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Assessing the Economic and Environmental Prospects of Stand-By Solar Powered Systems in Nigeria

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ABSTRACT: This paper presents an economic analysis of two stand-by power supply options for a typical Nigerian household namely diesel generator plant and solar powered systems. The analysis reveals that solar systems are the most economically viable. The environmental benefits associated with substituting diesel powered stand-by plants with solar powered photovoltaic systems were also estimated. The amount of diesel saved was estimated and the reduction in air pollution calculated. With this two analysis it is hope that individual households in Nigeria, will be encouraged to go for solar stand-by systems while Government will be encouraged to pursue further an energy-environmental friendly policy which will lead to reduction in the production of air pollutants. This kind of policy is very essential, as the number of household installing stand-by power plants in Nigeria has been found to increase exponentially over the past few years. @JASEM

Solar powered generating systems are well established and they have proved a reliable and problem-free alternative to conventional power generating systems as stand-by in few Nigerian homes. Many manufacturers in America and Europe, produce solar powered generating systems, which are becoming increasingly common in Nigeria. The technology is mature and the systems have proven that they can withstand the weather conditions. Their superiority to conventional systems lies not only in the economics but also in pollution abatement. The technical feasibility of solar power systems has been well established, while economic feasibility has been a major barrier restricting widespread use in Nigeria. Solar energy powered systems usually require a substantial initial investment as compared to conventional power system which makes them very sensitive and vulnerable to economic environment. However since solar powered systems usually have life span of about 30 years and the conventional system has a life span of about only 10 years there is room for comparison. The approach here is usually to compare the long run energy cost per annum of the solar system with that of the conventional system taking into account initial capital investment, running costs, maintenance cost, and fuel cost. In Nigeria, the National Electric Power Authority (NEPA) is the sole organ in charge of generation, transmission, distribution and sale of electric power. The NEPA system is susceptible to frequent breakdowns usually resulting in long outage duration.

Several researchers have done economic and environmental analyses of solar thermal systems, Brandemuehl and Beckman (1979), Sinha *et al.*, (1992), Kumar (1994) and Haralambopoulos and Spilanis (1997). In economic analysis, a slight error in assumption of life of a capital-intensive system can produce misleading results. Also in a country like Nigeria where the energy resources are abundant there is needed to really assess the economic viability of this kind of project.

Solar Radiation in Nigeria

Nigeria has a lot of potential in terms of solar energy as it lies between about latitude 4 – 14°North of the equator. Several studies have been carried out by many investigators on the solar radiation pattern in Nigeria (Adeyemo, 1997; Arinze, 1986). As a tropical country Nigeria receives on the average as high as 20MJ/M^2 per day of solar insulation depending on the time of the year and the location considered. As can be seen in the work of (Adeyemo, 1997; Arinze, 1986) the variations expected are quite small. The Nigerian Federal Ministry of Science and Technology estimates that the total annual energy consumption of about 21 x 109 kwh could be made by converting only 0.1% of the total solar radiation incident on the country at a conversion efficiency of 1% (Bugaje, 1999). In other to be able to select the required size of the photovoltaic system required to sustain a typical household in Nigeria, a parameter called the Peak Sun Hours is employed. The peak sun hours gives the number of hours needed at peak sunray condition to have an equal amount of solar energy for that day. Arinze (1986) gives the peak sun hours for various locations in Nigeria.

The Photovoltaic Power System

Direct conversion of sunlight into electricity can be achieved using photovoltaic cells. The technology involved in the fabrication of the cell is high and so are the initial costs of these cells. However, these systems are very attractive as they do not involve moving parts and hence are maintenance free. Photovoltaic cells were initial design for use in space programmes, but recently the cost of this cells have come down and they are now widely used for non-space application such as the one we are considering now. Research has shown that the individual photovoltaic module can convert solar radiation into electricity with an efficiency of about 15% (Herwig, 1997). The life span of these cells is estimated at 30 years. Voltage by photovoltaic modules is almost constant with only very insignificant variation with changing solar radiation intensity. With this characteristics the photovoltaic modules are very suitable for charging batteries so as to store part of the generated energy for later use after sunset. This is the basic principle behind the photovoltaic solar power plant.

