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Development of a User Friendly Cost Analysis Software for Photovoltaic and Diesel Generator Power Systems

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Abstract: In this work, a user friendly cost analysis software for solar photovoltaic (PV) and diesel power systems was developed using Java programming language and task model approach. The software was used to perform benefit to cost ratio (BCR) analysis and life cycle cost analysis (LCCA) for Trina solar company (a solar PV module manufacturing company) and Generac Holdings Inc. (a diesel generator manufacturing company) taking into account the costs and benefits applicable to these companies. The purpose of the analysis was to determine the best option for investment and most cost effective option for consumers use. Performing BCR and LCCA involves complex mathematical calculations which are laborious for most power system users. Also, errors such as under sizing and over sizing of systems usually occur during sizing of power generating systems which results to inaccurate analysis and results. This software application was developed to address the errors stated above. The BCR result of the analysis carried out with the software application developed shows that both power options are beneficial for investment. However, solar PV is more beneficial with BCR value of 3.7 while Diesel generator is less beneficial with BCR value of 1.27. In addition, LCCA result of a household in Nsukka Enugu State, Nigeria shows that solar PV power option is more cost effective with value of ₦45577197.51 (45.6 million Naira) while diesel generator has value of ₦130651093.96 (130.7 million Naira) for a period of 25 years.

Keywords: Cost Analysis; Diesel generator; Photovoltaic; Task model; User friendly.

1. INTRODUCTION

There are numerous sources through which energy can be generated such as wind, solar, hydro, nuclear, tidal, geo-thermal and biofuel etc. However in Nigeria, the major source of power generation is hydro through the use of dams. The production capacity of grid power generation source has been grossly insufficient in addressing epileptic power situation in Nigeria and other developing countries due to seasonal variation of water level in the dam, power losses during transmission and insecurity among other factors, Hence, there is the need for alternative power sources such as solar photovoltaic (PV) system and diesel generator system. Photovoltaic and diesel generator systems are viable power options because of high amount of solar energy which the country receives by virtue of its position between longitude 3^0 and 14^0 east of the Greenwich meridian and 4^o and 14^o North of the equator which is a high sunshine belt. Also, there is large deposit of crude oil in the country which depicts high availability of diesel fuel in the country. However, the analyses required for choosing the best option for investment and most cost effective for consumers use between these two alternatives involves tedious calculations i.e. benefit to cost ratio (BCR) analysis and life cycle cost analysis (LCCA).

Akinboro et *al*. [1] emphasized the use of solar PV systems in Nigeria as an alternative renewable energy source since less than 40% of the populace is connected to the national grid. Zahedi [2] suggested that solar energy is available at no cost. It offers a more efficient power supply to remote communities and facilities and it is also environmental friendly. Otasowie [3] buttressed through his analysis the severe challenges that Nigerians encounter as a result of electricity generation through the use of diesel generator sets. The analysis of solar energy cost per kWh using different sizes of PV and battery at Sohar-Oman was done in [4]. The result revealed that the use of PV system in powering a health clinic in rural area of Oman will help reduce greenhouse gases emission. Irfan et al. [5] developed a computer software used to determine initial, life cycle and unit energy costs of a stand-alone PV system in Turkey. An LCCA software for solar PV and diesel generator in Nigeria was developed [6]. The software was developed with Python programming language and command line interface. The result of the analysis carried out with the software shows that solar PV system is cost effective compared to diesel generator option because of zero cost of energy. LCCA of a diesel/PV hybrid power generating system for an off grid residential building in Enugu, Nigeria was carried out by [7]. The analysis shows that the hybrid system of solar PV and diesel generator system has the least life cycle cost when compared with other power systems namely stand-alone PV system and diesel generator.

A review in [8] revealed the formula for obtaining BCR. Massimo [9] developed Cost Benefit Assessment (CBA) model which was intended to deal with uncertainties associated with cost benefit analysis. Ronnie [10] employed the concept of cost benefit analysis in evaluating the beneficial nature of smart hospital project in Caribbean. In [11], Java was applied in the implementation of an algorithm that performs computer graphics and triangulations of polygon. Ashim [12] indicated that software development is achieved through structure and systematic development model. The author proposed a model for development of web application which include the following phases: feasibility, analysis, design, coding, testing, implementation and maintenance. Meanwhile, Osborn [13] proposed software development life cycle phases which include: planning, requirements, design and prototyping, software development or coding, testing, deployment, operations and maintenance.

The following gaps were identified in the literature reviewed. Emphasis has been made regarding health implication such greenhouse gases emission of both power option under consideration [4]. Not so much consideration has been given to benefit to cost ratio for companies manufacturing these power options in order to ascertain which option is more beneficial for investment by power stakeholders. The LCCA software for stand-alone PV system in Turkey developed in [5] can only perform LCCA of stand-alone PV system alone. Hence, there is a need for software that can perform LCCA of more than one power generating alternatives [5]. Mba [6] developed LCCA software of PV and diesel generator system using Python programming language. This software developed does not have a functional graphical user interface. This restricts the use of the software to only programmers who can work with command line interface

This work seeks to realize the following objectives:

- To develop a software application with a functional user friendly graphical interface.
- Use task model approach methodology and Java programming language in the software development.
- Use the software application developed to perform BCR analysis of solar PV and diesel generator manufacturing companies as well as LCCA of both power options for a lifetime of 25 years.
- This work also seek to develop desktop version of the application.

