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Photovoltaic-Battery Energy System Versus Fuel Generator in Grid Connected Residential Power Supply

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Abstract
The electric power availability and reliability in Nigeria is in a very poor state as most homes in urban centres connected to grid are for many hours without electricity supply each day, and often with zero supply for consecutive days. This calls for radical and serious effort by all stakeholders to address this challenge as regular power supply is indispensable to all forms of national development and quality of human living. The common use of fossil fuel-powered generators to augment the grid is not a sustainable solution among many other serious disadvantages. Photovoltaic (PV) has a key role to play in short, medium and long term in solving persistent grid power unavailability not just for rural electrification but particularly for residential power supply in urban areas. This paper shows the superior advantages of PV over fuel powered generator. The paper examines some success story of residential photovoltaic systems in some developing countries. This work identifies some of the reasons why the technology seems not to be working in Nigeria despite the high irradiation naturally available in the country. Finally, the paper suggests points of actions that can be taken by individual and government at all levels to promote mass deployment of photovoltaic technology. If these recommendations are implemented, it is hoped that power supply will drastically improve within a short term.
Keyword: Home PV system, Off-grid PV system, photovoltaic, renewable energy, rural electrification
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1. Introduction

Electricity is indispensable in any modern society, both in the rural and in urban centres. Regular availability of electric power is primarily linked to social-economy well-being of any nation, human development and enhanced quality of life. Electric power is supposed to be reliably available at all time, every second and 24-hour a day. It is a necessity to modern life. Without it, daily living becomes unbearable and difficult, particularly in urban centres.

While power supply reliability is very high in advanced countries, most African countries and Nigeria in particular have very poor availability of electricity due to acute shortage in the generated power and aging power infrastructure (Johnson 2015). A large population, particularly in the rural areas lack access to electricity because the grid could not be extended to them.

Off-grid electricity is therefore very important in countries like Nigeria where access to regular power supply is very limited. Petrol or diesel-powered generator is the commonest off-grid electricity used by most household in the country. It runs on gas or petrol or diesel fuel with output power rating ranging from small capacity of 0.50kW to very big ratings of 1500kW capacity or more. Most generators use in residential areas are small, compact, portable and affordable by most household because, relative to solar photovoltaics installations, it has very low initial cost. In addition, there are readily available technicians for its repair and services.

However, the use of fossil fuel-powered generators poses silent but very dangerous threats to the environment and human life, in terms of noise pollution, degradation of atmospheric oxygen and greenhouse gas emissions with its contribution to global warming which is of serious concern globally. The fume emitted from fossil fuel-powered generator has been causing thousands of death every year in the country, all in an attempt to meet their electricity need (Anyagafu 2014, *Akasike* 2019, Adum et al 2019, IFC 2019, Ede 2022, Lambo & Mohammed 2022, Obianeri 2022,).

The cost of fuel such as petrol, gas and diesel for powering generators is also subject to price volatility, which in most cases increases at any time. This increases the generator overall running cost.

A better alternative is a solar photovoltaic system. Unlike petrol generators, PV system is neat, noiseless, produces no pollution or waste, consume no fuel and its running cost is very minimal. Therefore, technically exploiting solar energy for power generation is easy, workable and sustainable option for Nigeria to substantially reduce the problem of high unreliability of grid supply, supplement grid supply, and also powers communities unreached with grid.

The massive adoption of photovoltaic system for individual off-grid residential power supply is essential in the drive toward decentralization of the grid, smart grid system, energy sustainability and reduction in carbon emission. Solar photovoltaic, with appropriate policy support and incentive from the government, could provide affordable and reliable supplies of electricity. Off-grid solar PV has a great potential in supplying the huge deficit of electric power demand in Nigeria.

