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# Sizing and Cost Assessment of Solar PV System for Energy Supply in the Telecommunication Industry in Nigeria

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**Abstract:** Electrical power from the grid is unreliable in Nigeria. This has forced mobile telecommunication operators to depend mainly on diesel generators. In this research, solar PV system is considered as an alternative power supply option. The PV system to power a Base Transceiver Station (BTS) was sized then Life Cycle Cost (LCC) method of economic assessment was used to compare the cost with the costs of diesel generator and grid utility over the life cycle period of the PV system which is 30 years. The LCC of PV system is \$0.84/kWh that of diesel generator, \$1.8/kWh and grid utility, \$0.063/kWh. Sensitivity, analysis was carried out using variations in module costs, diesel fuel escalation and grid utility escalation. The results suggest that the PV system is cheaper than the diesel generator and could be the best option out of the three in the future.

**Key words:** Base transceiver station, diesel, grid utility, life cycle cost, sensitivity analysis, generator

## INTRODUCTION

The global system of mobile telecommunication began in Nigeria in the year 2001. This was in line with the Federal Government policy of deregulation and liberalization of the telecommunication sector in order to break the monopoly of Nigerian Telecommunications Limited (NITEL) whose performance was unreliable for decades. The mobile telecommunication operator ECONET (now CELTEL) first acquired license in January, 2001 then followed by MTN and M-TEL. Globacom acquired her license in August 2002. There has been unprecedented growth in the telecommunication market in Nigeria since then. As at the end of 2007, out of 38.4 million telecommunication lines, 37 million were mobile while the remaining 1.4 million are fixed. In 2001, there were 0.6 million fixed lines and 0.27 million mobile. In the Mobile Telecommunication industry in Nigeria (MTN) has about 40% of market share, globacom, 32%, CELTEL, 27% while M-TEL, VISA phone and others, 1%. The country has over 10000 base stations where >2000 of them are located in Lagos. Nigeria's telecommunication investment was \$8 billion in 2005 and was expected to have reached \$12 billion by Agyeman (2007). Electric power supply is unreliable in Nigeria. As at the end of 2009, the installed electricity generating capacity of the Power Holding Company of Nigeria (PHCN) consists of 1930 MW (Oparaku, 2002) of hydroelectricity generation and 6221 MW of thermal generation, totaling 8151 MW.

The actual generating capacity falls short of the installed capacity and the country's peak demand which is 30 GW. In fact in the last 10 years, the power output was between 1.5 and 3.0 GW. Problems associated with the electric power sector in Nigeria include obsolete equipments, lack of spear parts, inadequate supply of fossil fuel, vandalism and theft of equipments, under pricing of electricity, corruption, etc. The last administration in the country spent billions of dollars to revitalize the power sector after the enactment of the power sector reform law but little results were achieved.

The previous constraints are responsible for the erratic power supply and frequent outages in the country's electric power system thus, compelling many domestic, commercial and industrial customers to procure personal generators. Experience has shown that gasoline and diesel generators incure high operating costs from fuel and replacement of parts. Also, these generators pollute the atmosphere with sound and poisonous gases like NO, CO, unburnt hydrocarbons and $CO_2$ which is responsible for global warming. Nigeria is about the 7th largest market in the whole world and number one destination for all manners of fossil fuel powered generators worldwide. GSM operators in Nigeria due to epileptic power supply, install 2 diesel generators at a base station with one working at a time (Agyeman, 2007). Due to long power outages, these generators are run for months and therefore, incure high operating costs from fuel and replacement of parts. This is frustrating. These problems culminated in the search for alternative sustainable and economically viable power supply options like the solar PV system. Nigeria is blessed with vast solar energy resource ranging from 3.5 kWh/m$^2$/day in the South to 7 kWh/m$^2$/day in the North (Ikuponisi, 2004; ICEED, 2006) and sunshine hours

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ranging from 5 in the South through 6 in the Middle Belt to 7 in the North. A base transceiver station is an integral part of the GSM network. A BTS links the major hop and the mobile phone users. The major hops are themselves linked to the mobile switching centre via backbone sites. A BTS is a fixed station in a mobile radio communication system. It is located at the centre or the edge of a coverage area and consist of radio channels and transmitter and receiver antennas mounted on a tower.

