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Energy-cost analysis of alternative sources to electricity in Nigeria

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Abstract

In this work, a comparative analysis of alternative energy sources has been carried out to ascertain their suitability in terms of availability, cost, advantages and disadvantages among other factors. The selected energy alternatives are solar and inverters. The first case study-site was an office suit located in government reserved area and the second a medium house unit within Lagos the most commercial city in Nigeria. Practical surveys and data collection were carried out for the selected sites coupled with their energy auditing to obtain the total energy consumed. An energy sizing analysis helped in determining the energy specifications and installation-cost of the alternative energy sources in the surveyed sites. The results obtained presented guiding principles among other solutions on how homes and offices can be powered by applying the method of selective-loading to reduce energy cost.

Keywords: Alternative energy sources; cost-analysis; electricity; energy auditing, Nigeria

Introduction

The development of any society is anchored on the steady supply of power which is an elixir to manufacturing companies. It is therefore a matter of utmost importance to analyse other means of energy supplies in term of cost-effectiveness, reliability, availability and environmental compatibility so as to alleviate the energy crisis prevalent in some developing countries. Alternative energy sources such solar cells and battery-powered inverters as researched in this work have become increasingly popular subjects (Mohan *et al.,* 1995; Abdulkarim, 2004; Sarah & Douglass, 2005; Zane, 2006; Iran, 2006; Nwokoye, 2006; Ezekoye & Ugha, 2007). Many of these reorts show that global warming has rapidly increased from anthropogenic causes.

Various energy resources are available in Nigeria. The hydropower resources which can be explored in Nigeria are over 11,000MW per annum (average capacity is more than 40,800GWh). The main sources of energy in Nigeria at present are mostly from Power Holding Company of Nigeria (PHCN). The installed capacity is 5296MW. However, about 99.5% of Nigeria power requirement come from the various power stations with 0.5% coming from other sources (Nwokoye, 2006). Thus, the 0.5% is purchased by private companies. Some of the problems faced by people in developing countries such as Nigeria which has been reported in this study and in earlier works (Akarakiri, 2002; Akin Iwayemi, 2008) include:

- *Inadequate electricity supply to household, offices and industries*: It is increasingly becoming difficult to get energy for domestic utilization. People now depend on generating set for their energy supply.
- *Low industrial productivity*: For many industries, technical changes are found to increase the shares relative to those from other inputs of production. Changes in electrical inputs contribute to notable alterations in output values. The unavailability of this crucial requirement of production has hampered production of goods and services.
- *Pollution of the environment:* Noise and air pollution caused by the use of generating sets as energy sources creates immeasurable level of health hazards to all forms of life in the environment.
- *High cost of commodities:* There is existing relationship between the price of commodities and energy. Energy is part of cost of production; exorbitant expenditure on energy will eventually lead to high cost of the product.
- *Increase in overhead costs of production:* Overhead cost is the money spent on rent, insurance, electricity and other things to keep the business running. Huge amount is spent of fuelling generating sets for production of goods and services, this tends to increase the overhead cost.

The general objective of this work is to minimize the adverse effects of over dependence on national electric energy generation which is unreliable in many developing countries. In attaining this general goal some specific objectives were considered. Namely; ascertaining the positive and negative aspects of alternative sources of energy; analysing the effectiveness, feasibility and viability of other alternatives energy to electricity; determining cost-implication of choosing alternative sources; reducing dependence on PHCN electricity supply; discovering the possibility of powering a portion of a household with alternative energy sources; prescribing likely solution to energy crisis in Nigeria; giving the urban and rural dwellers in Nigeria an improved living standards for a better quality of life (Oladele, 2009).

Theoretical concepts: Inverters and solar cells

The inverter is the heart of all but the smallest power systems. It is an electronic device that converts direct current DC power from batteries or solar modules into alternating AC power to operate lights, appliances or anything that normally operates on power supplied by the utility grid. The electrically-rechargeable-battery-powered inverters which have been considered in this work come in many varieties, sizes and qualities and offer various features that specialises them for particular applications. There have been a large number of articles written concerning power conversion in recent years. This can be attributed in part to the rise in popularity of high voltage DC transmission systems and their integration with existing AC supply grids. There is also a consistent demand for high efficiency inverter devices for lower power applications like houses, caravans, UPS and developing countries of the world. The resulting AC converted by inverters can be at any required voltage and frequency with the use of appropriate transformers, switching and control circuits. Due to the higher operating frequencies, inverters yield higher, more economical output power. This increased power source efficiency translates to decreased utility costs. Virtually all the inverters used with alternative power systems are transistorized, solid state devices (Ezekoye & Ugha, 2007). Solid-state inverters are preferred for their higher efficiency, ease of maintenance, and infrequency of repair. Important output specifications to consider when searching for DC to AC inverters include maximum voltage, maximum steady state current, maximum power, and frequency range.

