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RESEARCH ARTICLE OPEN ACCESS

Evaluation of an Alternative Source of Power for Ship Operations in Ports

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Abstract:

This research undertakes the provision of an alternate source of power of vessel that berths in Nigeria ports. Renewable energy such as solar power will be used to power these vessels. Port Harcourt port was used as a case study for this research. A total of 2.5mW was observed as the constant power needed to power vessels that berth in Port Harcourt port. A total of 10800 panels is connected in 1080 parallel and 10 series while 6578 Batteries are connected in 274 parallel and 24 series will be used to generate 2.5mW needed to power vessels that berth in Port Harcourt port. The cost of running this solar generator for 25 years which is estimated as the life span of the solar panel is shown in this research. The Solar batteries is replaced after 10 years as the assumption of the solar power plant (SPP) maintenance cost. This research will help reduce pollution and generate an alternative revenue source for Nigeria Port Authority. ETAP and MATLAB software will be used to carryout necessary analysis in this research.

Keywords: Renewable Energy, Nigeria Port Authority, Revenue Generation, Pollution, Solar Power Plant

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I. INTRODUCTION

The exhaust gas emission from vessels can be pollution emission (Achilleas et al, 2021). The emission of these gases is on the increase due to heavy demand of moving cargo from one point to another. The activities from marine operations in port such as loading and discharging of cargo is a major contribution to climate change due to this (Corbett, et al, 2007). The Nigeria Port Authority (NPA) operates and governs activities of ports in Nigeria. Calabar Port, Warri Port, Apapa port Complex and Tin Can Island Port in Lagos, Onne port and Port Harcourt port are major ports controlled by the NPA. In 2005 the federal government implemented its concessioning programme with an aim of promoting efficiency through public and private partnership.

Cold ironing, a process that enables ships to receive electrical power from the shore side while at berth, has been implemented in several ports worldwide as a means of reducing ship emissions and noise. This technology, also known as shore supply of power, has been successfully introduced in ports such as Los Angeles, Antwerp, Genoa, Gothenburg, and Oslo (Parth et al, 2016). By providing ships with an alternative power source during their stay at the port, cold ironing allows them to turn off their auxiliary engines, leading to a significant reduction in their environmental impact (Zis et al, 2014).

Many developing countries, including Nigeria, have not yet adopted shore power as a means of providing electricity to their ports. As a result, the emissions generated by port operations are causing health issues for nearby communities. Due to the epileptic power supply in Nigeria an alternative and reliable means of renewable energy such as solar generator will be used. To provide an effective shore supply of power, cost analysis of the solar/diesel generator will be compared as used in ports by ships that come to call.

II. LITERATURE REVIEW

Emodi and Yusuf (2015) identified various constraints on power access in Nigeria, including low competency and implementation, security of fuel source, administrative impediments, inattentive institutional organization, information inefficiency, ramshackle transmission and distribution, meager grid structure, and lack of approach and venture advancement. Solar power systems can offer solutions to these problems, such as no fuel cost for power generation, reduced running costs, and a more robust transmission grid structure (Dumkhana and Idoniboyeobu,

To determine the hourly yield force of photovoltaic (PV) and wind blend system, the hourly load variety of the examined region is drawn and the loss of load probability (LOLP) is assessed through Monte Carlo simulation. The battery storage system is then integrated into the system, and the LOLP unswerving quality list at several battery measures, PV, and wind blend are determined. Stiel and Skyllas (2012) have used Vanadium Redox Battery as an integrated technology model in extensive large-scale remote wind/diesel control systems using Hybrid Optimization of Multiple Energy Resources (HOMER) Micro-Power Optimization Model computer program built by the US National Renewable Energy Laboratory.

The results from this study show significant financial and ecological benefits to be achieved in mounting energy storage. A metering system will be installed in this research to charge batteries during low radiation of sunlight to reduce LOLP that may arise as a result of insufficient storage of power on the battery, and Surrette/Roll is used, having a rated capacity of 4560AH.