In this study, a 2 G BTS is considered. This type is used by MTN, CELTEL and M-TEL. Globacom employs 2.5 G BTS with single phase ac supply and less power requirements totaling about 500 W. The BTS usually houses 2 units of air conditioning units within its cabin, radio equipment (the number of which depends on capacity requirements and specification), DC power plants or rectifiers, stabilizers, battery banks/UPS, Automatic Mains Failure Panel (AMFP), surge protector, 3-phase mains distribution and socket outlets.

The power requirements of the BTS are 2 air-conditioning units each rated 1.5 hp and one operates at a time to cool the cabin, 1 kW ac lighting system and 1.2 kW DC of radio equipment. A cabin could contain up to four radio equipments depending on capacity requirements. The DC power plant is an interconnection of rectifiers running on +24 V DC (negative earth) or -48 V DC (International telecommunication union standard) to eliminate corona losses and interference. The DC is used to power the radio equipment and to charge the back-up batteries or battery bank. The radio equipments are either single or dual band. Where power from the mains fail, the battery bank or the UPS takes over the sustainance of the radio equipments during the brief period between the outage and changeover to generator (where the combination is mains+generator). The change is governed by automatic mains failure switch which is made up of contactors, relays and breakers. The economic viability of using a PV system to power a BTS with four radio equipments is carried out using the LCC method to determine the cost in \$/kWh and compare this with the costs in \$/kWh using diesel generator and grid utility supplies. LCC is the total cost of ownership of machinery and equipment including its cost of acquisition, operation, maintenance, conversion and/or decommission (Barringer *et al*., 2003). The first component in a LCC equation is cost (Mearig *et al*., 1999). LCC analysis provides better assessment than simple payback method used for capital expenditures only. It is pertinent to note that the LCC of a renewable energy system does not only depend on economic factors such as inflation rate, interest rate, etc., it also depends on level of development in the technology, how abundant is the renewable energy resource, system optimization, etc. For example, the LCC of a PV system may be costlier than that of diesel generator in Taiwan while it is cheaper than that of diesel generator for the same load in India due to the reasons highlighted above. Therefore, it is necessary to verify.

## MATERIALS AND METHODS

**PV system sizing (the PV system components):** Arrays, batteries, controllers, etc., were sized for a BTS with four radio links (each rated 1.2 kW dc), 1.5 hp Air Conditioning (A/C) unit and 1 kW of illumination both ac loads. Daily duty cycle of the radio links is 24 h, A/C unit, 12 h and illumination, 12 h. Energy demand in Wh day$^{-1}$ is given by:

$$E_d = \sum_{i=1}^{n} N_i I_i V_i H_i \quad (1)$$

Where:

- $N_i$ = ith load
- $I_i$ and $V_i$ = Current and voltage, respectively drawn by the ith load
- $H_i$ = Daily duty cycle in hours day$^{-1}$ (Bhuiyan and Asgar, 2003)

The load demand in ampere hours per day is given by:

$$P_d = \frac{\sum_{i=1}^{n} N_i I_i V_i H_i}{\eta_{pe} V_{nsv}} \quad (2)$$

Where, $\eta_{pe}$ is power conversion efficiency = 80% for ac load. This is inverter efficiency. For dc load (which requires no inverter) $\eta_{pe}$ = 1. $V_{nsv}$ = nominal system voltage = 48 V dc. This is International telecommunication union standard. Total ampere hour load:

$$P_T = P_{d(ac)} + P_{d(dc)} \quad (3)$$

$$\text{Corrected ampere hour load, } P_c = \frac{P_T}{\eta_w \eta_B} \quad (4)$$