There are two general types of inverters: *True-sine wave and Modified-sine wave (square wave).* Compared to the modified-sine wave, the true-sine wave inverters produce power that is either identical or sometimes slightly better to power from the public utility power grid system. The other divisions of inverters are: *(i) Off-Grid Inverters or standalone inverters*: These are the types considered in this evaluation study and are available in sizes from 100watts, for powering notebooks computers and fax machines and cars, to 60kilowatts, for powering a commercial operation. *(ii) Grid-tie inverter:* This is a sine wave inverter which has a higher cost, but can operate almost anything that can be operated on utility power. A grid-tie system uses an external utility company, in effect, as its storage battery. When more power is needed than the system can supply, the utility makes up the difference. This type of system makes the most sense in most cases where there is utility power, because there are no batteries to maintain or replace. Unfortunately, if the utility power goes down, this type of inverter will go off, too. These inverters are designed to run at voltages up to 600 VDC and faster to install, more efficient and allows the use of smaller gauge wire.

Load-selection and Installation of Inverters

A key consideration in the design and operation of inverters is how to achieve high efficiency with varying power output. It is necessary to maintain the inverter at or near full load in order to operate in the high efficiency region. However, this is not possible. Some installations would never reach their rated power due to deficient tilt, orientation or irradiation in the region (Mohan *et al.,* 1995). Inverters are very easy to install. Most of them are "plug and play" devices, especially smaller, low-wattage inverters. The selection of a location where the DC low voltage cable is the shortest possible distance to the battery is important as the longer a DC cable runs the greater the voltage loss. Ventilation is also an important factor to consider when installing inverter. Inverters generate a fair amount of heat, and therefore use cooling fans and heat dissipation fins to prevent overheating. More so, the unit must not be allowed to come in contact with any liquids or condensing humidity. Here in, the rules for choosing an inverter based on the load selection are discussed.

- The first step in selecting an inverter is to match the inverter to the voltage of the battery that will be used to power the system.
- The devices to be powered with the inverter must be determined. The wattage rating of the inverter must exceed the total wattage of all the devices to be run simultaneously. For instance, running a 600-watt blender and a 600-watt coffee maker at the same time needs an inverter capable of a 1,200-watt output.
- It must be ascertained that the inverter's peak rating is higher than the peak wattage of the device you intend to power.
- The final specification to look for is the wave output of the inverter. If there is the need to power any of the equipment that is sensitive to square waves, an inverter with a "perfect sine" wave output should be used.

Solar energy can be used to generate power in two-way; solar-thermal conversion and solar electric (photovoltaic) conversion. Solar-Thermal is heating of fluids to produce steam to drive turbines for large-scale centralized generation. Solar-Electric which is considered in this study is the direct conversion of sunlight in to electricity through a photocell. This could be in a centralized or decentralized fashion. Energy payback time (EPBT) is the length of deployment required for a photovoltaic system to generate an amount of energy equal to the total energy that went into its production. Roof-mounted photovoltaic systems have impressively low energy payback times, as documented by recent engineering studies. The value of EPBT is dependent on three factors. Namely, the conversion efficiency of the photovoltaic system; the amount of illumination that the system receives (about 1700 kWh/m^2/yr average for southern Europe and about 1800 kWh/m^2/yr average for the United States); The manufacturing technology that was used to make the photovoltaic (solar) cells.

A good place is chosen at home or certain cabin such that it is out of the way or main path of activity. It is on this basis that most people choose to mount on a roof, hence protection is ensured. There is a need to tap as much sunlight that can be reached. The more intensity of light received by the solar modules, the more power they will produce. The solar modules are kept away from shade between the prime hours of sunlight, 9.00 am to 3.00 p.m. shadows are known to reduce the module’s output. Shadow cast by telephone lines, trees, buildings, electricity poles, parked vehicles all can affect the module’s output. Another factor given rapt attention is the angle of tilt for maximum exposure. The modules are mounted at the best angles so as to get more sun. The best known tilt for a module is the one that puts it at right angles to the noontime sun.