The country enjoys nine hours of clear and bright day-light, from 8:00am -5:00pm throughout a year in adequate quantity of irradiation varying from 3.5kWh/m^2 to 7.0 kWh/m^2 depending on the geographical location and season. Solar resources is bountiful in the country and provides opportunity for sun energy conversion to electric power. This solar to electric energy conversion technology is fully mature, robust and reliable. Solar power system is scalable and appropriate for powering a single load, household, community and industrial level operations as well as grid scale power generation

Off-grid electric power supply reliability is enhanced when more than one method (hybrid) of power generation technologies are combined. It could be PV-wind, PV-diesel, wind-diesel, PV-wind-diesel hybrid systems. The hybrid option complements the strengths and demerits of each involved power generating technology; although it can be capital intensive and requires sound technical design and thorough analysis. For good reliability of residential off-grid PV system, the design should be combined with at least Battery Energy Storage BES because of cloudy days and night when daylight is not available.

Off-grid photovoltaic system basically consists of PV module (solar panel), maximum power point tracker (MPPT)~~,~~ inverter, charge controller, battery energy storage, DC cables and other accessories. The PV module is the DC generator which receives direct sunlight and produces DC electricity. The MPPT incorporated into the battery charge controller monitors the performance of PV modules and cause it to operate at voltage and current at which it can yield maximum electric power the module is capable of despite varying photons energy from daylight. The charge controller ensures that the storage batteries are charged optimally from the energy that is generated by the solar modules. The inverter converts DC electric power to AC electric power which is the suitable form most appliances are designed to work with. The PV modules also charges the battery during the hours of daylight and the battery act as source when the level of solar irradiation is insufficient for the adequate generation of electricity by the PV modules. This enhances the system reliability.

The ever-increasing cost of fuel for generator with its attendant environmental pollution should naturally make photovoltaic power system more attractive to households. Other reasons include regular threat by power utility companies to increase grid electricity tariff in Nigeria without any service improvement and the falling cost of solar PV systems.

As the overall cost of solar photovoltaic system keeps falling, its massive use and adoption of the technology for residential power supply in Nigeria will majorly still depend on affordability, its supply reliability and durability. This is hinged on integrity and quality of the PV modules and all other accessories and associated devices. These are the major issues causing very poor performance and early failure of the few installed PV system in the country. Most of the business men in Nigeria procure very poor quality PV module from certain companies in Asia to sell in Nigeria

In addition, the soundness of the technical design and installation to meet the required load is also critically important for the system performance. For good PV system design, the technician must be well proficient in the technicalities of DC power system and solar electricity. It is not every electrician that have this knowledge. Training is required to be a competent solar electrician.

For effective design, the solar electrician must first assess the loads to be powered, taking cognizance of inductive load and the total peak load, time of the peak load, average daily load and irradiance of the location. This knowledge will determine the capacity and specification of the module and then advise the users appropriately. Of equal importance is a good knowledge of battery technology, days of autonomy, MPPT charge controllers, DC/DC and DC/AC power electronics. The standard of the PV system design is prerequisite to its reliability and durability

This paper seeks to dispels from technical point of view and based on recent advances, the misconception of poor reliability of solar photovoltaic power system and establish that the residential PV system is cheaper and safer than fuel power generator commonly use in the country.

2. Review of Related Studies

Elusakin et al. (2014) studied the challenges of sustaining off-grid powers generation in Nigeria's rural communities. The authors identified reasons for failure and abandonment of most off-grid electricity projects in Nigeria as corruption/misappropriation of fund, substandard equipment and components, lack of adequately planning particularly on maintenance and performance monitoring, technology gap in term of right design and sizing, and operational challenges. The authors' proffered solutions include proper planning that covers the life span of the off-grid electricity project, seriousness on the part of government in commitment to off-grid projects and encouraging reputable power companies with specialty in off grid electricity to invest in Nigeria both in term of human resources and power projects as well as easy access to loans and subsidies for off-grid power projects.

Ani (2016) in his study presented a very small and simple but effective design of stand-alone photovoltaic system as off-grid electricity for only lighting purpose for use in typical rural village house in Nigeria. The authors used two to three and half modules each at 130W capacity and include battery energy storage in the design. They used Hybrid Optimisation for Electric Renewable (HOMER) software tool to study the system's energy production for different energy consumption levels ~~so as~~ to decide on the system configuration that gives the best reliability at the least possible lifecycle cost. The author confirmed that cost of energy design depends on energy consumption pattern and that the use of energy efficient bulb as well as good energy management is the best way to cut cost.