2. METHODOLOGY

In this work, task model approach and Java programing language was used. Java programming is a platform independent, secure, object oriented and multithreaded [14]. The task modeling approach adopted in this work is the use of Concur Task Tress which has hierarchical structure, graphical syntax and task allocation capabilities [15]. The Concur Task Tree operators were used to describe the operational flow of the application. Some of the operators and their functions are presented in Table 1.

Table 1. Task models operators and their uses [16]

Task Model Operators	Uses
Independent concurrency (|||)	It implies that action belonging to two tasks can be performed in any order without any specific constraints.
Choice operator ([])	It enables a particular task to be chosen from a set of task. Once an option is chosen, other tasks are suspended until the chosen task is terminated.
Concurrency with information exchange operator (|[]|)	It enables two tasks to execute concurrently but they must be synchronized in order to exchange information.
Order independent operator (|=|)	It allows both tasks to be performed but when one task is started, it has to be completed before the second one can start.
Deactivation operator ([>)	It is used for terminating an operation for new one to start.
Activation operator (>>)	It activates an operation in execution of a task.
Enabling with information operator ([] >>)	This allows exchange of information from the first task to the second instead of only activating it.
Suspend and resume operator (| >)	This interrupts the first task for the second to be complete, after which the first continues in its execution.
Iteration operator (*)	This allows a task to be performed repeatedly. This continues until the task is deactivated by another task.
Finite iteration operator (n)	This is used when the designer knows in advance how many times a task will be performed.
Optional operator [T]	This shows that the performance of a task is optional

3. DESIGN AND IMPLEMENTATION

The design framework used in this work involves the following phases which is consistent with software development life cycle methodology.

3.1 Business Modelling Phase

This phase involves requirement engineering in the problem domain. A use model scenario was employed to show various interrelationships among the user requirements. The requirement engineering development process of the application involves two phases namely:

a) User Requirements: The user requires the software to provide a graphical user interface (GUI) where the parameters for analysis can be entered.
b) System Requirements: The system should be able to size the power systems, perform the analyses using parameter on the interface and those entered by the user and display the result. The operational view of the application is shown in Figure 1.

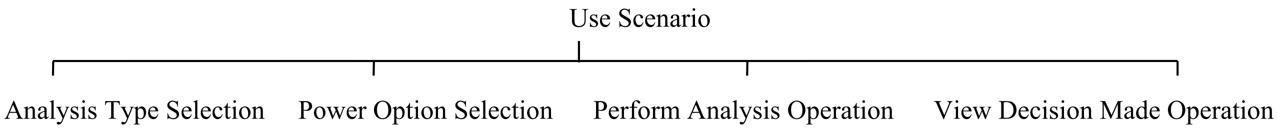

Figure 1. Modeled use scenarios of the software application

In the design of the application, it is very important to know the various costs and benefits required when performing BCR analysis of the power generating options. These costs are BCR production, administrative expenses, research cost, cost of maintenance of production facilities and taxes. The benefits considered are government grants, government subsidies, revenue from production, income tax benefit and contribution from investors. The parameters considered for LCCA of diesel generator are: maximum load power, generator capacity, salvage value, years of analysis, fuel escalation value, generator fuel consumption per hour, price per litre of diesel, discount rate and cost of generator and its components. On the other hand, the parameters considered for LCCA of solar PV system are wire efficiency factor, battery efficiency factor, power conversion efficiency, general inflation rate, years of analysis, discount rate, the number, capacity and cost of components namely module, inverter, battery and charge controller.

3.2 Task Analysis Phase

Task analysis and modelling is done first to identify the relevant tasks to be carried out during analysis. Proper knowledge about the various sizes of the components of the system is required to perform LCCA. This is done through load determination, system sizing and resources assessment. Each of the cost and benefits of the system components are assigned monetary values in the present worth values before BCR and LCCA is performed. BCR is the ratio of the benefits of a project expressed in monetary terms relative to its costs also expressed in monetary terms in discounted present values [17]. The BCR is performed by the application using Equation (1) [10]:

$$BCR = \sum_{n=1}^{\infty} \frac{B_i}{C_i} \tag{1}$$

where B_i and C_i are discounted values of benefits and costs respectively, obtained from the net present value of benefits and costs using the relations: $\text{benefits}/(1+d)^n$ and $\text{costs}/(1+d)^n$. d is discount rate and n is years of analysis.