Research methodology

The research methodology of this study is presented in three stages, namely, *(i) Site selection; (ii) Energy Auditing and AC Sizing (iii) Energy-Cost Analysis.* The reasons for selecting the case study sites and performing energy audit for the sites, the different types of cost analysis and phases of energy audits applied in the work are all discussed in this section.

Site selection

The first site selected is an Engineering Consulting firm located in a Government Reservation Area (GRA) in Lagos the most commercial city in Nigeria. This office site uses a diesel-generator and its organization offers solution to infrastructure projects in the areas of water supply, waste disposal and transportation. The building has three general sections and two offices with kitchen and all other necessary facilities. The second case study is typical three-bedrooms flat in the same city of Lagos. The flat is one of the flats in a one story building. The most important reasons for selecting these sites are because the locations are in an area where energy consumption is frequent and mostly unavailable and hence the rate of diesel is on the high side due to the unsteady power supply

Energy auditing and Ac sizing

Energy audits carried out at the two sites were for the following reasons: (i) to ascertain the total energy consumed in the office and home (ii) to discover the appliances that consumes most energy (iii) to reduce avoidable expenses on energy. Types of energy audits considered in this work were (i) *preliminary audit* (ii) *general audit* (iii) *investment-grade audit*. The preliminary audit alternately called a simple audit, screening audit or walk-through audit is the simplest and quickest type of audit. It involves minimal interviews with site operating personnel, a brief review of facility utility bills and other operating data, and a walk- through of the facility to become familiar with the building operation and identify glaring areas of energy waste or inefficiency. The general audit alternatively called mini- audit, site energy audit or complete site energy audit expands on the preliminary audit described above by collecting more detailed information about facility operation and performing a more detailed evaluation of energy conservation measures identified. Utility bills are collected for a 12 to 36 month-period to allow the auditor to evaluate the facility's energy/demand rate structures, and energy usage profiles. Additional metering of specific energy-consuming systems is often performed to supplement utility data. In-depth interviews with the facility operating personnel systems as well as insight into variations in daily and annual energy consumption and demand. This type of audit will be able to identify all energy conservation measure appropriate for the facility given its operating parameters. A detailed financial analysis is performed for each measure based on detailed implementation cost estimates; sites-specific operating cost savings, and the consumer's investment criteria. *Investment-Grade Audit:* The investment- grade audit alternatively called a comprehensive audit, detailed audit, maxi-audit or technical analysis audit expands on the general audit described above by providing energy use characteristics of both the existing facility and all energy conservation measures identified. The building model is calibrated against actual utility data to provide a realistic baseline which is used to complete operating savings for proposed measures. In a comprehensive or investment-grade audit extensive attention is given to understanding not only the operating characteristics of all energy consuming systems but also situations that cause load profile variations on both an annual and daily basis. Also existing utility data is supplemented with sub-metering of major energy consuming systems and monitoring of system operating characteristics.

Phases of energy auditing: The Phases involved in the energy auditing were: (i) data collection (ii) data verification (iii) energy-saving opportunities (iv) energy conservation opportunities (v) executive summary. In d*ata* collection*,* visitation was done on the two case studies. The results of the data gotten are indicated in figures 2-8. The results show the data collected for two study sites the office suit and the three bedrooms flat. Data verification is the process of checking for the accuracy and adequacy of the data collected. This procedure is carried out due to challenges that might have been faced while performing the study. Energy saving opportunities technique aids the selection of load that were analysed and presented in figures 5-8. It indicates how some bulbs can be replaced by energy saving bulbs. Energy saving opportunities identifies cutting energy consumption to bearable minimum. Energy conservation opportunities is an avenue to identify the ways energy can be conserved in the through the usage of energy saving bulbs. This also involved reduction of the no. of appliances being used. It identifies and eradicates energy wastage in the house or office. Executive summary is a report which indicates all the aforementioned. It defines the details of the audit; cost implication, energy saving opportunities etc. it is usually presented to the concerned organization on individual depending on the context.