Guda & Aliyu 2015 and Msughter & Celestine 2016; in a separate study, a stand-alone PV system was designed for use in standard 3-bedroom flat located in major Nigeria cities of Makurdi and Bauchi. The system is found, by simulation result, to work effectively in meeting the energy requirement of the building at all time with incorporation of battery energy saving for night operation. The home PV system's cost was found to be a fraction of fossil fuel generator cost within the same service year. The limitation of these studies, however, is that it was never prototyped and so the system performances in reality still need to be verified.

Pal and Mukherjee (2021) presented detailed analysis of hybrid system of off grid solar PV with Hydrogen fuel cell and asserted that it offers better efficiency during consecutive cloudy days than hybrid off-grid solar PV with BES. Barzola-Monteses and Espinoza-Andaluz (2019), proposed hybrid design of PV-fuel cell-battery system to power a residential house in a Guayaquil city, Ecuador. The cost of the energy generated by the system is still much higher because the cost of grid power in Ecuador is low. The system however offers advantage of releasing no pollutant gases into the environment.

Schulte et al. (2022) worked on analysis of intention to adopt residential PV system using four different models for the explanation of the intention. The authors' analysis suggests that perceived benefits are most important

reasons of the adoption intention. Kiray (2021) researched into impact of orientation, slope and shade on the roof-top mounted residential PV power system and how to mitigate these effects to considerably improve the performance the PV system. The author presented a solution of system design of dual-axis solar tracking system integrated gazebo without compromising the building's roofing aesthetic.

Patel et. al (2022) proposed a web-enabled technique for predicting the amount of power generated by off-grid photovoltaic system. The authors use Internet of Things (IoT) platform to developed a scaled-down prototype of a data logger to monitor photovoltaic system. The platform is used to collect data, store them and visualize the off-grid PV system which may be at remote location. When date and time are keyed into the system, it gives the expected humidity, temperature and then the forecasted power generation of a particular standalone PV system is estimated by linear regression machine learning algorithms. The technique according to the authors is more than 90% accurate.

3. Off Grid Home PV System with Energy Storage

The major drawback of PV system is the intermittency of its power generation. It can only generate electric power when there is bright, clear daylight. When the weather is cloudy and at night, the output power from a PV system is zero. This demerit can be effectively mitigated when the system is well-designed with energy storage. Battery Energy Storage (BES) is the most suitable for PV system of all energy storage technologies. With appropriate BES sizing and good load management, the system can work efficiently for several days during unfavourable weather conditions. During excess energy production, the surplus electrical energy is converted to chemical energy in the battery through charging. During shortage the chemical energy is reconverted to electrical energy for use.

Inverter, a power electronic device, is very important in integrating BES and PV generator output to drive electrical loads. An Inverter converts the DC output from BES and PV module into AC electricity that is required by most loads.

4. Off-grid PV System for Rural Electrification

People living in rural areas also deserved to be provided with electricity by their various country governments. In most developing nations, natural food, fish and most agricultural produce for urban centres are produced by rural dwellers. So in a very good way, rural dwellers contribute to survival of any nation. They in turn as citizen need to be included in welfare, infrastructural and developmental planning of their countries particularly in the areas of education, health care and provision of electricity. Other reasons, like social equity, poverty eradication, economic and rural development should motivate present and future sustainable rural electrification projects and funding programmes by various governments and institutions.

However, extension of electric grid facilities to remote, scattered, sparsely populated and low energy-demand rural villages in difficult terrain is not economically viable. Off-grid electrification is therefore a good option because it requires no transmission lines and therefore cost less and also takes advantage of available local resources like solar, wind, biomass and hydro. Of all these resources, solar is the most readily and abundantly available everywhere in Nigeria; and solar photovoltaic requires very minimal maintenance and its maintenance does not need highly skill professional once the design and installation is robust.