Girma (2013) recommended the most reasonable design of a solar PV system with a diesel generator as support for suggested rural school electrification. The technical and economic evaluation of the ideal system was prepared, contrasting the economic energy of a sunlight-based PV/generator/battery mixture control system with that of a separate diesel generator system, using HOMER simulation software for the analysis. In this research, Matrix laboratory (Matlab) and Electrical Power System Analysis (ETAP) software are used to analyze a solar power plant (SPP) in electrifying NPA, and it gave a reasonable result compared to the diesel generator currently in use.

Zaheeruddin et al. (2015) examined a blend of one or more renewable sources like PV and wind, either in separate or grid-connected mode with energy storage capacity-based energy systems. The hybrid system was modeled, optimized, and analyzed using HOMER software built by the National Renewable Energy Laboratory, Colorado USA. The hybrid systems were evaluated based on Net Present Cost, Cost of Energy, Initial Cost, Operation Cost, and Renewable Fraction attained on the basis of analyzed outcomes.

To assess the technical state and economic potentials of new energy systems or sources that appear to match economic development, engineers, technologists, and students concerned with renewable energy systems must undertake modern-related software and hardware tutoring to aid them in carrying out both technical and economic analysis on other energy systems. This research aims to analyze real-time life cost analysis and the rate of pollution that auxiliary generation vessels produce using a diesel generator and compare its operating cost to a solar generator. It will also enable NPA to generate funds through cold ironing processes and reduce pollution present in Nigerian ports.

III. MATERIALS AND METHODS

A power audit is shown in Tables 1 to 3 on the auxiliary engines and the various metric tonnes (MT) of fuels on Ships that berth in Port and Terminal Operator Nigeria Limited (PTOL). This data was obtained by me from 4th of January 2018 to 31st of May 2023. A 2.5mW solar generator power as observed from the table will be capable of powering all vessel that loads and unload cargo at this berth. An analysis of using SPP will be carried out during this research with the aim of reducing operational cost, pollution and generating revenue for NPA.

TABLE 1:

The power and running cost of a vessel in PTOL terminal in January 2018

Days in a week	**Name of vessel**	**Number of days in a port**	**Gross Registered Tonnage**	**Cargo carried**	**Generator power used in port (KW)**	**Fuel consumption MT/Day**	**Total power used in 24hrs**	**Total fuel used in a week**	**Total cost of running vessel in port (N)**
1st week of January	MV. Leonarisso	4	27989	Wheat	1210	5.0	5.0*4+ 4.3*2+ 4.16*4	45.24* 206,280=	9332107.20
	MSC.Maria	2		Container	900	4.3			
	MV. Bold Voyager	4	25905	Salt	880	4.16			
2nd week of January	MV. Frio Shinano	4		Fish	1100	4.7	4.7*4+4.3* 1	23.1*206,2 80=	4765068.00
	MSC. Maria	1		Container	900	4.3			
4th week of January	MV. Secombus	4		Fish	900	4.42	4.42*4 + 4.74*4+4.3 5*1	40.99*2062 80	8455417.20
	MV. Angara	4		Fish	1200	4.74			
	MV. Andermatt	1		Salt	910	4.35			

TABLE 2:

The power and running cost of a vessel in PTOL terminal in February 2018

Days in a week	Name of vessel	Number of days in a port	Gross Registered Tonnage	Cargo carried	Generator power used in port (KW)	Fuel consumption MT/Day	Total power used in 24hrs	Total fuel used in a week	Total cost of running vessel in port (N)
1st week of February	MT. Biskra	2	8744	Bitumen	660	3.92	3.92*2+4.35*5 +4.16*7 +4.75*4+4.3*2	86.31*206280	17804026.80
	MV. Andermatt	5	12578	Salt	910	4.35			
	MV. Paraskevi	7	26330	Wheat	850	4.16			
	MV. MercsKelani	4		Bulk malt	1100	4.75			
	MV. MSC Maria	2		Container	900	4.3			
2nd week of February	MV. Bold Voyager	4		Salt	880	4.16	4.16*4+2.75*7 +4.32*7	66.13*206280	13641296.40
	MV. Hibisus	7		Bulk wheat	400	2.75			
	MV. Pamyatilliche	7		Fish	960	4.32			
3rd week of February	MV. PamyatIlliche	1		Fish	960	4.32	4.35*1+2.75*6 +4.3*4+2.62*4	48.53*206280	10010768.40
	MV.Hibisus	6		Bulk malt	400	2.75			
	MV. Maria	4		Container	900	4.3			
	MV. Interlink Levity	4		Wheat	350	2.62			
4th week of February	MV. Sierra Leyra	4		Fish	820	4.21	4.21*4 + 4.02*4 + 4.3*2	41.52*206280	8564745.60
	MV. China Frost	4		Fish	740	4.02			
	MV. MSC Maria	2		Container	900KW	4.3			

TABLE 3:

The power and running cost of a vessel in PTOL terminal in March 2018

Days in a week	Name of vessel	Number of days in a port	Gross Registered Tonnage	Cargo carried	Generator power used in port	Fuel consumption MT/Day	Total power used in 24hrs	Total fuel used in a week	Total cost of running vessel in port (N)
1st week of March	MT. Biskra	1	8744	Bitumen	660	3.92	3.92*1 + 4.21*4 + 3.86*7	47.78*206280	9856058.40
	MV. Da Qing	4	12578	Cargo	870	4.21			
	MV. Discover	7	26330	Wheat	550	3.86			
2nd week of March	MV. MSC Maria	2		Container	900	4.3	4.3*2 + 4.15*1 + 4.29*7 + 4.16*1	46.94*206280	9682783.20
	MV. Numalik	1		Cargo	740	4.15			
	MV. Sweet Lady	7		Bulk salt	810	4.29			
	MV. Bold Voyager	1		Salt	880	4.16			
3rd week of March	MV. Sweet Lady	1		Bulk salt	810	4.29	4.29*1 +4.16*3 + 4.42*4	34.45*206280	7106346.00
	MV. Bold Voyager	3		Salt	880	4.16			
	MV. PamyatKirova	4		Cargo	930	4.42			
4th week of March	MV MSC Maria	4		Container	900	4.3	4.3*4+ 3.92*1	21.12*206280	4356633.60
	MV Briska	1		Bitumen	660	3.92			

After closely observing the power used in ports by vessels when they berth as shown in the Tables 1 to 3 in which both power requirement and fuel consumption for each vessel was tabulated. A 2.5mW power generator set is selected to be used initially for port operation and during the course of this research, a comparative analysis is carried out between a solar and diesel generator.

A. *Data Collection on Power Consumption of Ship Operations in Port*

Various vessel such as dry, liquid and bulk carriers predominantly occupy this berth. The current available power requirement for this research work was carried out from 4th of January to April 31st 2018. The full power requirement carried out in this research work entails that the power during working hours of the vessel and crew comfort was placed into consideration.

Tables 1 to 3 shows the expected power requirement of vessels when in port and terminal operations limited (PTOL) berth with respect to the generators used and the running cost due to Intermediate fuel oil (IFO) needed to run the vessel. The price of IFO 180 sales for $573 (N206,280.00) for one Metric Ton (MT).

B. *Solar Panel Sizing for 2.5MW*

The size of a PV array depends on both technical and economic factors related to the PV panel. It is generally assumed that the output of a PV panel is directly proportional to the amount of incident radiation it receives (Podder et al, 2015). In order to determine the appropriate size for a PV panel, several key parameters must be taken into consideration, including the total daily energy (E) in watt hours, the average number of sun hours per day (T_{min}), and the Direct Current (DC) voltage of the system. Once these parameters have been determined, the sizing process can begin.

For this particular project, the Solar Panel Model 270W Polycrystalline Solar Panel is to be used. This panel boasts a cell efficiency of around 30% and utilizes advanced low sunlight technology, which ensures high performance even in low light conditions. Additionally, it comes with a 25-year warranty and can handle high charging currents. The unit cost for this panel is N 55,000.