Shown in Fig. 1 is the frame work of the energy audits and AC sizing carried out in this work. As depicted in Fig. 1 complete energy audits were firstly carried out for the two sites and then followed by the Alternative Current

(AC) sizing at each site for three different energy loadings, namely, (i) with complete load (ii) without heating equipment (iii) without heating and A/C. This procedure was adopted to minimize cost for the cases of solar power generation and Inverters. The results obtained such as Total Connected Load (T_{CL}), Total Daily

Load (T_{DL}) and Total Amperes Needed (T_{AN}) for the three cases and the two sites were compared in Tables 1 and 2. As presented in Tables 1 and 2, the Connected Load *(C_L)* and Daily Load *(D_L)* were obtained using equations 1 and 2 respectively where I_{WL} is the Instant Watts per Load; *Q* is the quantity of items or appliances present in the home or office and R_T is the average hours the each equipment is run daily.

$$C_L = I_{WL} \times (Q) \dots\dots\dots\dots\dots\dots\dots\dots (1)$$

$$D_L = C_L \times R_T \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

Also, the Watts required With Loss *(W_{RL});* The Amps hrs Required per Cycle *(A_{RC});* the Battery Bank required *(B_{BR})* and *PV* Generating Amps needed (P_{VG}) were all pbtained using equations (3), (4), (5) and (6) respectively.

$$W_{RL} = D_L \times (E_F + 1) \dots\dots\dots\dots\dots\dots (3)$$

$$A_{RL} = \frac{W_{RL}}{D_{CV}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4)$$

$$B_{RR} = \frac{A_{RC}}{D_{DOD}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (5)$$

$$P_{VG} = \frac{A_{RC}}{kw/sq.meter/day} \dots\dots\dots\dots\dots (6)$$

Where E_F is the efficiency factor; D_{CV} is the DC system voltage and D_{DOD} is the Desired Depth of Discharge

Energy-cost analysis

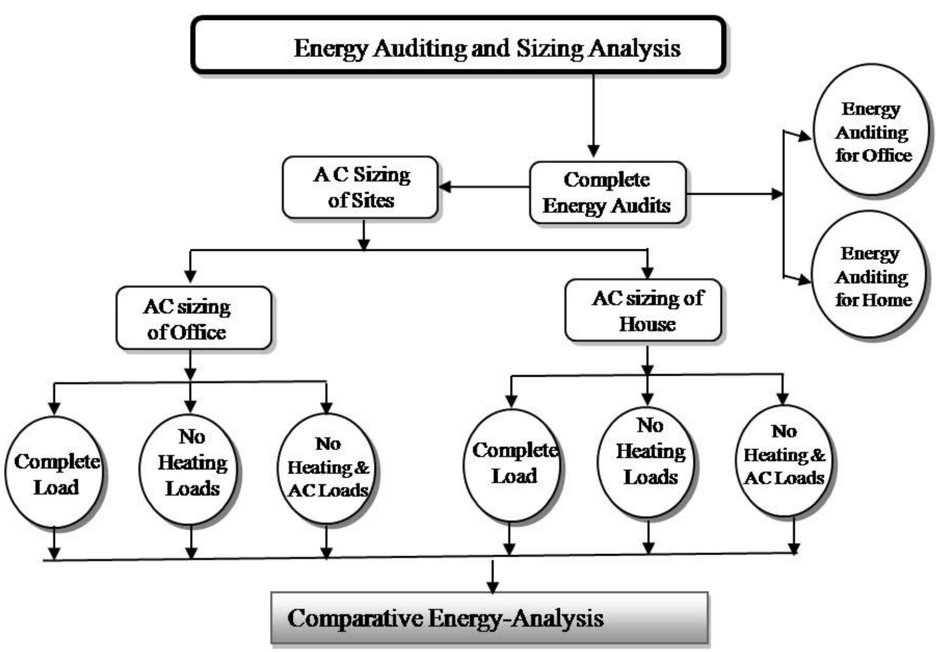
There are several cost analysis methods that have been propounded such as: (i) *Cost-of-illness analysis* (ii) *Cost-minimization analysis* (iii) *Cost-effectiveness analysis (CEA)* (iv) *Cost-utility analysis (CUA)* (v) *Cost-consequence analysis* (vi) *Cost-benefit analysis (CBA).* Cost-of-illness analysis is a determination of the economic impact of an illness or condition (typically on a given population, region, or country) e.g., of smoking, arthritis or bedsores, including associated treatment costs. Cost-minimization analysis is a determination of the least costly among alternative interventions that are assumed to produce equivalent outcomes. Cost-effectiveness analysis *(CEA) is* a comparison of costs in monetary units with outcomes in quantitative non-monetary units, e.g., reduced mortality or morbidity. Cost-utility analysis (CUA) is a form of cost-effectiveness analysis that compares costs in monetary units with outcomes in terms of their utility, usually to the patient, measured. Cost-consequence analysis is a form of cost-effectiveness analysis that presents costs and outcomes in discrete categories, without aggregating or weighting them. Cost-benefit analysis (CBA) compares costs and benefits, both of which are quantified in common monetary units.