Where:

- $\eta_w$ = Wire efficiency
- $\eta_B$ = Battery efficiency

They take care of the losses in the wiring and battery. Their estimated values are 0.98 and 0.9, respectively. Design current is:

$$I_D = \frac{P_c}{S_p} \quad (5)$$

where, $S_p$ is peak sun hours. The value for the worst case month (which is August) should be used. In Nigeria $S_p$ in the south is 5 h in the middle belt, 6 h and in the North 7 h. An average of 6 h was used. Battery capacity is:

$$B_{cap} = \frac{P_c \times D_s}{(DOD)_{max} \times \eta_T} \quad (6)$$

where, $D_s$ is battery autonomy. Total 3 days was used. Maximum Dept. of Discharge $(DOD)_{max}$ of 50% was allowed while temperature correction factor, $\eta_T$ of 1 was used. Batteries in parallel is:

$$B_p = \frac{B_{cap}}{B_{scap}} \quad (7)$$

where, $B_{scap}$ is the capacity of the selected battery in Ah. Batteries in series:

$$B_s = \frac{V_{nsv}}{V_{nbc}} \quad (8)$$

where, $V_{nbc}$ is nominal voltage of selected battery. Total number of batteries:

$$B_T = B_p \times B_s \quad (9)$$

Modules in parallel:

$$M_p = \frac{I_D}{\eta_d \times I_R} \quad (10)$$

where, $\eta_d$ is module derate factor. This takes care of loss due to dust accumulation, mismatch loss between modules and degradation over time. Value of 0.98 was used. Modules in series:

$$M_s = \frac{1.25 \times V_{nsv}}{V_{M, T_M}} \quad (11)$$

where, $V_{M, T_M}$ is highest temperature module voltage. Total number of modules:

$$M_T = M_p \times M_s \quad (12)$$

Total array rated power:

$$P_A = P_m \times M_p \times M_s \quad (13)$$

where, $P_m$ is module rated power. Maximum controller current:

$$I_{MC} = 1.25 \times I_{msc} \times M_p \quad (14)$$

where, $I_{msc}$ is maximum module short-circuit current. Module chosen: 123 Wp, 7.1 A sharp PV module, battery chosen: 210 Ah, 12 VDC DEKA battery:

**LCC analysis**

**Capital cost:** This has no equation because it is a fixed cost consisting installation and purchasing costs.

**Recurring cost (operation and maintenance cost):** This consists fuel and servicing costs:

$$LFC = AFC \times \left[\left(\frac{1+F_e}{D_r - F_e}\right) \times \left(1 - \left(\frac{1+F_e}{1+D_r}\right)^p\right)\right] \quad (15)$$

Where:
LFC = Life cycle fuel cost
AFC = Annual fuel cost
$F_e$ = Fuel escalation

Value of 20% was used because in the last 5 years, the cost of diesel/litre has increased by >20%. $D_r$ represents discount rate. A value of 9.5% (Dec 31, 2007) was used. Central bank discount rate for December 31, 2008 was not available as at the time of writing this research. The cycle period in year is p. A period of 30 years was used because a PV system can last for >30 years:

$$LMC = AMC \times \left[\left(\frac{1+G_e}{D_r - G_e}\right) \times \left(1 - \left(\frac{1+G_e}{1+D_r}\right)^p\right)\right] \quad (16)$$

where, LMC represents life cycle maintenance cost and AMC, annual maintenance cost. $G_e$ represents general escalation (inflation rate) (Bhuiyan *et al*., 2000). A value of 10.5% (2008 estimate) was used.

**Non-recurring cost (repairs and maintenance cost):** This is the cost of replacement of parts:

$$LRC = \sum \left[IC \times \left(1 + \left(\frac{1+G_e}{1+D_r}\right)^{R_y}\right)\right] \quad (17)$$

where, item cost is non recurring expenditure in present day costs and $R_y$ is the replacement year. Life cycle energy cost is:

$$L_T(\$/kWh) = \frac{CC + LFC + LMC + LRC}{Period \times 365 \times kWh\,day^{-1}} \quad (18)$$

**LCC for different options:** Costs of PV system and generator parts were obtained from vendors and service men, respectively. The LCC for different options-solar PV system, diesel generator and grid utility are calculated as follows.