A simple but robust PV system design of 0.1kWp capacity can effectively power rural household in Nigeria. Most loads in rural areas are basically lighting, Radio, and TV. The high initial cost has long been limitation to massive deployment of solar PV power in Nigerian villages. With the ever-falling cost of the PV system, support from government and international donors, as well as amortized payment over a given period will, to a large extent, greatly enhance affordability resulting in increasing use of PV system both in urban and rural settings particularly for residential power system.

5. Off-grid Home PV System in Urban Centres

Off-grid electricity is mostly proposed for or used in relation to rural electrification in most literatures. While off-grid electricity for remote locations is acceptable and understandable in countries where grid supply is adequate but uneconomically viable to extend grid facility to rural areas, it has also become a viable alternative to supplement supply where the grid covers but inadequate to meet demands particularly in Nigeria. Home Solar Photovoltaic is a good technology that can supply off-grid electricity in urban centres in the country.

Roof-mounted home PV system is a common sight in most advanced countries. Interestingly, these are countries with reliable and consistent supply from the grid while in countries where grid supply system is very poor, Home PV system as alternative, is scarcely seen. Of course, cost is the major hindrance. This is why government needs to provide encouragement and incentive for the home owners to use PV electricity to power their residence instead of the common petrol generators. Government needs to actively discourage the use of petrol generators because of its adverse effect on the environment and human life.

The available solar energy on roof top of most residential buildings in Nigeria could produce all or much of the energy requirement in the building (Johnson & Ogunseye 2017)

6. Cost Analysis of Grid supply, PV Power and Generator for 3-Bedroom Flat

The flat is assumed to have six occupants, the father, mother and four children some of whom may be adult or live-in relative as we have in some Nigerian household. Common appliances in household, their rating and consumption rate are tabulated below as Table 1. A number of studies (Guda & Aliyu 2015 and Msughter & Celestine 2016) have attempted to do cost estimation of home PV power system but none seem to compare it to cost of grid power and the cost of common petrol/diesel generator for the duration of PV system service life. In each of the cases, there is either gross overestimation of the load demand of average household and consequently that of PV capacity. Another key issue is that household where PV is to be used, it is necessary to go for highly energy-efficient home appliances which are on the increase in the market.

Table 1: Load profile of an average household in Nigeria

S/N	Appliances	Rating (Watt)	Quantity	Used hours /day	kWh/day
1	Bulb	10	10	10	1.00
2	Colour TV	60	1	6	0.36
3	Fan	50	5	10	2.50
4	Fridge	200	1	16	3.20
5	Deep freezer	300	1	10	3.00
6	Blender	200	1	0.5	0.10
7	Washing Machine	300	1	1	0.30
8	Radio	60	2	3	0.36
9	Iron	1000	1	0.2	0.20
10	Cell phone	5	4	2	0.04
11	Laptop	30	3	2	0.18
12	DVD player	20	1	6	0.12
	TOTAL	**2660watt**			**11.36kWh**

This is even advisable even if the household are on grid as this can cut energy use and bill as much as up to 60-70%. In addition, practice of demand side management will further improve the efficiency and durability of PV system and its accessories.

The estimation in this study is based on energy demand of average Nigerian household and the commonest household fuel generator in the country. The total wattage in the flat is 3007W, so an average household needs 3kVA source to power all the appliances at a time. However not all the appliances will be on at the same time particularly if they are being powered by fuel generator, so most or an average home in the country is satisfied with 2.5kVA fuel-fired generating source.