The photovoltaic power plant is made of the following parts – the photovoltaic cell, battery bank, battery charge controller, inverter, protection devices and other accessories of the solar systems.

Photovoltaic cells: In photovoltaic cells the open voltage remains fairly constant with changing solar radiation intensity. Variations are only found in current output. These variations have found to be almost linear with respect to solar radiation intensity. Photovoltaic cells are usually connected together in what is known as module. They may be connected in series or in parallel or both. Series connection of the cells increases the voltage output to the module whereas parallel connection increases the current output to module. In a photovoltaic power plant several modules are connected in an array to achieve the desired electric power output. The electric power is given by P = I x V: where P is in Watt, V is in Volts and I is in Amperes. The photovoltaic power system is usually designed such that the solar cells operate at the point of maximum power, which can easily be achieved by using a maximum power point tracker in the system (Bugaje 1999).

Battery Bank: These storage batteries are required because of the mismatch between supply and demand for power. Depending on the power requirement the batteries can be arranged in series or in parallel. The powers generated by the photovoltaic cells are direct current type, which is only good for few domestic operations like lighting.

Inverter: These converts direct current to alternating currents. They are required because some of the loads that will be serviced by the power plant require alternating current like the operation Television Sets.

Battery Charge Controller: They are required to protect the batteries against excessive charging current.

Protection Devices: They are required to protect the array of modules from consequences of failure in any of its modules. These devices are actually diodes place along the bypass connection around the module. See figure 1– 3. A module may fail due to deterioration of electrical contacts or shading.

The Photovoltaic Power System Sizing

In photovoltaic power system design the following data are required in order to properly size the system. Accurate data on the solar radiation of the location concerned; Accurate data on the characteristics of the solar cells employed in the design of the plant; The peak load of the system to be powered together with variation of this demand on daily/seasonal bases.

The above data are then use to estimate the following parameters, which gives the size of the plant.

(1) The required number of the photovoltaic modules; this for stand-alone systems can be given by the equation:

$$P_{PV} = \frac{E_L + (\frac{E_L D}{C_R} xBE)x100}{k} \quad \text{-----(1)}$$

where P_{PV} is the photovoltaic module array size in peak watt, E_L is the daily energy requirement (Wh/day); D is the number of storage days; C_R is charge recovery of the battery efficiency (days); BE is watt – hour efficiency of the battery; and k is the annual average equivalent peak hours per day (sunshine period).

(2) The required number and size of the storage batteries. This for stand-alone systems can be given by the equation

$$C_t = \frac{E_L xD}{C_D} \quad \text{----(2)}$$

where Ct is the storage capacity of battery (Ah) and C_D is maximum permissible depth of discharge (DOD) and E_L and D as previously defined.

(3) The capacity of inverter, Battery charger controller and other accessories: This depends on the electrical parameter (voltage to current) that is expected to go through the equipments. Several sizes are usually available in the market.

For the hybrid system the above equations are still applicable but only that the values obtained from the equations has to be multiplied by the demand factor, which can be determine by using the average outage duration of the conventional system.

Diesel Engines used in Most Home Holds as Standby

A survey has shown that most Nigerian household seeking standby power supply for their houses usually go for the clone system, which is schematically illustrated in figure 1. The system is usually made up of a diesel engine, a 10 kilowatts alternator, two water drums to act as cooling units, and one diesel drum. The system is usually noisy and consumes a lot of fuel thereby generating a lot of smoke. Even though the systems live was being estimated at five years. This has to be sustained at very heavy maintenance cost. The most worrisome problems in the households using this system now are its economic, noise, maintenance cost, fuel cost and its environmental impact.