C. *Peak Power*

Equation 1 allows us to calculate the total number of PV panels required based on the required power (P) and the average sun hours per day (T_{min}).

$$E_{rough} = P * T_{min} \quad (1)$$

To ensure that the system is not undersized, we first divide the total daily energy demand (E) by the efficiency (η) of the system components. This gives us the daily energy requirement from the solar array, which can be obtained using equation 2.

$$\frac{E}{\eta} = E_r \quad (2)$$

Where E_r is the dialy energy requirement, E is the dialy average energy consumption; and η_{overal} is the product of component efficiencies as shown in equation 3.

$$E_r = \frac{E}{\eta_{overall}} \quad (3)$$

To achieve the Peak power (P_p), the result of equation 3 is divided by the average sun hour per day T_{min} for the geographical location as shown in equation 4.

$$P_{peak} = \frac{\text{dialy energy requirement}}{\text{average sun hours per day}}$$

$$P_{peak} = \frac{E_r}{T_{min}} \; Kwp \quad (4)$$

To obtain the total current required in DC, Equation 5 indicates that the peak power must be divided by the DC voltage of the system (Dumkhana and Idoniboyeobu, 2018).

$$I_{DC} = \frac{Peak\ Power}{System\ DC\ Voltage}$$

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$$I_{DC} = \frac{P_{peak}}{V_{DC}} \quad \text{Amps} \qquad (5)$$

D. *Number of Series (N_s) and Parallel (N_P) Modules*

To meet the desired voltage and current requirements, the module needs to be connected in both series and parallel. To calculate the number of modules connected in series *(Ns)*, the DC voltage of the system (V_{DC}) needs to be divided by the rated voltage of each module (V_M), assuming V_M =34.5 as shown in Equation 6. This will determine the string length of the module. As a result, TN_S represents the number of modules in series.

$$\text{TNs} = \frac{V_{DC}}{V_M} \qquad (6)$$

To determine the number of parallel modules (TN_P), we divide the total peak power of all modules (P_P) by the peak power capacity of one module (P_M), and then multiply the result by the number of series modules (N_S), as shown in Equation 7.

$$TN_p = \frac{P_P}{P_M * TN_S} \qquad (7)$$

To calculate the total number of modules (TN_M), we multiply the number of series modules (TN_S) by the number of parallel modules (TN_P), as shown in Equation 8. These calculations are based on a 2500kW load and a PV lifespan of 25 years, according to Franklin (2017).

$$TN_m = \text{TN}_\text{p} * \text{TN}_\text{S} \qquad (8)$$

E. *Total cost of PV Panel for a 2500KW System*

The total cost of the solar panel is calculated by multiplying the total number of PV modules (TN_m) and the unit cost of PV panel (U_{ppv}) in which a unit price of PV panel in Nigeria is ₦55,000.00. Total Module Area occupied is calculating by multiplying the total number of PV module (TN_m) and the dimension of solar panel as shown equation 9 and 10.

$$\boldsymbol{TC_{PV}} = TN_M * U_{PPV} \qquad (9)$$

$$\text{A} = \text{TN}_\text{m} * \text{Dimension of SP } mm^2 \quad (10)$$

F. *Battery Sizing and Cost*

The choices of the batteries are taking into consideration the capacity, the load time and depth of discharge. They are designed to be recharged hundreds or thousands of times. The batteries are rated in amp hours (AH) and its properties are shown in table 4. Like solar panels, batteries are wired in series or parallel to increase voltage to the desired level and increase amp hours.