3.3 Sizing of Solar PV System

This include the following tasks:

a) Load Determination: The total ampere-hour load (AH_T) requirement in Ampere hour (Ah) is calculated as [6].

$$AH_T = \frac{L_p \times D_{DC} \times 52 \times W_{DC}}{360 \times V_{ns} \times \eta_{pc}} \tag{2}$$

where
L_p - The total load power requirement (i.e. AC and DC loads)
D_{DC} - Daily duty cycle (i.e. Total number of hours that each of the load will be operational daily)
W_{DC} - Weekly duty cycle (i.e. Total number of hours that each of the load will be operational weekly)
V_{ns} - Nominal system voltage required to power the load by the PV system
η_{pc} - The power conversion efficiency of the inverter.

b) Voltage System Selection: The rule of thumb for system voltage selection during sizing of PV system is summarized in Table 2.

Table 2: Rule of thumb for selecting system voltage [18]

System Voltage Selection	
AC Power Demand (watts)	Inverter Input Voltage (volts DC)
< 1,500	12
1,500 – 3,000	24
3,000 – 5,000	48
>5,000	120

The life maintenance cost (*LMC*), life cycle replacement (*LCR*) and life salvage cost (*LSC*) for a solar PV system are given by [19]:

$$LMC = AMC \times \left(\frac{1+g}{d-g}\right) \times \left(1 - \left(\frac{1+g}{1+d}\right)^n\right) \tag{3}$$

$$LRC = ARC \times \left(\frac{1+g}{d-g}\right) \times \left(1 - \left(\frac{1+g}{1+d}\right)^n\right) \tag{4}$$

$$LSV = ISV \times \left(\frac{1+g}{d-g}\right) \times \left(1 - \left(\frac{1+g}{1+d}\right)^n\right) \tag{5}$$

where *AMC* is the annual maintenance cost, *ARC* is the annual replacement cost, *ISV* is the initial salvage value of the PV system, *g* is general escalation rate and *n* is the life cycle period.

3.4 Sizing of Diesel Generator Power System

Generator capacity and the annual fuel cost (*AFC*) can be determined as [3]

$$Generator\ capacity = \frac{maximum\ load}{power\ factor} \tag{6}$$

$$AFC = AOH \times FCR \times price\ per\ litre \tag{7}$$

where *AOH* is the average generator operating hours in a day and *FCR* is fuel consumption rate. On the other hand, the life fuel cost (*LFC*), life routine service cost (*LRS*C), life replacement cost (LRC_{Gen}) and Life salvage cost (*LSV*) of diesel generator are given by [3]:

$$LFC = AFC \times \left(\frac{1+f}{d-f}\right) \times \left(1 - \left(\frac{1+f}{1+f}\right)^n\right) \tag{8}$$

$$LRSC = ASC \times \left(\frac{1+g}{d-g}\right) \times \left(1 - \left(\frac{1+g}{1+d}\right)^n\right) \tag{9}$$

$$LRC_{Gen} = ARC \times \left(\frac{1+g}{d-g}\right) \times \left(1 - \left(\frac{1+g}{1+d}\right)^n\right) \tag{10}$$

$$LSV = ISV \times \left(\frac{1+g}{d-g}\right) \times \left(1 - \left(\frac{1+g}{1+d}\right)^n\right) \tag{11}$$

where *f* is the fuel escalation value, *ASC* is annual service cost, *ARC* is annual replacement cost for generator components, and *ISV* is initial salvage value of the diesel generator system. Routine services usually take place every 250 hours of operation which implies that routine service per year takes place 35 times.

The life cycle cost (LCC) is used to obtain the total life cycle cost of both power systems. This is given as [18]:

$$LCC = C + M_{pw} + E_{pw} + R_{pw} - S_{pw} \tag{12}$$

where C is a capital cost of equipment, M_{pw} is a maintenance cost including a service cost, E_{pw} is an energy cost including yearly fuel cost represented with the differential fuel inflation rates for diesel generator. Energy cost is zero for PV system since the energy source is free from the sun. R_{pw} is a replacement cost of PV system and diesel generator components and S_{pw} is a salvage value which is 20% of the capital cost.

3.5 Data Modelling Phase

The data used for BCR and LCCA of solar PV and diesel generator in this work are as discussed in this section. The following assumptions were made in this work regarding data usage and interpretation:

i) The target baseline for the BCR analysis is 1
ii) BCR value greater than 1 (i.e. BCR > 1) shows that the benefits of the project exceeds the costs hence the project will be beneficial if invested in.
iii) BCR value equal to 1 (BCR = 1) shows that the benefits of the project is equal to the costs hence the project may be allowed to proceed with little benefits.
iv) BCR value less than 1 (BCR < 1) shows that the costs of the project exceeds the benefits hence the project should not be executed or invested in because it will be non-beneficial.
v) DC loads of 1 kW and below was assigned 12 V by the application.
vi) The inverter, controller and battery voltage was 12 V for loads below 1 kW and multiples of 12 V for loads above 1 kW.
vii) Naira to Dollar rate = ₦365, Fuel Escalation rate = 20%, General escalation rate = 16.9%, Discount rate = 16.7%, Diesel price = ₦155, Life time= 25 years.
viii) Wire efficiency factor = 0.98, Battery efficiency factor = 0.9, Power conversion factor = 0.9
ix) Life span of battery, inverter and charge controller = 10 years
x) Number of battery, inverter and charge controller replacement in a year = 1
xi) Number of generator replacement for 1 year = 1
xii) Number of top cylinder replacement for 1 year = 4
xiii) Number of Engine replacement for 1 year = 1

The data for BCR analysis was obtained from financial report of Trina Solar Company and Generac Holdings Inc. in Naira. The various costs and benefits of both companies incurred in the production of solar modules and diesel generators are shown in the Table 3. Table 4 shows the load description of the house hold while Table 5 gives the specification of module, battery, inverter and charge controllers. Table 6 gives the generator specifications and capacity.