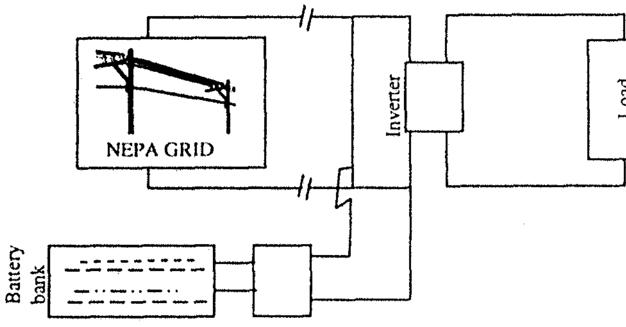

Fig.1: Schematic diagram of the Battery back–up system in use in most household in Nigeria.

The Photovoltaic Systems used in Few Nigerian Households

In the Nigerian solar market there three kinds of systems in used – namely the Battery back – up system; the stand-alone photovoltaic solar system; and the hybrid photovoltaic system.

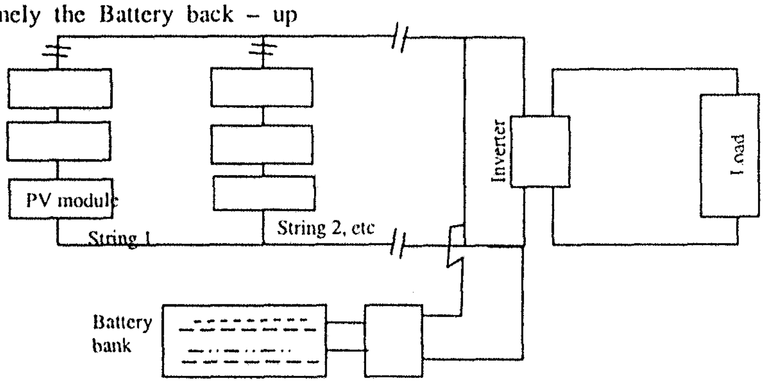

Fig. 2: Schematic diagram of a stand-alone photovoltaic power plant for use in Nigeria household

The Battery back-up system is schematically shown in figure 1. Basically the Battery back up system is a combination of the NEPA system, battery bank, inverter and all the necessary solar installation accessories without the photovoltaic modules. Domestic consumers usually use them where NEPA supply is fairly stable for example in Government reserved Areas. Specifically they are usually recommended where NEPA outage hours are not more than 1 hour per day. The batteries are charge by the NEPA system when it is on and the electricity stored is sufficient to last till the NEPA comes on again.

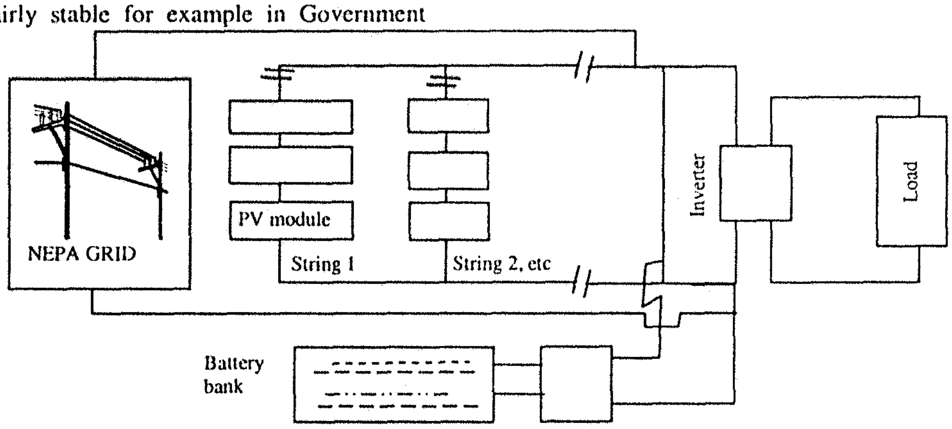

Fig 3. Schematic diagram of a hybrid photovoltaic power plant for use in Nigeria House hold

The stand-alone photovoltaic solar system is schematically shown in figure 3. The stand-alone system is a complete solar system made up of photovoltaic modules, battery bank, inverter and all the necessary solar installation accessories with out the advantage of being also connected to NEPA. Consumers in remote areas where NEPA grid has not been connected usually use them. This remote area includes islands, isolated telecommunication stations, remote villages, river – data region and isolated desert locations. The photovoltaic storage battery involved here are usually many so that they can sufficiently charge/store power in the system in the day times such that there will be power all night.