The suitability of any of these methods depend upon the purpose of the assessment the availability of data and other resources. A flexible and

Table 1. Alternative current sizing for office-energy consumption

Loads	Q	I_{WL}	C_L (w)	R_T	D_L (Wh)	E_F(%)	W_{RL}	D_{CV}	A_{RC}	D_{DOD} (%)	B_{RR}	KW/Sq m/day	P_{VG}
Fridge	2	78	156	12	1872	15	2153	12	179	33	542	4.25	42.2
Iron	1	1800	1800	1	1800	15	2070	12	173	33	524	4.25	40.6
Light Bulb	18	60	1080	10	10800	15	12420	12	1035	33	3136	4.25	243.5
Radio	2	100	200	8	1600	15	1840	12	153	33	464	4.25	36.1
Fan	5	80	400	12	4800	15	5520	12	460	33	1394	4.25	108.2
A/C	4	745.7	2982.8	12	35793.6	15	41163	12	3430	33	10394	4.25	807.1
Phone	1	9.6	9.6	12	115.2	15	132	12	11	33	33	4.25	2.6
Laptop	1	40	40	6	240	15	276	12	23	33	70	4.25	5.4
DVD	4	60	240	8	1920	15	2208	12	184	33	558	4.25	43.3
TV	4	90	360	8	2880	15	3312	12	276	33	836	4.25	65.0
Microwave	1	1200	1200	0.5	600	15	690	12	57.5	33	174.3	4.25	13.5
Blender	1	700	700	0.25	175	15	201	12	17	33	51.5	4.25	4.0

Fig. 1. Methodology frame work for energy auditing and AC sizing



non-distinctive method which combines some of these methods was applied to this work. From Fig. 2 the four different sources of energy analysed for the two selected sites were (i) Solar (ii) Inverters (iii) Electricity supply (iv) Portable Generators. Load selections were done for the cases of solar and inverters and energy cost estimates and were obtained and comparisons made based on this selection. Energy-cost analysis carried out on electricity supply and generators entailed collection of data on billing and usage of petrol (for the 3-bedroom site) and diesel (for the office site) for a period of one year. Comparisons were made of results obtained leading to clear measurable cost-implications while predictive recommendations on selection and usage of energy sources were made possible from the work findings. The cost analysis for the inverter and solar (PVC) which gave rise to figure 8 were obtained after the load selections had been carried out and the total (T_{CL}) of the connected load (C_L) calculated earlier with equation (1). The total load (T_L) in KVA is obtained by equation (7) where A_{PP} is same as (T_{CL}).

$$T_L = \frac{A_{PP}}{0.8} \times 1000 \qquad (7)$$

Also putting equation (8) into consideration, the selected inverter capacity (S_{IC}) is obtained from equation (9). Finally the inverter cost is evaluated based on S_{IC}. L_{MAX} is the maximum load on inverter and T_{IP} is Total Inverter Power

$$L_{MAX} = 80\% \, (T_{IP}) \qquad (8)$$

$$\therefore (80\%) \, S_{IC} = T_{CL} \qquad (9)$$

Results and discussions

Three types of selective loadings as discussed in section 2.2 and 2.3 were carried out. The results presented in Tables 1 and 2 are those for complete energy loadings i.e. with heating elements and A/Cs for the two case studies considered. However in figure 3, the Total Connected Load (T_{CL}), the Total Daily Load (T_{DL}) and the Total PV Generating Amperes Needed (T_{PVG}) were compared for all the three different loadings for the chosen sites. The values for the complete loadings were highest and those for selected loading (without heating and A/Cs) were lowest for two sites thereby confirming the ideal situations. Based on these data, the comparison presented in Fig. 4 was done. It entails selective loadings (without heating and A/C) for the generators; with complete loadings (with heating elements and A/Cs) for electricity supply. Despite the selective loadings, the energy costs for the generators were still higher with the cost for diesel-generator consumption highest for the period considered.