TABLE 4:
The Specification/Details of the Batteries (Dumkhana and Idoniboyeobu, 2018)

Model	2YS-62P
Series	5000
Manufacturer	Surrette/Rolls
Type	Flooded- Dual Wall
Dimension	27.38"*9"*31.63"
Weight	570lb
Nominal Voltage	2V
Rated Capacity (24 hours)	4560AH

G. *Calculating for twenty-four (24) hour a day autonomy using solar Battery*

In view of the full load calculated from the power review of the building, the energy required is 2500kW. Presently computing for twenty four hours a day independence by using Battery. The safe energy storage $E_{safe}$is equal to the E_{rough} divided by the maximum allowable level of discharge (MDOD) as shown in equation 11.

$$E_{safe} = \frac{E_{rough}}{MDOD} \quad (11)$$

The capacity of the battery bank as shown in equation 12 is in ampere hour is equal to the E_{safe} divided by the rated voltage for each battery V_h to be used in the battery bank.

$$c = \frac{E_{safe}}{V_b} \quad \text{Ah} \quad (12)$$

Where C is the capacity of the battery bank and V_b is the battery bank voltage. The total number of batteries ($TN_{batteries}$) used are obtained by dividing the capacity of the battery bank needed (C) in ampere hours by the capacity of one of the battery C_b selected in ampere hours as shown in equation 12, since the battery bank is composed of batteries we have

$$\text{TN}_{\text{batterie}} = \frac{C}{C_b} \quad (13)$$

The number of series connection (TN_s) equals to the DC voltage of the system divided by the voltage rating of one of the batteries selected is presented in equation 14. The number of parallel paths (TN_p) is obtained by dividing the total number of batteries by TNs as shown in equation 13

$$TN_s = \frac{V_{dc}}{V_b}$$
$$TN_p = \frac{TN_{batteries}}{TN_S} \quad (14)$$

Therefore the total cost of battery (TC_b) is the product of the number of battery to the unit price of one battery (U_{pb}) as represented in equation 14 (Ishaq et al, 2013).

$$TC_b = TN_b * U_{pb} \quad (15)$$

H. ***Inflation and Replacement Cost of batteries:***

The National Bureau of Statistics disclosed that the consumer price index has dropped from 11.37% to 11.3% as price rose at a slower rate for all categories. Inflation rate in Nigeria average 12.46% from 1996 to 2019 (World Bank, 2019). A rate of 11.37% inflation will be used as commodity inflation rate of batteries, maintenance cost of diesel engine and replacement cost of diesel engine.

$$TC_b = TC_b * (1 + \text{r})^{ni} \quad (16)$$

Grid power supply or generator can also be used to power the vessels in Port during nighttime. It requires a battery to store the DC generated from the solar cell DC to power all lighting appliances, motors and so on and are designed to use AC power while most solar power systems generate DC current which is transmitted to the inverter (Jayakumar, 2009).

A 4680AH battery system will deliver power using a power for one day autonomy. In view of the fact that we are neither designing nor constructing the battery for this research work a 2YS-62P Surrette/ Rolls battery is used with a replacement cost (TC_b) of 10 years with a unit cost of ₦500,000.

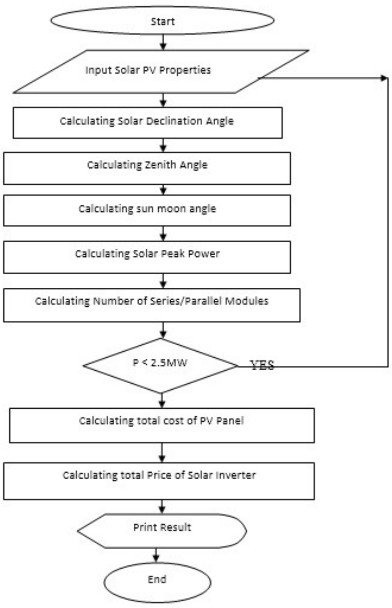

Fig 1 Flow Chart of 2.5mW Solar Generator for Powering Vessels in Port Harcourt Port

3.9 Inverter Cost

The total load calculated is 2500KW and a 500kVA inverter is suitable. In view of the fact that we are neither designing nor constructing the inverters for this research work, we will recommend: A 500kVA, 3-Phase Solar UK Xantra with Product Code: FR-UK33500; Weight: 3,300.00kg; Dimensions: 1000mm *42000mm * 2000mm is recommended with a cost price of₦ 52,000,000.