**PV system:** Nigeria does not manufacture PV modules and components. They are imported into the country. Therefore, the prices here may be higher than obtainable in Europe and America. Also, exchange rate used is 150.00 to $1.00 (US):

$$\text{Load demand} = 169\ \text{kWh day}^{-1}$$

**Capital costs ($):**

Array 123 Wp×320 @ 6.67$/$W_p$ = 256,000.00

Battery 210 Ah, 12 V× 400 = 200,000.00

Inverter 2.5 kW = 10,000.00

System controller = 2,333.33

BOS, transportation, installation, etc. = 53,333.33

Total = 512,666.66, Fuel cost ($) = 0.00

Annual maintenance cost ($) = 2% of capital cost. Therefore, LMC is 361,480.14.

**Non-recurring cost ($):** This consists replacement of batteries, inverters and controllers every 10 years. This is 30% of capital cost:

LCC replacement cost = 675,379.30

Grand total for 30 years = 1,558,526.10

Therefore, from Eq. 18:

LCC of PV system ($/kWh) = 0.84

**LCC for diesel generator:** The generator used in the BTS is 3-phase, 50 Hz, 440 V, 27 kVA Perkins diesel generator.

**Capital cost ($):** 26,666.67

**Fuel cost ($):** The generator duty cycle is 24 h day$^{-1}$ and the fuel consumption is 2200 L month$^{-1}$. Therefore:

Fuel cost year$^{-1}$ = 15,840.00

Assuming fuel escalation of 20%; LCC fuel cost is 2,642,296.8.

**Recurring cost ($):** This consists servicing and fuel costs. The servicing cost includes the costs of fuel filter, oil filter, oil, air filter, handling and sundaries, labour, transport and Value Added Tax (VAT). The manufacturer's specification demands servicing of generator every 200 h of usage. At the end of 800 h, a cycle of servicing is completed. Servicing cost is 0.3% year$^{-1}$ of capital cost (Oparaku, 2003). Therefore LCC recurring cost is 2,806.38.

**Non-recurring cost ($):** The non-recurring cost includes the cost of minor or top overhaul which is done every 5000 h and cost of major or total overhaul which is done every 10000 h. Minor overhaul involves replacing the gaskets, seals, piston rings, valves, etc. and it costs about 2.5% of the capital cost. Major overhaul involves replacing the crankshaft and its bearings boring of the engine block, replacements of the sleeves, pistons, cylinder heads, etc. It costs about 6% of the capital cost (Oparaku, 2003). Generator is replaced every 20000 h (i.e., 2¼ years) of usage. Therefore, a diesel generator needs two minor overhauls and one major overhaul before replacement. Over a 30 years period, there will be 13 generator replacements:

LCC minor overhaul = 70,392.32

LCC major overhaul = 82,702.58

LCC generator replacements = 542,335.69

Total = 3340533.77

LCC of generator ($/kWh) = 1.8

**LCC utility supply:** 1 kWh of energy in Nigeria costs $0.057 for a commercial customer on 3-phase supply. In addition, a metre maintenance charge of $3.33 and a fixed charge of $8.00 month$^{-1}$ are also charged. At energy escalation of 10% is:

