4C2_LCCA-2.pdf
16. Nigeria Data Portal.CPI and Inflation Report May 2018. Accessed: 29-06-2018. Available:http://nigeria.opendataforafrica.org/NGNBSNCPIR2017/cpi-and-inflation-report-may-2018
17. Trading Economics. Nigeria Consumer Price Index (CPI) 1995-2018. Accessed: 29-06-2018. Available:http://tradingeconomics.com/nigeria/consumer-price-index-cpi