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Comparative Economic Analysis of Photovoltaic, Diesel Generator and Grid Extension in Cote D'ivoire

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ABSTRACT

The supply of electricity to the rural communities of Côte d'Ivoire continues to be major problem. This study presents an economic comparison between Photovoltaic (PV), Diesel Generator and Grid Extension. The purpose of the study was to analyze which technology is more cost effective suitable to use in remote areas in Cote d'Ivoire by using life cycle cost techniques. The parameters used for simulation were load energy demand and grid extension distance. The results have shown that Diesel Generator could be considerably more expensive than PV system in long term (up to 6 years). Compared to Grid, PV cost effectiveness would both daily load demand and distance to Grid dependant. Over 5 kWh day^{-1} load demand the distance to Grid should be at least 1 km. Over 50 kWh day^{-1} load demand the grid extension distance should be up to 6 km. The results show that PV is the cost effective option for low power energy demand in rural areas and also when the locality is very far from grid.

Key words: Life cycle cost, solar energy, breakeven point, grid extension, daily load demand

INTRODUCTION

A large proportion of the population in Côte d'Ivoire lives in rural areas, often in isolated homesteads that are difficult to supply with grid electricity. Only 30% of the localities have access to electricity. Furthermore, household connections do not keep growing, thus the absolute proportion of the population without electricity is increasing. The supply of power to rural area is not economically viable because of the exorbitantly high cost of distribution and associated transmission loss. Transmission losses were estimated to 23% in 2007 (Koffi and Koman, 2008). Many electric utilities suffer from poor reliability. As an alternative, one may think of auto-generator power. Auto-generator entails establishing standalone electric power generation at the village and/or building level. Local electrification approaches to produce energy services with a quality compatible to grid electricity were: diesel generator, photovoltaic system, photovoltaic-diesel hybrid system (Schmid and Hoffmann, 2004).

One of the main objectives of the development policy is also to encourage the use of renewable energy sources. Renewable energy technologies, such as photovoltaic one, can offer flexible small scale solution matching the energy needs of rural population (Shafie and Abdelaziz, 2011; Dimas *et al.*, 2011; Khatib, 2010; Schmid and Hoffmann, 2004).

Many studies show that photovoltaic power systems will have an important share in electricity in the future (Dincer, 2011; Carrion *et al.*, 2008).

The electricity from PV can be used for a wide range of applications, from power supplies for small consumer products to large power stations feeding electricity into grid. Many studies in recent years are developed in grid-connected PV systems (Erge, 2001; Celik, 2006; Kim *et al.*, 2009).

In Nigeria, a study that compared PV, diesel and grid extension found that PV has a remarkable potential as a cost effective option for low power electrical energy supply to the rural communities in the country (Oparaku, 2003). In another study in Brazil, it has been shown that it was more economic to convert diesel systems up to 50 kW peak power into PV/diesel hybrid systems (Schmid and Hoffmann, 2004). In Thailand, it was concluded in a study that compared diesel generator with PV system and line extension, that PV/diesel hybrid system with 75% of the load supplied by diesel provided the lowest electricity production cost (Boonbumroong *et al.*, 2004). In an economical comparison of diesel and photovoltaic water pumping system in Namaqualand, South Africa, it has been shown that diesel water pumping systems could be considerably more expensive than PV systems in the long run, if life cycle costing is used as the basis for comparison (Matlapeng *et al.*, 2006).

Research to date has arrived at various conclusions due to costs used for different times (thus the impact of inflation on purchase of equipment, fuel and labour were ignored) and at different locations (thus studies were based on different insolation levels). This study makes an economic comparison between photovoltaic, diesel generator and grid extension. The purpose of the study was to analyze which technology is more cost effective suitable to use in rural areas by simulation. For all the systems, the initial costs and the life cycle costs were determined. The parameters used for simulation were load energy demand and grid extension distance.

MATERIALS AND METHODS

Solar energy resources in côte d'Ivoire: Côte d'Ivoire lies within a tropical region and hence has a tropical climate. The country has two main distinct seasons: the rainy season (from March to August) and the dry season (from November to March). The other months are the boundaries of the two seasons.

The temperatures throughout the year respectively range from a minimum average of 22°C to a maximum average of 32°C. The average experiences between 5 and 8 sunshine hours per day. This gives an annual average solar insulation of about 5.0 kWh m^{-2} day^{-1} with a peak of sunshine being received between March and April, according to regions and the SODEXAM (national meteorological office) (Sako *et al.*, 2007; Andoh *et al.*, 2007).

Systems design and operation: The following set of technical was considered:

- Decentralized photovoltaic system alone, consisting of photovoltaic modules, batteries and inverter, able to supply the energy demand
- Diesel generator plus energy storage using batteries and inverter, so that the generator will only be operated at full load during the necessary hours to supply the daily energy requirements

The sizes of the photovoltaic system components (arrays, batteries and inverter) were determined using the peak sun hour method. To calculate the size of the PV panel needed by using that method, the load demand per day and solar energy availability for site have to be determined (Dimas *et al*., 2011; Chancelier and Laurent, 1995). The average insolation value of 4 kWh m^{-2} day^{-1} was used. The efficiency factors of losses in battery and inverter were estimated to be 0.8 and 0.85, respectively. Three days of battery storage were considered to compensate low insolation and cloudiness. The maximum depth of discharge of battery was assumed to be 0.7. The diesel generator capacity was calculated from the total load demand. The generator is operated daily at a duty cycle of 5 h per day.