In Fig. 5, comparison of all the sources of energy was made. Fig. 5 compares (i) the total cost of setting up inverters and solar units for selected loading (ii) running-costs for diesel and petrol generators for selected loading (iii) cost of electricity supply for complete loading at the two sites considered. Results show that the cost required for setting up solar energy usage for the home is highest despite the selective loading. The energy-cost variations for the inverter and solar presented in Fig. 6, presents a guide for the choice and cost implications for solar or inverter systems set up as energy sources for homes or offices. The figure combines the energy-cost analysis with selective loadings to predict home and office requirements for different Connected Loads (C_L) in KVA. Shown in Fig. 7 and 8 are the comparison of cumulative energy cost extrapolated over five years for office and home use respectively. The cost for using solar and inverters are high initially but tend to be regular and stable over the years. The points C_{B1} and C_{B2} shown in Fig. 7 and 8 indicate the Cost-Benefit points for using the inverter at the office sites and home respectively. Beyond these points the cost of using inverters becomes lower (though for selected loading) than other alternatives for some period of time until major replacements or servicing are needed for the inverters. The comparison also takes into consideration the maintenance and re-charging cost of the inverter and the solar units. However, selected loading was used for all the other alternative sources of energy to electricity in this comparison.

Fig.2. Methodology frame work for energy-cost analysis

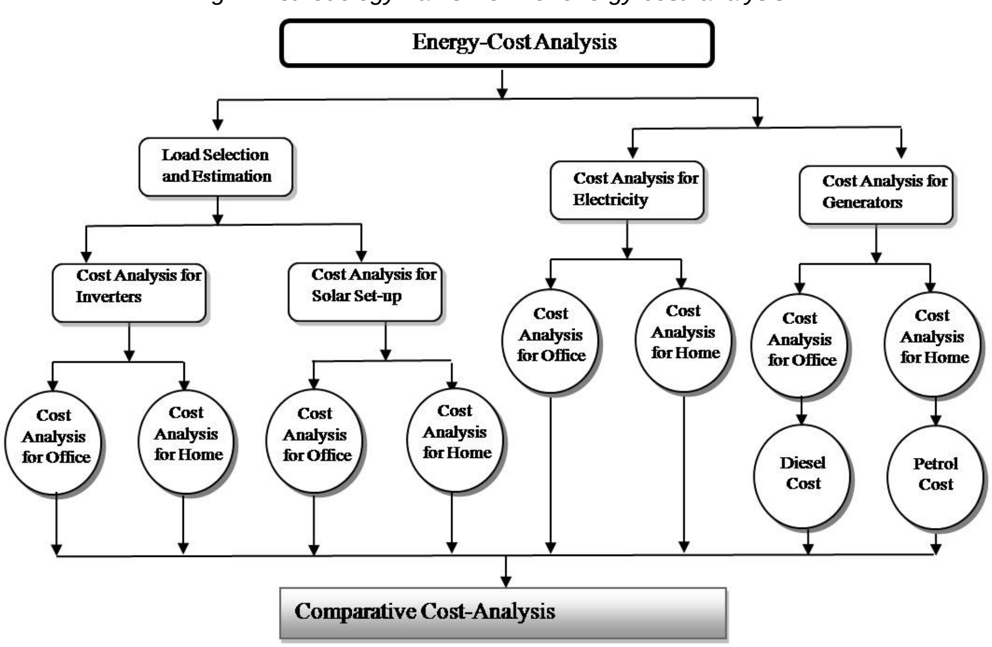


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Fig. 3. Comparison of AC sizing results (T_{CL}, T_{DL}, T_{AN}) for different selected loadings