6.1 Cost of Grid power

For 3-bedroom flat, the cost of grid electric prepaid bill is usually between ₦5000 to ₦15000 on average, though it still depends on the usage and hours of availability in a month as we all know it is extremely rare in Nigeria for 24-hours grid power availability. The best is usually between 12-18hours/day availability while overwhelming number of household is average of 6 hours per day or less (Johnson 2015). So we take the average to be ₦5, 000 per month. So in 25 years, the total cost of grid electric bill for 3-bedroom flat is:

₦ 5000/month × 12 × 25 = ₦ 1,500,000

6.2 Cost of fuel generator

We assume the 3-bedroom flat is run exclusively on generator. In most household, the generator only runs for hours not the whole day. We assume the generator runs for 6-hour a day. The fuel consumption depends on the generator's capacity. For 3-bedroom flat, 2.5kVA capacity is sufficient to power the entire appliance. The cost of 2.5kVA generator ranges from ₦ 180,000 to ₦ 250,000 (₦ 215,000) depending on the quality and brand. Note that a single generator will not last for the 25 years, so it has to be bought at least one more time during the period making the least total cost of purchase to be ₦ 430, 000

A 2.5kVA generator use minimum of one litre per hour though dependent on percentage loading and fuel efficiency of the generator. So for 6-hour a day consumption at ₦ 600 per litre for 25year period

600 × 6 × 365 × 25 = ₦ 32,850,000

At least, it should be serviced or maintained once in every three months at a reasonably assumed cost of ₦ 3,000 making it 3000 × 4 × 25 = ₦ 300,000 for 25 years. So, the total cost for using fuel generator for twenty-five years is

32,850,000 + 430,000 + 300,000

= ₦ 33, 580, 000

6.3 Cost of Solar PV Power System

As at January 2023, the cost, on average, of good quality solar power system which consist of solar module, inverter, charge controller, DC cables, switch gears, robust deep-cycle battery energy storage and other accessories is between $2.00-$3.00 per watt depending on the country (Hoymile 2022, Solar.com 2023, 2023]. However, if it is on industrial scale, the cost per watt goes lesser as the total wattage installed increases.
Based on irradiation of 3.5-7kWh/m^2 available in Nigeria and the average load demand of 3-bedroom flat, a PV capacity of 3-4kW_p is adequate.

So, at exchange rate of $1 to ₦750, 3.5kWp PV capacity cost 3500 × 3.0 × 760 = ₦ 7,980,000

If the cost is to be further broken down, experience in solar photovoltaic industry has shown that the price of each constituent part of solar PV system is mostly at definite percentage of the aggregate cost. For example, the PV modules' cost is about 20% of the total cost of the PV system, the inverter cost is between 10-15% of the total cost contingent on the configuration and type of inverter use. Battery cost depend on the day of autonomy i.e. the number of days it is expected to work without charging but is usually around 15-20%, cost of labour is dependent on country but usually falls within 5-15%. Operational cost,

cost of repair and maintenance for 25 years of the solar photovoltaic system's service life is mostly fall within 35-40%. Operational and maintenance cost includes repairs, change of battery and inverter after some years. Other components cost include cost of meter, AC isolator, gear switch, fuse, DC disconnector etc.

6.4 Cost Comparison

From the analysis above, the cost of grid power is by far the cheapest source of electricity in Nigeria for an average household. However, grid power system in the country is highly unreliable and unstable with availability of less than 10-hour for an average home (Johnson et. al 20220), In countries like Germany, Australia and USA where grid power is very stable and reliable; the PV system cost is less or at parity with the grid electricity cost (Wehrmann 2022, Smart Solar Energy 2020, Graham et. al. 2023).

As expensive as PV system is, it is still far cheaper than fuel generator commonly used in the country to augment the grid supply. The PV system's cost is less than a quarter of the cost of fuel-fired generator. However, PV require a very high initial cost which is still prohibitive for most householders due to prevailing economic situation and absence of government subsidy and support. This notwithstanding, PV system seems to be one of the most viable alternatives for better electric power availability in Nigeria. In addition, it is sustainable energy source, it is environmental friendly and cheaper in the long term.

Fuel-fired generator power supply is by far the most expensive but it is affordable to purchase particularly at lower capacity up to 1kVA. The running cost is very high such that average household are not able to run its every day. Once PV system is installed, it produces electrical power every day whether the owner use it or not.