LCC of energy from utility ($/kWh) = 0.063

## RESULTS AND DISCUSSION

From the calculations of life cycle costs of solar PV system, diesel generator and grid utility supply over a period of 30 years, we see that the LCC of the PV system is $0.84/kWh that of diesel generator, $1.8/kWh and grid utility $0.063/kWh. That is LCC of PV system is about 47% of that of the diesel generator. The LCC of grid utility is 7.5% of that of the PV system and 3.5% of that of the diesel generator based on diesel generator price of $0.6 L$^{-1}$ and fuel escalation of 20%. These results show that the PV system is a better power supply option compared to the diesel generator. Although, grid utility option is cheapest, it is very unreliable. Sensitivity analysis was carried out to show how the LCC costs vary with decrease in module price/$W_p$, fuel escalation and utility escalation as shown in Fig.1-3, respectively. The results show that the PV system is a more promising option in the future. Module prices decrease every year. With research and development modules with better conversion efficiency are produced. An added advantage of the PV system is its environmental friendliness. LCC cost of diesel generator and grid utility vary exponentially with fuel escalation and utility escalation, respectively. The LCC of the grid utility becomes equal to that of

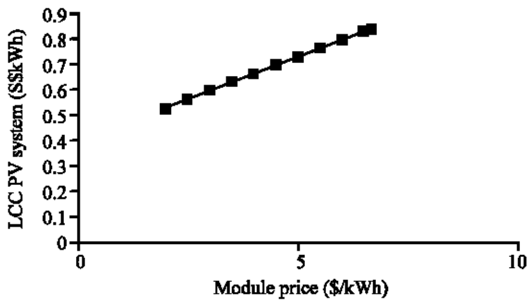


Fig. 1: Sensitivity of LCC of PV to module price

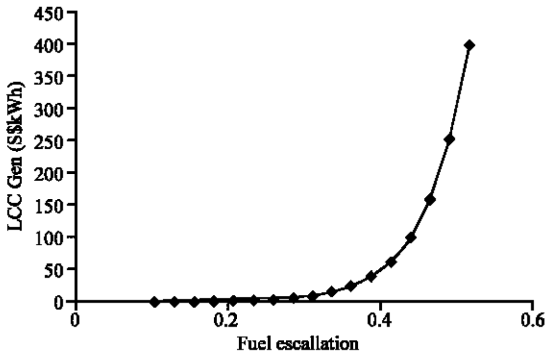


Fig. 2: Sensitivity of LCC of gen. to fuel escalation

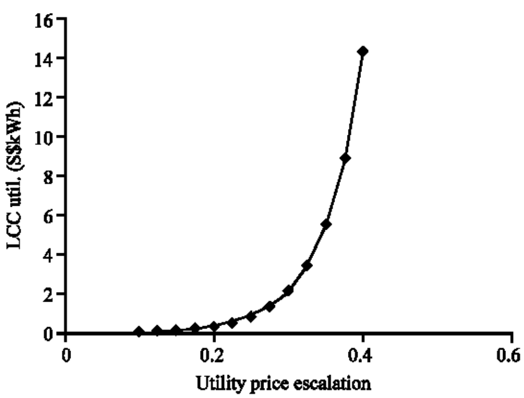


Fig. 3: Sensitivity of LCC utility to utility escalation

the PV at utility escalation of about 25% at the current module price while it becomes equal to that of the diesel generator at fuel escalation of about 30% at the current diesel price/litre. With the abundant solar resource in Nigeria and with the development of more advanced BTS with far less power requirements, the solar PV system will become easier and cheaper to deploy in the telecommunication sector of Nigeria.

## CONCLUSION

The results of this research reveal that the solar PV system is more cost effective than the diesel generator for powering a BTS in Nigeria. Apart from the cost effectiveness, it is environmentally friendly. Therefore, it is recommended. In the rural areas of Nigeria where 68% of the population resides and most of them do not have access to mobile telecommunications with PV system supply option, mobile telecommunications operators could build their BTS's in the rural areas. Land is readily available to fix the solar panels and there is no need of manning the BTS's since, solar PV system needs little maintenance. In the urban areas where the availability and acquisition of land may be difficult it is recommended that BTS's employing the 3 or 4 G technology should be deployed as it has far less power requirements than the 2 G technology. This translates to cheaper solar PV system with fewer modules.

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