Table 3. Costs and benefits of Trina Solar Company [20] and Generac Holdings Inc. [21]

TRINA SOLAR COMPANY			
COSTS	**AMOUNT(Billion ₦)**	**BENEFITS**	**AMOUNT(Billion ₦)**
Production expenses	10.711	Government grant	0.328
Administrative expenses	0.488	Cash subsidies	2.017
Research expenses	0.124	Revenue from manufacturing	27.928
Maintenance expenses	0.088	Shareholders contribution	12.371
Taxes	0.111	Tax benefit	0.011
GENERAC HOLDINGS INC.			
Production expenses	6.234	Government grant	0
Administrative expenses	9.326	Cash subsidies	0.005
Research expenses	0.097	Revenue from manufacturing	6.554
Maintenance expenses	0.211	Shareholders contribution	0.170
Taxes	0.110	Tax benefit	0.00051

Table 4. Load description

AC LOADS (watts)					DC LOADS (watts)				
S/N	ITEM	Qty.	DDC (Hrs/day)	WDC (Days/Week)	S/N	ITEM	Qty.	DDC (Hrs/day)	WDC (Days/Week)
Load 1	Pressing Iron (1400 W)	1	2	3	Load 1	Fan (25 W)	5	4	7
Load 2	Refrigerator (350 W)	2	6	7	Load 2	Blender (24 W)	1	1	2
Load 3	Washing Machine (600 W)	1	2	3	Load 3	Radio (80 W)	2	3	7
Load 4	Toaster (300 W)	1	1	7	Load 4	Lights (60 W)	7	4	7
Load 5	Water Dispenser (500 W)	1	6	7	Load 5	Television (65 W)	3	4	7
Total	3500	6	17	27	Total	924	18	16	30

Table 5. Specifications of module, battery, inverter and charge controller

ITEM	MODEL	CAPACITY	NUMBER	COST
Module	Allmax plus	270 – 295 W	16	₦ 912 000
Battery	XC2 Flooded Lead Acid Battery	12V	4	₦ 540 000
Inverter	Prags 1.2KVA	12V	4	₦ 304 800
Charge Controller	EPEVER 30A Solar charge controller	12V	4	₦ 47 100

Table 6. Diesel generator specifications [22]

Model	Load Capacity (W)	Generator Rating (kVA)	Fuel Consumption (LTR/HR).
SDO 10	10,000	12.5	4.30
SDO 15	15,000	19	5.60
SDO 20	20,000	25	6.70
SDO 25	25,000	31	9.50
SDO 30	30,000	38	10.40

3.6 Process Modelling

The application is required to provide a user friendly graphical user interface (GUI) that will enable users to perform BCR and LCCA for solar PV system and diesel power generating system. It should be able to display the results from the analysis performed and also determine which option is more beneficial to invest in. It should also give the most cost effective option for use over a period under consideration. The Concur Task Tree and activity diagrams are employed to demonstrate this functionalities. This section describes the modules in the system and the interconnection of processes that makes up each subsystem.

Figure 2 shows how the software performs BCR analysis. The analysis is activated (>>) when the user selects the analysis type (BCR) and power option (Solar PV or Diesel Generator) type which runs concurrently (|||). The application then uses ([]>>) the years, Discount rate, costs and benefits entered by the user on the application interface and equation (1) above to carryout benefit to cost ratio analysis. These benefits and costs include: production, administrative expenses, research cost, cost of maintenance of production facilities and taxes while the benefits are government grants, government subsidies, revenue from production, income tax benefit and contribution from investors. The application displays the result of the analysis which leads to the termination of the operation ([>).

Figure 3 shows the LCCA operation process of the application. The operation is activated (>>) when the user selects LCCA as analysis type. If the user selects ([]) Solar PV as power option type, the application prompts the user to enter the years and discount rate for the analysis, AC and DC loads concurrently(|||). The application then calculates the total load power by adding the number of AC and DC loads together. The application sizes the system according to thumb rule for voltage selection in Table 2 above in order to obtain the voltage requirement of the battery, inverter, charge controller and number of module. The user is required to enter cost of components such as operational and maintenance, capital, Battery, inverter and charge controller replacement costs. The application then performs LCCA using the parameters entered by the user and Equations (2) - (5) and Equation (12). The operation gets terminated ([>) when the result of the analysis is displayed. However, If the user selects ([]) diesel generator as power option type, the application then requires the user to the enter the year, discount rate, maximum load (Max load) which is the total load power obtained by adding AC and DC loads together. The application then determines (**[]>>)** the right generator capacity according to Table 6 above. The user is required by the application to enter the cost of component such as capital cost, annual service cost, annual generator replacement, annual top cylinder and engine replacement cost. The application then performs LCCA using the parameters entered and Equations (6) – (12) above and the operation is terminated (**[>**).