7. Government Responsibility

Promotion of renewable energy has always been responsibility of each country government. Enabling environment, appropriate policy and incentive to encourage use of photovoltaic power system has always come from government. Where does Nigeria government stand? Nigeria Government at the three levels needs to participate actively in promoting wide use of PV system for household electrification. In addition, there should be effective synergy among various tiers of Nigeria government in solar PV proliferation. Government incentive will trigger and drive PV market in the country.

However, with appropriate policy support, financial incentive and offer of soft loan towards renewable energy promotions will greatly enhance affordability of the citizenry. This can drastically reduce demand for diesel power generators which is injurious to the environment. Thus, all these efforts will result in improve access to electricity which in turns enhances social services, economic activities and of quality of life.

8 PV Renewable Energy Market and Financing

Although, the long term sustainability of solar photovoltaic power system is on its cost effectiveness rather than government subsidy. Yet at initial stage, for massive deployment of solar PV power system for home electrification application in the country, a definite, consistent support, incentive and encouragement is necessarily important from the Nigeria government to trigger PV market. Serious government effort can help motivate international donors and agencies' supported PV projects targeted at meeting specific electric power needs and at the same time creating market for solar photovoltaic. There is pressing need for decentralized, individualised power system as an alternative (other than fuel generator) to unreliable power grid in the country and home photovoltaic power system is the most viable and healthy alternative as there are excellently favourable weather condition.

This need can create huge solar PV market and drive the demand for it. The growth in PV market will appeal to local and international investors, further causing market surge. This offers good potentials to create employment opportunities for teeming jobless Nigeria youth. Growth of PV market and demands for solar PV product will necessitate training and retraining of solar PV energy technicians for installations and maintenance of the system,

thereby providing good opportunities for educational institutions like universities and polytechnics as well as renewable energy developers to offer social and technical services to the society.

9 General Awareness of PV Power Supply System

General awareness of solar PV power system and its potential in solving incessant power failure in the country is still low. Understanding of solar power of many is still not beyond the level of solar cell to power calculator and wrist watch. One study found out that only 60% of Nigeria population is aware of solar electric power (Abdullahi et. al. 2022). To compound the issue, a good number, even among the educated, think that renewable energies, particularly PV system are not reliable. Poor design and implementation of PV projects in the country which results in the systems' early failure have also not helped the reliability reputation of solar photovoltaic. So, there is still need to create adequate awareness among the populace as well as provide right education and correct information on PV capability as viable source of power generation. This is very important if renewable technology is to be fully embraced by all.

10. Home PV Power System's Growth in Some Developing Countries.

Bangladesh is also a developing country like Nigeria with a population of around 170million. The country has made good progress in off grid home PV power system and with the support of World Bank assisted programme, USAID, UK-DFID, other international agencies/donors and various local development partners; has installed PV power system for around 6 million households in the country as at 2021. This provides clean, reliable electric power to more than 20 million people in off-grid areas and in total 367.95MW supplies from solar power systems initiatives (Siddique et. al. 2021, Abdullah-Al-Mahbub et. al 2022). Commercial banks in the country assist in providing soft loan towards renewable energy projects (Cabraal et. al. 2021)

Kenya is probably the African leader in off-grid PV electricity with 14% of the population relying on solar photovoltaic for lighting, powering electronic and charging sources particularly in the country rural areas (M-KOPA 2015, Tigabu 2016). In Kenya, PV market has flourished in stages as technological and commercial innovations have made it affordable for lower-income earners. Solar PV technology was made affordable to Kenyan masses by 'Pay As You Go' method as well as other consumer financing model. Solar PV energy developers in Kenya are making a good progress in gradual proliferation of PV products and also offer affordable payment options that practically work for the consumers. In addition to many residential standalone PV power systems in the country, Kenya has successfully developed numerous mini-grids for rural electrification predominantly powered by photovoltaic and supported with battery capacity (Johannsen et. al 2020). Efforts are ongoing to replace diesel generator with wind turbine. Nigeria need to learn from Kenya in this area.

Ghana, a fellow West African country is making significant progress in photovoltaic technology deployment. The country through the Energy Commission of its Ministry of Power has been implementing a Rooftop Solar Photovoltaic (PV) Programme of up to 500Wp for any interested citizen with residential facility. The intention is to relief the national grid of 200MW peak load by using solar Photovoltaic energy technology.