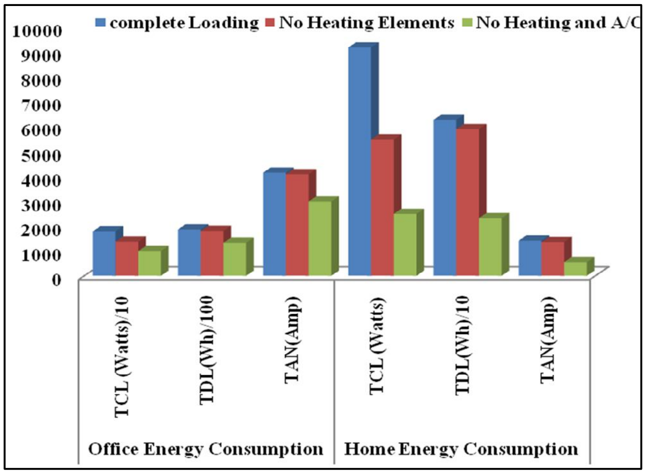

Fig . 4. Energy-cost comparison for electricity, diesel and petrol generators

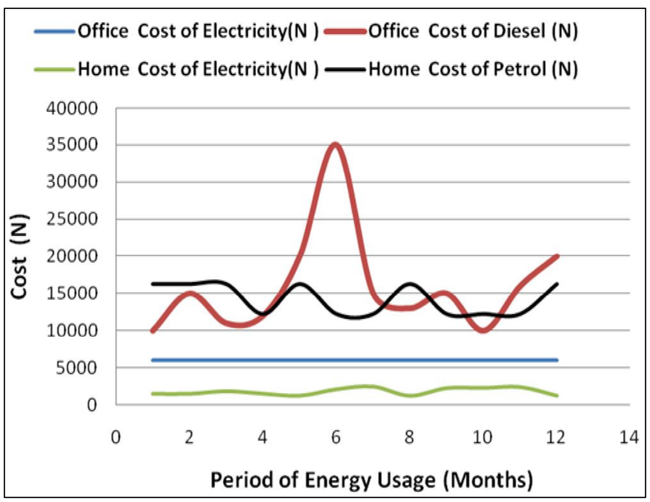

Fig. 5. Comparison of total energy cost for a year

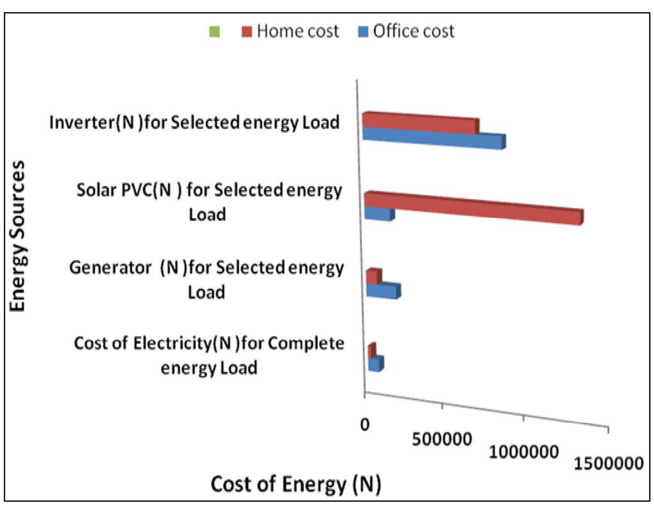

Fig. 6. Energy-cost variations for Inverters units

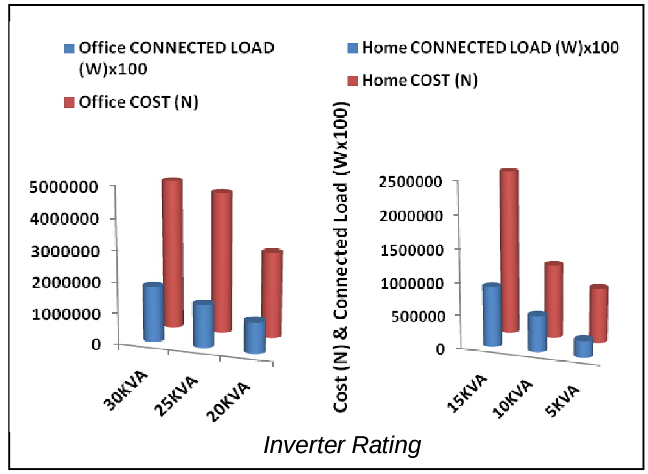

Fig. 7. Ccumulative energy cost extrapolated for over five years for office use

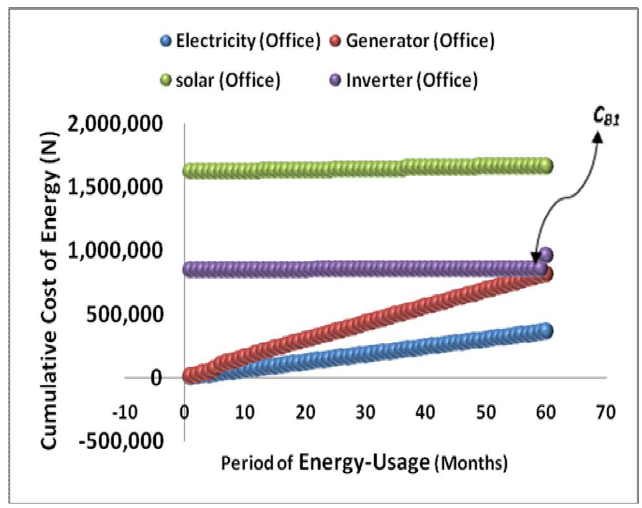

Fig. 8. Ccumulative energy cost extrapolated over five years for home use

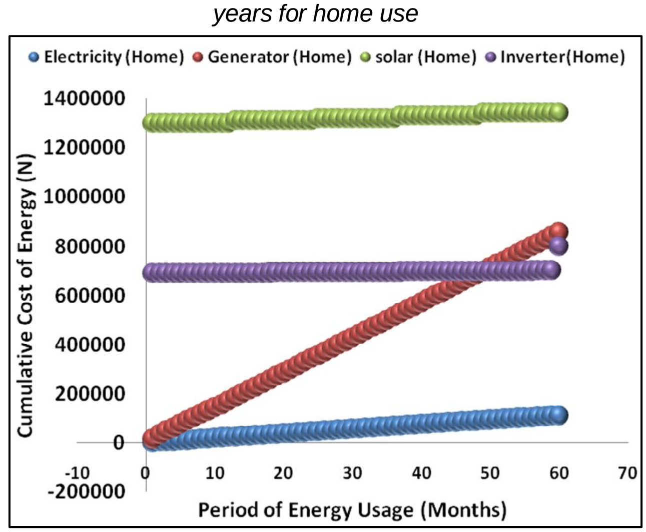

Table 2. Alternative current sizing for home-energy consumption

Loads	Q	I_{WL}	C_L (w)	R_T	D_L (Wh)	E_F (%)	W_{RL}	D_{CV}	A_{RC}	D_{DOD}(%)	B_{RR}	KW/Sq m/day	P_{VG}
A/C	5	745.7	3728.5	13	48470	15	55741	12	4645	33	14076	4.25	1092.9
Fridge	1	78	78	24	1872	15	2153	12	179	33	542	4.25	42.1
Fluorescent	9	36	324	8	2592	15	2981	12	248	33	752	4.25	58.4
Light Bulb	12	60	720	8	5760	15	6624	12	552	33	1673	4.25	129.9
Radio	1	100	100	6	600	15	690	12	58	33	176	4.25	13.7
Fan	7	80	560	13	44800	15	51520	12	4293	33	13009	4.25	1010.1
Computer	2	350	700	10	7000	15	8050	12	671	33	2033	4.25	157.9
Stabilizer	1	2200	2200	10	22000	15	25300	12	2108	33	6388	4.25	496.0
UPS	4	600	2400	10	24000	15	27600	12	2300	33	6970	4.25	541.2
HP K7103	2	60	120	1	120	15	138	12	12	33	36	4.25	2.7
Out light	4	500	2000	10	20000	15	23000	12	1917	33	5809	4.25	451.1
TV	1	90	90	6	540	15	621	12	52	33	158	4.25	12.2
Laptop	7	40	280	6	1680	15	1932	12	161	33	488	4.25	37.9
Scanner	1	60	60	1	60	15	69	12	6	33	18	4.25	1.4
Backlight	3	40	120	8	960	15	1104	12	92	33	279	4.25	21.7
W/ Heater	2	1200	2400	.5	1200	15	1380	12	115	33	348	4.25	27.1
HP 1220c	1	90	90	1	90	15	103.5	12	9	33	27	4.25	2.1
HP F4180	2	65	130	1	130	15	150	12	13	33	39	4.25	3.1
Iron	1	1800	1800	1	1800	15	2070	12	173	33	524	4.25	40.7

Conclusion and recommendations

The main objective of this work which is to present a quantitative energy and cost-predicting analysis of energy sources using Nigeria as case study and thereby proffer alternative and immediate alleviating measures to unsteady National electric supply in some developing countries while embarking on upgrading has been achieved. In the process of the work, energy audits, AC sizing, net load selections and cost estimations were carried out for two selected sites representative of home and office-energy usage. The cost implications of employing alternative sources of energy such as Inverters and Solar panels were the closely surveyed while those for energy sources from petrol and diesel generators were also considered. The results obtained presented guiding steps among other solutions on how homes and offices can be powered by applying the method of selective loading to reduce the cost of setting up alternative sources to electricity such as inverters and solar units. Though the need for the affected developing countries to step up their national power supply cannot be over stated, the following are suggestions based on this work.

- The usage of energy saving bulbs should be encouraged in home and at office. This energy saving bulbs can replace the conventional 60W bulbs, fluorescent and security light which consume a lot of energy.
- Energy conservation culture must be imbibed to eradicate the culture of energy wastage.
- There should be public awareness on the advantages of using these alternative sources of energy.
- People must inculcate the culture of close monitoring of their energy bills and fossil fuels bills while adequate record should be kept to ascertain their expenditure.

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