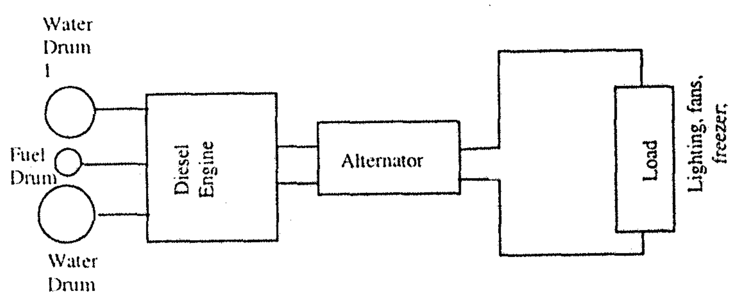

Fig. 4: Schematic diagram of the conventional diesel power plant use most Nigerian households.

The hybrid photovoltaic solar system is schematically shown in figure 4. The hybrid system is a complete solar system made up of photovoltaic module, battery bank, inverter and all the necessary solar installation accessories with the additional advantage of being also connected to NEPA

The hybrid systems are the most commonly used as stand – by systems in most Nigerian households. The hybrid system is usually cheaper than the stand-alone systems because it requires less number photovoltaic cells and Batteries. Hence we are going to compare the hybrid system with the diesel plant in our analysis.

Economic Evaluation

The systems size will determine the systems fuel requirements, which is important for economic-environmental evaluation of the diesel powered system against photovoltaic solar powered system. The first step in doing this is to estimate the plant size and average load requirement for a typical household in case study location in Nigeria. From table 2, the size of the generator required is a 1.5kw Engine since the total load is only 0.5kw and the average power requirement is 1.53kwh/day (approximately 1.6kwn/day) assuming each equipment is operated for 3h/day.

The cost of the diesel engine is estimated at ₦160, 000.00 and maintenance cost are estimated at 25% of capital cost per annum. Empirical studies have shown that 5 litres of fuel per day (i.e. 1825 litres per annum) will be required to deliver the estimate 1.6kwh. With diesel cost at ₦35 per litre (realistic price instead of government fixed price) the total cost of fuel can be put at ₦63, 875 per annum. The life expectancy of this diesel engine from empirical studies can be put at 10 years

Table 2: Load Data

Load Type	Total Load	Power Requirement (Load x 3h/day)
6 lamp 40w	240w	720wh/day
2 lamp 25w	50w	300kwh/day
1 refrigerator 25w (1/6 Hp)	125w	375wh/day
1 television set 40w	40w	120wh/day
1 video set 40w	40w	120wh/day
1 radio set 15w	15w	45wh/day
Total	0.50kw	1.5kwh

In order to determine the cost of a solar photovoltaic system, the photovoltaic module size must be estimated. Using equation 1, the load data, insulation data, and market survey of battery data the size of the PV module was estimated at 200-peak watt. Thus, a total of 2 square meter PV modules of 100-peak watt per square meter are to be used. Also in order to determine the cost of solar photovoltaic, it battery storage capacity must be estimated. Using equation 2, the load data, and market survey of battery data the battery storage capacity was estimated at 2.5kwh. The total costs of the required modules and inverters (output 230V, 50Hz) are ₦995, 000.00 from market studies. Installation costs and spares including battery replacement twice during the photovoltaic life span is estimated at ₦505, 000.00. The total comes to ₦1.5 million.

With any photovoltaic system there is no fuel cost, maintenance cost is negligible, and the life expectancy of the system is 30 years.

The annual cost of energy supply for the systems can be determine from the equation below:

$$E = \frac{C_C}{L_E} + M_C + F_C \quad \text{---- (3)}$$

Where C_C is capital cost; L_E is the life expectancy; M_C is the maintenance cost; and F_C is the fuel cost. Table 3 below compares the annual cost of energy supply for the diesel generator system with the photovoltaic system.

Table 3: Annual costs of energy supply for the diesel generator and photovoltaic systems.