The Ghanian government is providing the capital subsidy either as cash payment for solar panels component of the PV system or supply the panels after beneficiary has bought and installed other PV system components such as batteries, inverter, charge controller etc (Energy Commission of Ghana). At present, thousands of rooftop solar PV power systems of various capacities have been installed with benefits for beneficiary to export excess power to the power distribution companies who in turns credit them with supply when PV power generation is in short supply. This is done by means of net metering.

11. Simple Design of a 4kW$_p$ Solar Power System

For off-grid home electrification, a simple stand-alone PV system of 4kW$_p$ is designed to power 3-bedroom flat. In this design a high efficient module SW 350 XL MONO model is used. Table 2 shows the electrical features of the module. The module is manufactured by SolarWorld in high tech, modern factories in US and Germany

which meet strict environmental and quality standards and offer 20-year product warranty. Its performance is almost constant for 25-year period diminishing by less than 0.7% every year meaning that after the 25 years, the product will still be able to produce output of at least 84% of it nameplate. This feature is particularly needed in Nigeria where there are many cases of substandard PV products from China leading to early failure of many PV projects and consequently giving the impression that PV renewable is not reliable.

The PV array is connection of nine modules in parallel. With each module rated V_{mp} =38.4 V and I_{pm} = 9.17A; then the effective output of the array is 38.4V and 82.53A. This effective value is similar to that of series and parallel arrangement of batteries.

The circuit diagram of the solar power system is as shown in Figure 1.

Rated Power (P_{max})	350W
Maximu Power Voltage (V_{pm})	38.4V
Maximum Power Current(l_{pm})	9.17A
Open Circuit Voltage (V_{oc})	48.0V
Short Circuit Current (l_{sc})	9.82A
Temperature Coefficient P_{max})	-0.043%/^{0}C
Temperature Coefficient (V_{oc})	-0.304%/^{O}C
Temperature Coefficient (l_{sc})	0.042%/ ^{O}C
NOCT	46.^{0}C
Module Efficiency	17.54 %
Weight	21.6kg
Operating Temperature	-40°C to 85°C