APP B shows the individual property of the selected inverter. A total of six (6) pieces of this inverter will be needed for this design. A flow chart showing the implementation of the above steps to obtain the total costing of this 2.5mW solar generator plant is shown in Fig 1.

IV. RESULTS AND DISCUSSION

1. PV Arrangement

Matlab and ETAP simulation are used to verify the arrangement of PV panels, which are suitable for analyzing the Solar Generator behavior of a PV module. The proposed PV model is validated by the results shown in figure 2a and figure 2b ETAP simulation. The specification of the user defined PV module and batteries which demonstrates the series and parallel parameters PV module operating under standard test conditions.

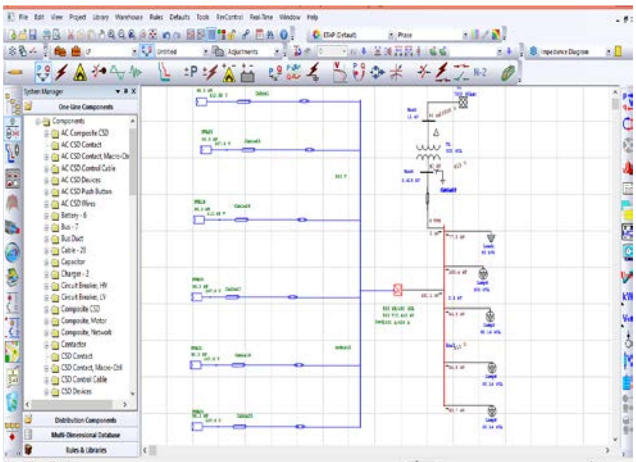

Fig 2: The ETAP Simulation of the Alternating Current (AC) 500KVA Solar Generator

Figs 2 and 3 shows the ETAP simulation of 500KW solar Generator set in which the PV module is arranged in 10 series and 180 parallel and a total of 1800 panel was used.

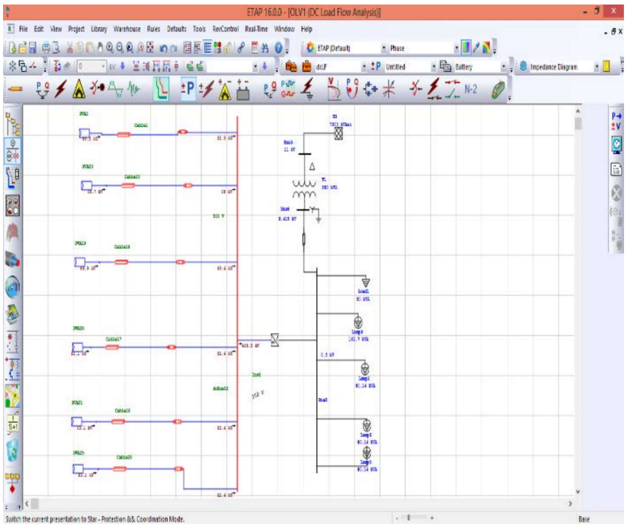

Fig 3: The ETAP DC Simulation of 500kva Solar Generator

Fuses and line wire cost was considered negligible. Loads shown in Figs. 2 and 3 represent watercraft load as shown in table 1 to 3. The inverter connects converts the DC to AC current. Figure 3 shows the ETAP simulation for a 2.5MW Solar Generator system that runs for 24 hours. A total of 10800 Panels was used to generate 2.5MW Power in which 1080 panels was connected in series and 10 parallel and 6578 batteries was used and connected in 24 parallel and 274 series.

2. Cost of Running Solar Generator

The total cost of running solar generator for 25 years was calculated to be ₦ 8,867,000,000 for the initial cost and ₦ 22,889,000,000 as the final cost after 25 years with battery replacement as the only maintenance cost of running the solar generator since inverters and solar panel are said to have 25 years warrantee. The battery replacement cost for 10 and 20 years caused a spike in the cost of the solar generator as shown in figure 4. The main costing of the solar generator was obtained from the number and unit cost of PV panel, batteries and inverter used while cable, fuse and metering cost were considered negligible.