Figure 4 shows the decision making operation of the software. The software fetches ([]>>) the various results of the analysis and compares them after which it determines concurrently (|||) the most beneficial and cost effective option. The operation is terminated ([>) after the result is displayed.

The activity diagrams showing the operational flow of the application are shown in Figures 5, 6 and 7.

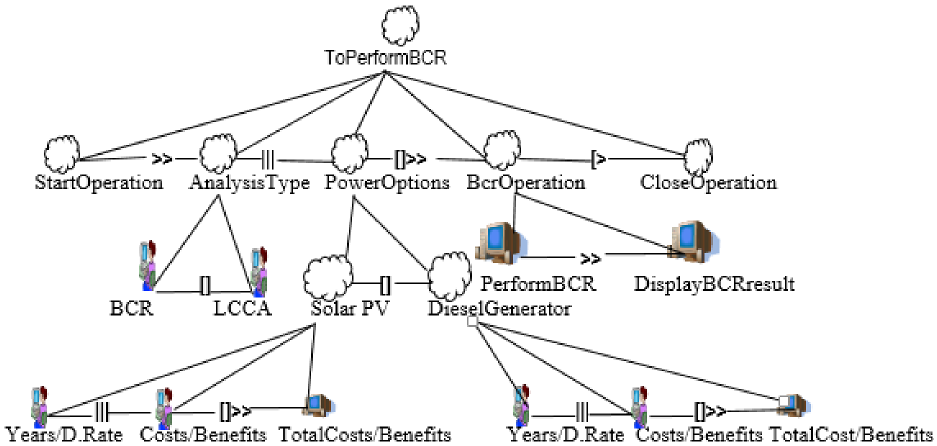

Figure 2. BCR analysis of solar PV and diesel generator of the software application