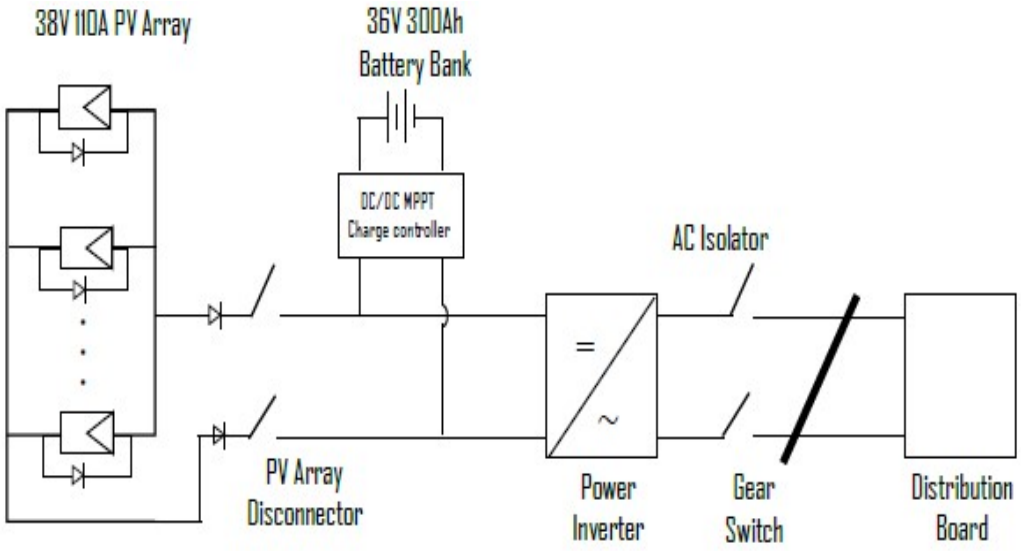

Figure 1: Schematic diagram of the Home Photovoltaic System

The array generates power at 38.4V and 82.53A and feed the boost converter. The DC/DC boost converter incorporate MPPT which enables the modules to operate at maximum voltage and current it is capable of irrespective of varying weather condition. The converter also steps up the voltage from 38.4V ±20% to 340V DC before feeding the inverter. The inverter transforms the 340VDC electricity into 240V AC electrical power which is the form most home appliances are designed to work with. In this design, the inverter should be carefully selected to produce pure-sine wave signal. It should be the type whose capacity is three times the sum of all possible inductive load in the building so that it can effective operate inductive load like water pump,

blender, refrigerator in the flat. This is to prevent avoidable overheating and production of harmonic in the system which non-sine wave inverter might generate with some appliances.

The design of boost converter and inverter is outside the scope of this paper as its technical details and analysis is a separate work. In-between the boost converter and the inverter are batteries arrangement meant to store energy during the day and discharge it at night or when weather is not favourable for modules to generate electric power. The PV array charges the battery bank. The battery bank is intelligently monitored by charge controller to ensure that the battery bank is not excessively charged or discharged.

Battery Arrangement

In this design, provision is made for deep cycle battery energy storage. The storage bank is two three-in-series, connected in parallel arrangement consisting of six 12VDC 150Ah batteries with combine output of 36VDC, 300Ah. The battery voltage is deliberately chosen so that the PV output which is at a slightly higher potential can conveniently charge it within a very short time. In this design, when the batteries serve as the source, important loads like lighting, TV, phone charging, fans are to be use. Load whose use can be postponed without any effect on convenience of the building occupants should be shelved so as to extend its days of autonomy. In other words, demand side or good load management should be practiced. In addition, the use of high energy saving appliances is highly recommended. The design makes provision for modification of the batteries storage capacity at any point in time. However, with this simple design, power can be available 24-hour every day for utmost convenience of the flat occupants.

12.0 Recommendation

1. Nigeria government should first take the bull by the horn by actively promote and finance PV projects and then seek for support from United Nations, World Banks and other International donors to assist in renewable energy deployment of home PV system. This approach helped Bangladesh to develop solar renewable energy.

2. Formulation of appropriate and friendly policy on development of PV renewable for investors and home owners. The policy should be backed up with right action like tariff and loan support with no or negligible tax/interest; all aimed at encouraging massive deployment of PV system in the country. In addition, the government should come up with a clear cut effective strategy for renewable energy development.

3. Highly skilled manpower development in offgrid PV system is necessary for sustainability of the PV technology use. The system installer should be duly qualified and accredited. This is very essential for safety and durability of the PV system projects.

4. Promotion of international standard, solar product consumer protection scheme, formulation and effective execution of high quality standard scheme of PV products undertaken by relevant government agencies are
very important in promoting solar PV reputation and reliability.

5. Raising more general awareness on PV power potentials in Nigeria and on the benefits of super-energy efficient appliances at homes. This can be done in various forms like campaign in electronic media, outreach programme at various public centres, seminars, talk by appropriate government agencies and renewable energy developers.

Conclusion

Home photovoltaic power system is critically essential technology that can effectively address Nigeria dire need for clean, regular, reliable and affordable power supply. The system can play a significant role in supplying huge unmet electric power demand in Nigeria. It is the most viable power generating technology that can effectively mitigate the gross inadequate grid power in Nigeria in the shortest possible time. Home PV power system is increasingly becoming smaller and safer and far much cheaper in long term than petrol/diesel generators

commonly use in most homes in Nigeria. It however need active government involvement in term of policy support and financial incentives like soft loan for nation-wide proliferation of the technology for home electrification particularly in rural areas. Private participation of Renewable Energy developers, commercial banks and international donors and agencies can also play a very helpful role for mass adoption of the Home PV system. If the listed recommendations are carefully implemented, it could transform the present state of power epilepsy in Nigeria to much better power services in the country.

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