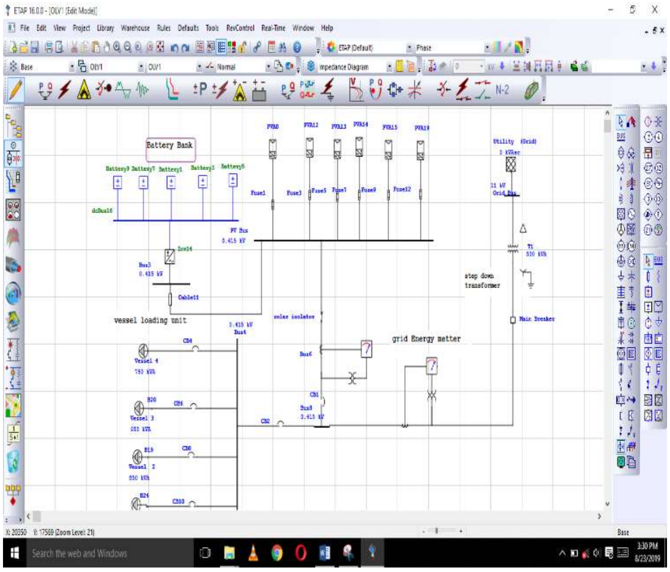

Fig 4: The ETAP Simulation of 2.5mW Solar Generator Power System

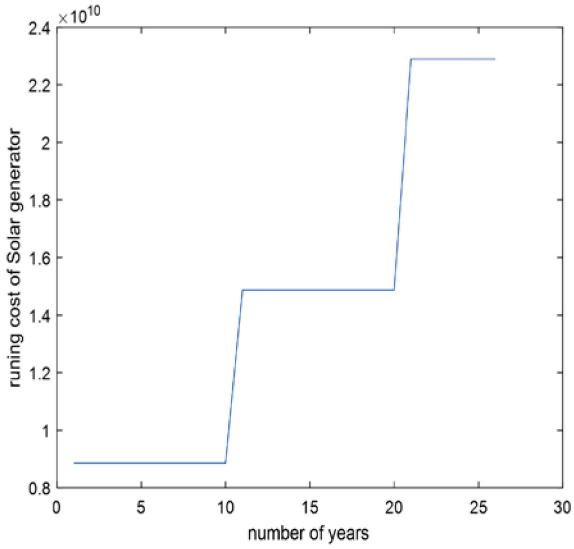

Fig 5: Cost of Running Solar Generator for 25 years

V. Conclusion and Recommendations

The mainstay of NPA is to provide a good working environment for its staff, generate revenue for federal government and have a low operational cost for ship owners. It is therefore needed to implement an alternative source of power for vessels when they berth in Ports to facilitate speedy port operation and reduce auxiliary engine downtime that may occur as a result of engine failure due to over usage.

A life cycle cost analysis of a solar generator set in which initial cost, maintenance and replacement cost of the generator component was considered. The maintenance cost of solar generator is comparatively low as to when compared with its initial cost, and hence considered as the best choice for comparison.

The result of using this choice of generation as to the traditional diesel engine used in our ports today will reduce the rate of pollution produced. The diesel engine due to its fuel consumption will cause greenhouse gas effect and make the ports a potential health hazard to NPA staff. A step-by-step analysis of the SPP parameters obtained was used to write a program to determine the cost analysis of the generator thereby holistically monitoring this generator for 25 years. This program could be extended to other power plant such as gas and wind turbine plants.

Based on the results obtained in the course of this work, the following recommendations are hereby made:

a) A solar generator should be aimed at during implementation of shore supply of electricity in Port Harcourt port.

b) There should be an increase in research in shore supply of electricity on old vessels.

c) More stringent laws should be enacted and enforced to reduce the rate of pollution that occurs due to fuel consumption of diesel engines

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