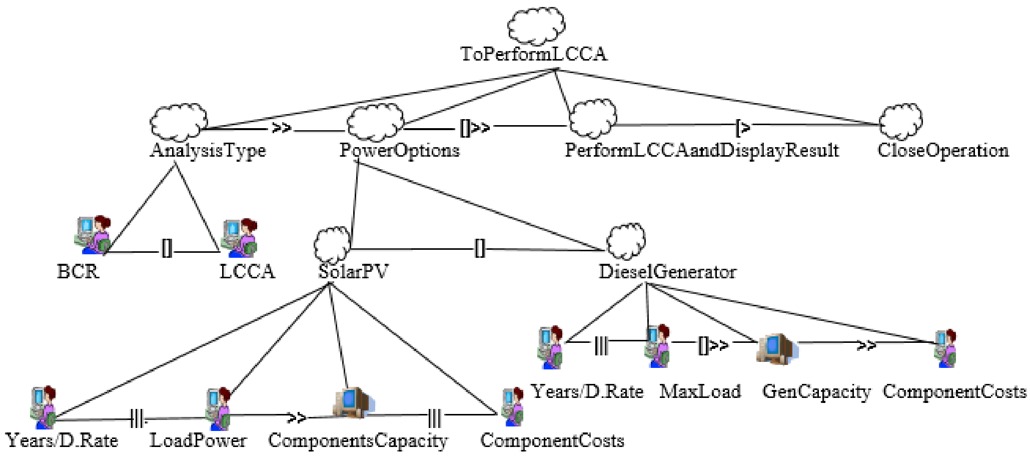

Figure 3. LCCA of solar PV and diesel generator of the software application

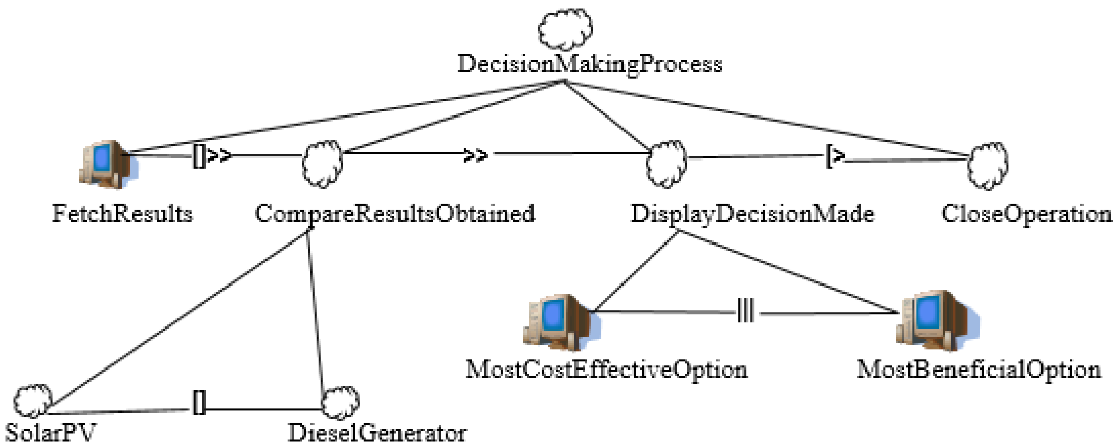

Figure 4. Decision making concur task tree diagram of the software application

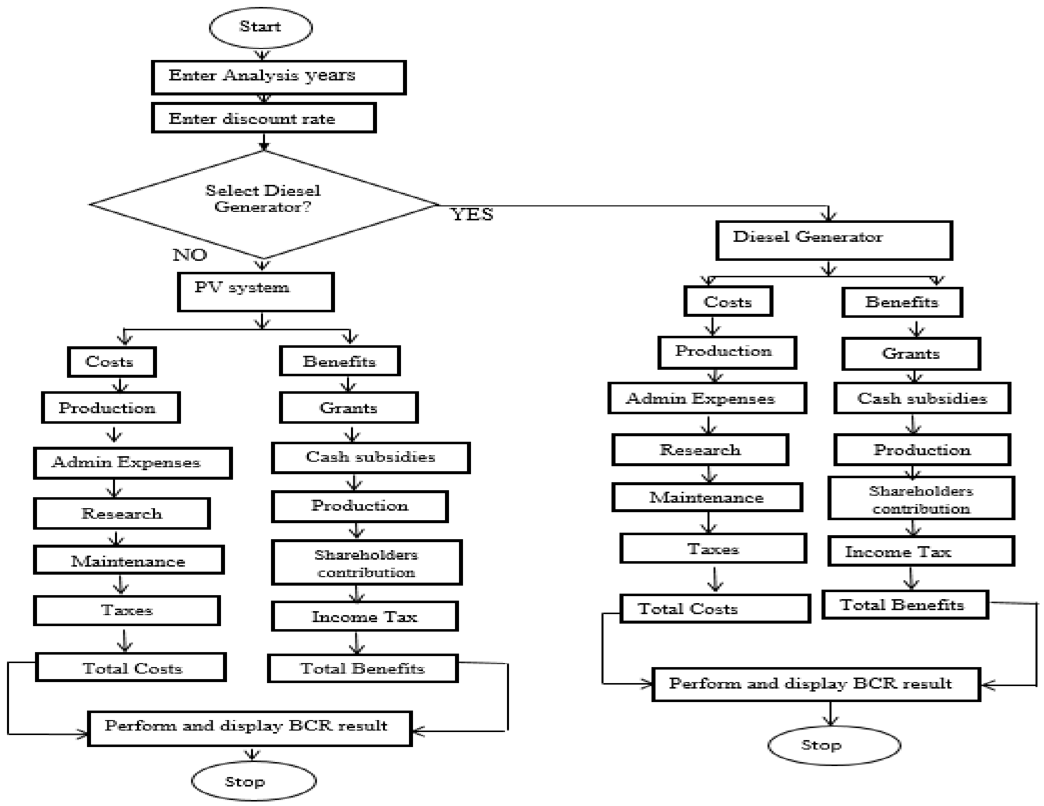

Figure 5. Activity diagram for BCR analysis

3.7 Software Application Generation

The application was developed using Java tools provided by INTELLI J Integrated Development Environment (IDE). Java programming language was used because it is simple, robust, secure and multithreaded. This implies that applications developed using Java programming language can handle more than one task at the same time. The application was developed by creating Java classes with the INTELLI J IDE. The Home page contains the link to analysis platform and decision making platform for users. The reusability of each class or component of the classes ensures that one class or component can be called up without designing new classes where and when the need arises. The various classes created in the application are shown in Table 7.

4. TESTING AND RESULTS

The software was tested with data from previous work on life cycle cost analysis. The result obtained is consistent with the equations for LCCA and BCR analysis. The test interface is shown in Figure 9. Various interface of the application during implementation and analyses are shown in Figures 10 – 16.

The result of the BCR analysis obtained for Trina Solar Company and Generac Holdings shows that investing in any of the power option will be beneficial because they are both viable alternatives for electricity generation. However, Trina Solar Company with higher value of 3.7 is more beneficial for investment than Generac Holdings with BCR value of 1.27. In addition, the LCCA result also shows that solar PV is the most cost effective option for period of 25 years with value of ₦45577197.51 while diesel generator power option is less cost effective with value of ₦130651093.96. The cost of owning a solar PV system will continually drop as a result of increase funding of photovoltaic industry globally which encourages research and better solar PV products. The result of such actions can be seen in reduced cost and high performance of solar PV components. Nevertheless, diesel generators will continue as a major power generation alternative in developing countries such as Nigeria because of availability of fuel and low initial purchasing cost of diesel generators.

5. CONCLUSION

In this work, a functional and robust analytical software was successfully developed. Task model approach was used successfully to describe the operation of the application. The application developed was used to carry out benefit to cost ratio and LCCA of both power options. A desktop version of the software was developed successfully in this work. However, there is need for the software application to be developed in other versions such as web (internet) and android versions which will provide easy and convenient use of the application by most users. In addition, the software application has provision for only five costs and benefits, five (5) alternating current (AC) and five direct current (DC) loads. Hence, the need for the interface to be enhanced to include additional costs, benefits and loads.