Economic analysis: The life cycle cost calculation used is the present worth technique in which the present worth values of the capital, maintenance, repair and energy costs have been determined. The repair and replacement costs of the system include the costs of replacing solar batteries every five year. Equipment prices were obtained from local suppliers. The costs of the grid extension and energy were obtained from the National Electric Company. Time horizon considered was of 30 years corresponding to the expected life of photovoltaic panels. The interest rate and the inflation rate considered were respectively 10 and 4%. An exchange rate of 500 was used to convert the costs in local currency to US$. Regarding the diesel generator operation, a specific consumption of 0.4 l kWh^{-1} was adopted.

Data analysis: Sensitivity analysis was performed using variation in load demand and grid extension distance. For all the systems the life cycle costs over 30 years life cycle are considered. Technical and economic factors are examined by simulation using Microsoft Excel.

RESULTS AND DISCUSSION

The life cycle costs of diesel generator and Photovoltaic (PV) system have been compared to determine the conditions under which either technology is more cost effective for the same energy demand.

The capital and operating costs for diesel generator and photovoltaic system are laid out over 30 years in Fig. 1. A major distinction between the two technologies is shown in this graph. Diesel generator has a relatively low initial capital cost and a significantly higher maintenance and operating cost. The photovoltaic system has a large initial capital cost and a negligible operating cost. These results are in concordance with those of Oparaku (2003) and those of Schmid and Hoffmann (2004).

Since the photovoltaic system has no moving parts, it has minimal maintenance and no fuel costs. The graph shows that the photovoltaic system has a lower life cycle cost.

Sensitivity analysis was performed to determine how the costs will vary with charges in load demand and grid extension distance. Figure 2 shows the results of the economic comparison model. The relative cost of grid extension versus photovoltaic system is calculated over a 30 year photovoltaic system life. The PV/grid cost ratio is established by rating the cost for PV system installation and generation and the cost of grid extension and generation. The PV/grid ratio is plotted against the distance between the grid tie point and the site using the load energy demand variable.

When the PV/grid ratio is less than one, PV is a more economical alternative. The graph shows that PV system is more cost-effective than the grid extension when the load is less than 10 kWh per day. From 10 to 50 kWh day^{-1}, the site must be at least 3 to 5 km away from the grid point.

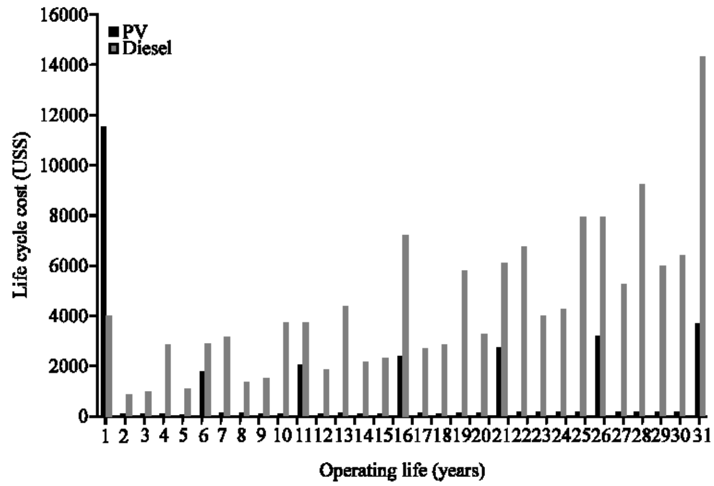

Fig. 1: Diesel versus PV (Load demand: 3 kWh day^{-1})

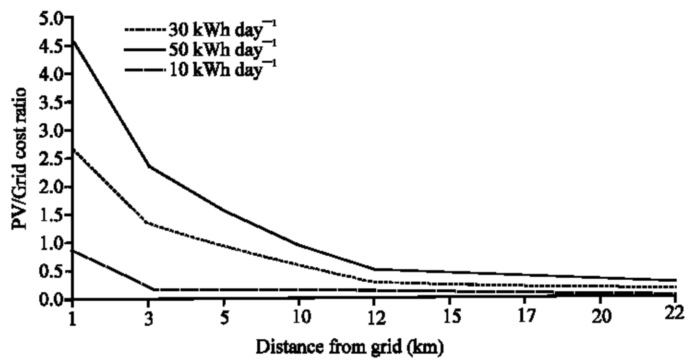

Fig. 2: PV versus Grid extension varying distance from Grid and daily energy demand

Figure 3 shows the cumulative costs for PV vs Diesel and Grid extension. The life cycle costs were calculated over 30 years period taking into account upfront costs, operating costs, maintenance costs and replacement costs. The Grid extension distance considered was 1 km. The daily energy requirement was assumed to be 3 kWh day^{-1}.