Economic Parameter	Diesel Generator System	Photovoltaic System
Life expectancy (L_E)	10 years	30 years
Capital cost (C_C)	₦160, 000.00	₦1, 500,000.00
Maintenance cot per annum (M_C)	₦40, 000.00	-
Fuel cost per annum (F_C)	₦63, 875.00	-
Annual cost of energy (E)	₦120, 000.00	₦50, 000.00

From table 3 it can be seen that the diesel generator system is the costliest option. The high cost of the diesel generator system arises mainly from the high running costs in terms of fueling and maintenance. The hybrid solar photovoltaic system is therefore the most viable power supply system as stand-by for house holds usage.

Environmental Evaluation

The environmental benefits associated with the substitution of the diesel powered system with the solar powered system can easily be estimated by determining the reduction in the production of air pollutants associated with this substitution. Haralambopoulos and Spilanis (1997) gives the pollutant emission factors necessary for the calculation of the emissions from the electricity producing thermal plants using diesel oil as shown in row 1 of table 4. From the load estimation the system requires 1.6kwh, dividing this value by 1000 and multiplying the result with the emission factors for diesel oil gives the values in row 2 of table 4 which gives the emission per day of the pollutants for one household plant. Row 3 of tables 4 gives the emission per year of the pollutants of one household plant. Notice that the values in row 3 of table 4 can be obtained by multiplying in the values in row 2 of tables 4 with 365 the number of days in a year.

Table 4: The emission per annum of pollutants by one household diesel plant

Emission	Pollutants in Kilograms			
	NO_X	CO_2	SO_2	Particulates
Emission factors for diesel (kg/1000kwh)	1.5	1062.5	19.4	1.0
Emission per day of the pollutants by a diesel plant	0.0024	1.7	0.03104	0.0016
Emission per annum of the pollutants by a diesel plant	0.876	620.5	11.3296	0.584

In 1991 approximately 88.5 million people live in Nigeria (Census, 1991). Using the equation (obtained from Iwuagwu, 1991):

$$P(n) = (Po)\ \exp\ (r\text{^}n) \quad \text{--- (4)}$$

Table 5: Annual emission of pollutants into the Nigerian atmosphere

Percentage of household in Nigeria using the diesel plant as stand-by	Emission per annum of pollutants in million kilograms			
	NO_X	CO_2	SO_2	Particulates
100	9.986	7073	129.2	6.628
90	8.987	6366	116.2	5.992
80	7.989	5658	92.96	5.326
70	6.990	4951	81.34	4.661
60	5.991	4244	69.72	3.995
50	4.993	3537	58.10	3.329
40	3.994	2829	46.48	2.663
30	2.997	2122	34.86	1.997
25	1.997	1415	23.24	1.332
15	1.498	106	17.14	0.999
12	1.198	848.8	15.50	0.799
10	0.999	707.3	11.62	0.666
7	0.499	353.6	5.810	0.33

Where P(o) is the population of a place at census year, P(n) is the population of a place n years after census and r is the annual growth rate. With r = 2.5% (Census, 1991) in the year 2001 ten years after census the population of Nigeria will be P(n) = 88.5 exp (0.025^10) = 113.64 million ≅ 114 million About 10 persons on the average make up a household in Nigeria. Hence with 114 million people there should be about 11.4 million [114 million /10] households in Nigeria. Table 5 shows the annual emission of the various pollutants into the Nigerian atmosphere should the given percentage of household in Nigerian installed a diesel generator set. Row 1 in table 5 is gotten by multiplying row 3 of table 4 by 11.4 million the number of households in Nigeria. Multiplying row 1 in table 5 by 0.9 gets Rows 2 in table 5. Row 3 in table 5 is got by multiplying row 1 in table 5 by 0.8 and so on. For now it is reasonable to assume that only about 12% of household in Nigeria are using stand-by diesel plants. Hence the amount of pollutant that will be save the Nigerian environment should this household consider the most economical option – the photovoltaic system – is given as 1,997,000kg for NOx, 848,800,000kg for Co_2, 15,500,000kg for So_2 and 799,000kg for the particulates.

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