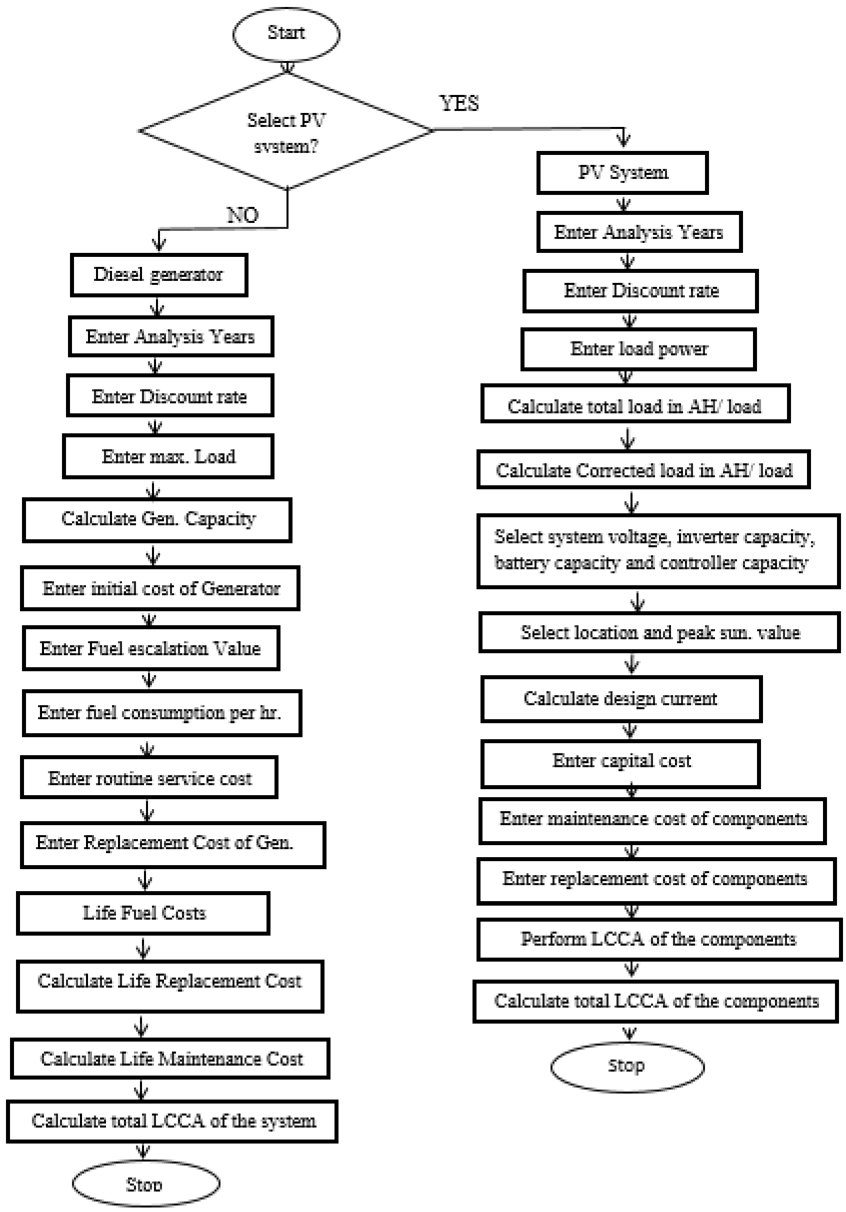

Figure 6. Activity diagram for LCCA

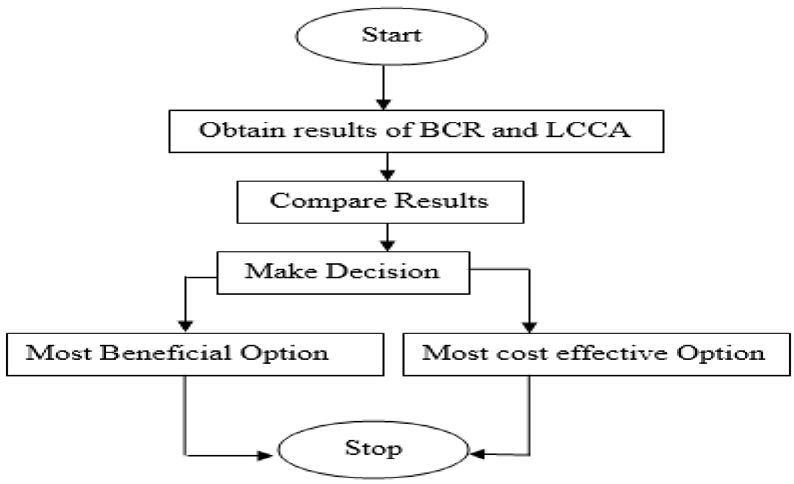

Figure 7. Activity diagram of decision making operation of the application

Table 7. Java classes of the software application

JAVA CLASSES OF THE SOFTWARE APPLICATION	COMPONENTS OF EACH CLASSES
Home Page Class	File Menu Button, Analysis Platform Button and Decision Making Platform Button and help button
Analysis Platform Class	Power Option Button, Analysis Type button, cancel and the start analysis button. The Analysis type button is linked to the BCR and LCCA classes.
Decision Making Platform Class	Contains Text Fields for the display of most cost effective option and most beneficial option and also the Find Button used to initiate decision making operations. These information is displayed when the find button is clicked