PV system has a low cumulative cost when compared to Grid extension. In this case PV is more cost effective than Grid. As previously stated, PV has a high upfront capital cost but low maintenance cost compared to Diesel. The breakeven point of PV system with Diesel generator is 6 years while that of Grid is 15 years. Grid extension has the highest upfront capital cost. When the daily demand rises to 15 kWh day^{-1} for the same grid extension distance (Fig. 4), Grid becomes more cost effective than the others after 5 years. The breakeven point of PV system with Diesel generator decreases to 5 years.

Compared to Diesel, PV is more cost effective for long period. Grid extension costs are both distance and daily energy demand dependant. This assessment is in well concordance with Oparaku (2003) results.

The critical factors in comparing Grid to PV system are the size of the daily energy requirement and the grid extension distance. The present value costs of Grid versus PV are shown in Fig. 5 for

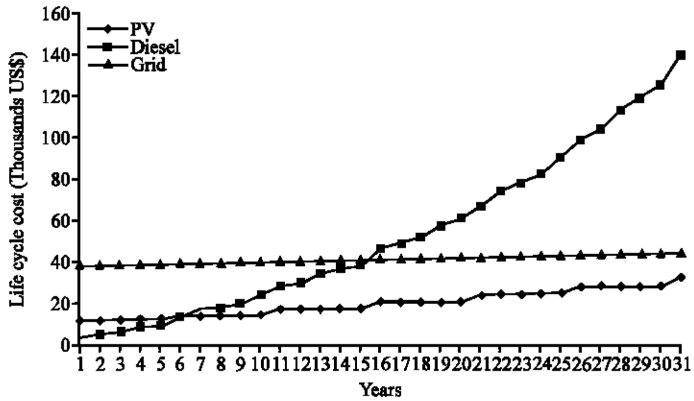

Fig. 3: PV versus Diesel and Grid, daily energy demand: 3 kWh day^{-1}, load distance from Grid: 1 km

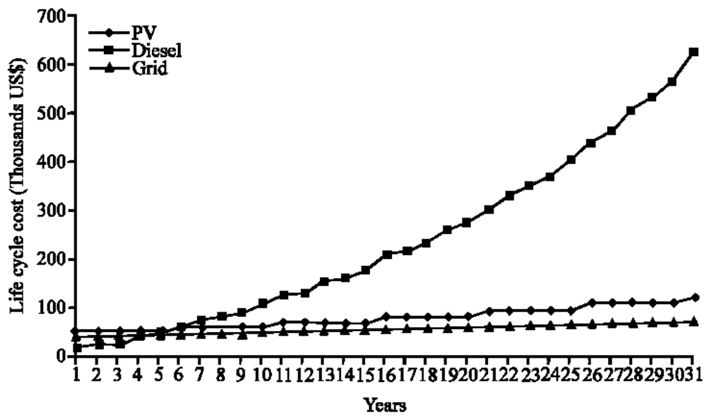

Fig. 4: PV versus Diesel and Grid, daily energy demand: 15 kWh day^{-1}, load distance from Grid: 1 km

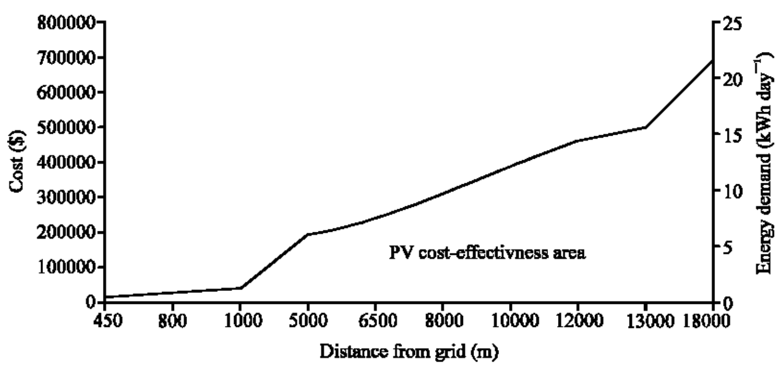

Fig. 5: PV versus Grid for different load demand sizes and grid extension distances

differing load demand sizes and Grid extension distances. PV is the most cost effective source compared to Grid in the area below the curve. This graph can be used to predict which of PV and Grid is more economically suitable to use in remote site.

CONCLUSION

This study proves that diesel generator can be considerably more expensive than PV system in long term (up to 6 years) because of the high operating cost of diesel generator. The difficulties of purchasing imported spare parts and fuel and the requirement of skilled labor to keep it running make diesel generator a non realistic alternative solution for remote sites.

Compared to grid, PV cost effectiveness is both daily load demand and distance to grid dependant. Over 5 kWh day^{-1} load demand, the distance to grid must be at least 1 kilometer. Over 50 kWh day^{-1} load demand the grid extension distance must be up to 6 km.

As we project into the future, the price of PV is surely to come down while the price of petroleum products is likely to go up. This can lead to a reduction in the years to breakeven. It has also been proved that PV systems are an environment friendly source of energy and what must also be taken into consideration.

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