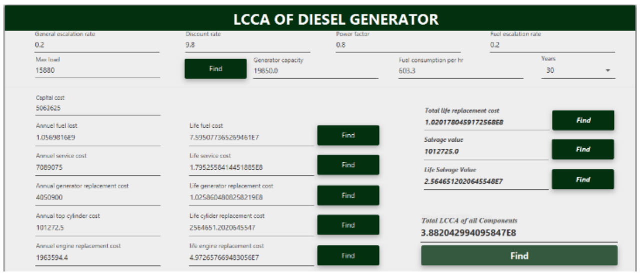

Figure 8. Test interface of the application

Figure 9. The application homepage

Figure 10. Analysis selection and decision making platform of the software application software

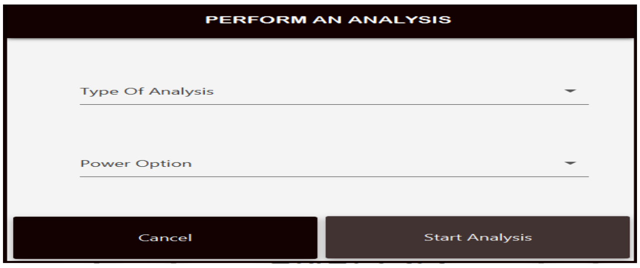

Figure 11. Analysis and power option selection platform of the software application

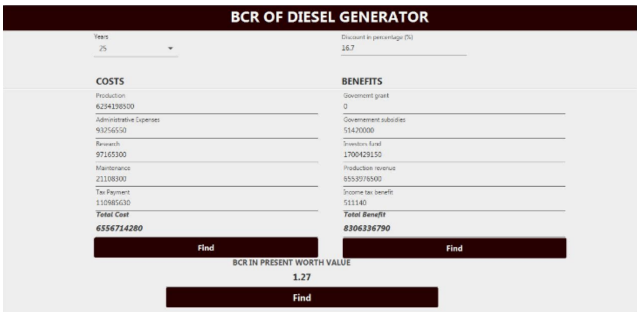

Figure 12. Benefit to cost ratio platform of diesel generator option

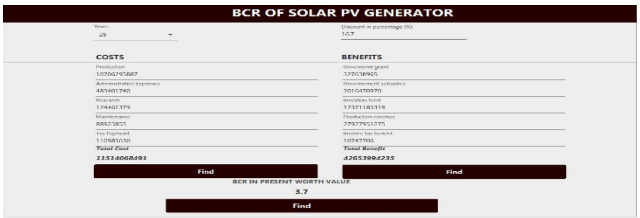

Figure 13. Benefit to cost ratio platform of solar PV option

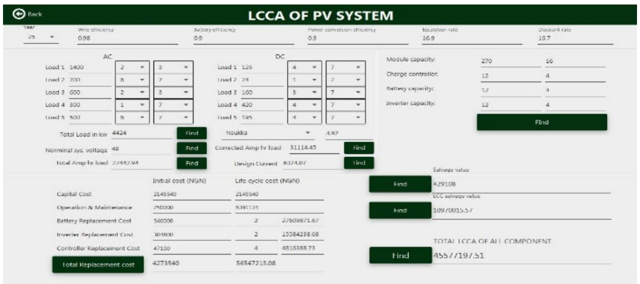

Figure 14. LCCA platform of solar PV option

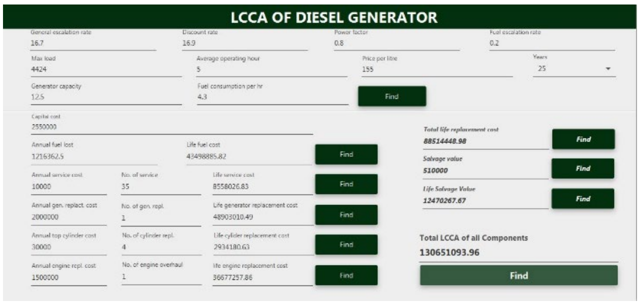

Figure 15. LCCA platform of diesel generator option

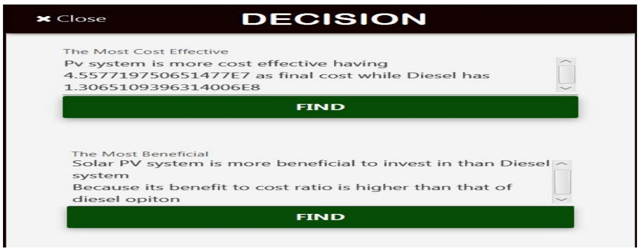

Figure 16. Decision making platform of the software application

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