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An Overview of Renewable Energy Development in Nigeria over the Years: Challenges and Control Measures

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Abstract
Nigeria is one of the most populated countries in the world and the largest in Africa. With a population of about 200 million, the nation is enriched with diverse renewable and nonrenewable energy sources. Despite this vast energy potential, only about 50% of her population has access to electricity. In this study, current perspectives on solar energyutilization as a renewable energy option in Nigeria are examined and discussed from the standpoint of sustainable development. The country, being a world crude oil and natural gas producer, is overdependent on the seen energy sources for electricity generation and other energyapplications.This has currently put the country at risk of impending energy crises given the fast-diminishing fossil reserves, inadequate refining capacity to meet domestic consumption, and severe energy insecurity in restive regions where exploitations exist. Despite the vastfossil-based energy reserves, an insufficient electricity production capacity at 4517.6MWas of December 2012 is generated to support the economy of a teeming population ofapproximately 200 million people. Nigeria is naturally endowed with an abundant deposit ofrenewable energy resources, of which solar energy from the Sun (beingtheworld0s most abundantand permanent energy source) has for decades been enjoying very high-level utilization by ruraldwellers for agricultural processing in the country. The possible motivations for extensively developing solar energy conversion systems in Nigeria are also discussed, and some barriers and challenges are presented. Finally, steps and policy measures to overcome the challengesand facilitate the utilization of this resource are suggested.
Keywords*: Photovoltaic, Renewable energy, Solar energy, Solar arrays*

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I. INTRODUCTION

Electricity indicates a comfortable life, and the demand for this energy source isincreasing. Energy is the prime mover of economic growth and is vital to sustaining amodern economy (Ray &Subhadarsini, 2013). Future economic growth crucially depends onthe long-term availability of energy from sources that are affordable, accessible, andenvironmentally friendly. Government, industry, and independent analyses have shown that cost-effectiveenergy efficiency improvements could reduce electricity use by 27% to 75% of totalnational service within 10-20 years without impacting the quality of life or manufacturing output. Forinstance, Ray and Subhadarsini (2013) reported that in India, about 66% of the electricityconsumed is generated by thermal power plants and 20.88% by hydroelectric power plants and2.57% by nuclear power plants and 11.2% from renewable energy sources. According to a 2011projection by the International Energy Agency, solar power generators may produce most of theworld’s electricity within the next 50 years, dramatically reducing the emissions of greenhouse gasesthat harm the environment. This shows that energy from renewable would increase appreciably.Energy plays a pivotal role in our daily activities.

For this reason, a country's degree of development and civilization is measured by the energy utilized by its citizenry.Energy demand is increasing daily due to increasing population, urbanization, andindustrialization with its concomitant lifestyle. The world’s fossil fuel supply, e.g., coal,petroleum, and natural gas, will thus be depleted in a few hundred years.

II. Historical overview

The photovoltaic effect was discovered in the first half of the 19th century. In 1839,a young French physicist Alexandre Edmond Becquerel observed a physical phenomenon or product that allowedlight conversion into electricity. The solar cells' work is based on thisprinciple of the photovoltaic effect. In the following years, several scientists have contributed tothe development of this effect and technologies through their research; the most relevantamong them are Charles Fritts, Edward Weston, Nikola Tesla, and Albert Einstein, who was awarded the Nobel Prize for his work on "photoelectric effect" in the year 1904. However, due tohigh production rates, a more significant development of this technology has begun only along with thedevelopment of the semiconductor industry in the late fifties of the 20th century. During the sixties,solar cells were used exclusively for supplying electricity to orbiting satellites on Earth orbit,where they proved themselves as very reliable and competitive technology. In the seventies, therewere improvements in production. The word,, photovoltaic "consists of two words: photo, a Greek word for light, and voltaic,which defines the measurement value by which the activity of the electric field is expressed, i.e.,the difference of potentials. Photovoltaic systems use cells to convert sunlight into electricity.Converting solar energy into electricity in a photovoltaic installation is the most known way of using solar energy.

2.1 Photovoltaic Generation

PV cell technologies are usually classified into three generations, depending on the primary material used (Irena working paper, 2012).
I. Crystalline Silicon
II. Thin Film
III. Concentrated photovoltaic (CPV) and Organic Material

2.2 First-Generation: Crystalline Silicon

Silicon is a semiconductor material illustrated as suitable for PV applications, with an energy bandgap of 1.1 eV. Crystalline silicon is commonly used in the PV industry wafer-based C-Si PV cells and modules dominate the current market. Crystalline silicon cells are classified into three types:
I. Mono-crystalline (Mono c-Si).
II. Poly-crystalline (Poly c-Si) or multi-crystalline (mc-Si).
III. Ribbon silicon

Commercial production of C-Si modules began in 1963 when Sharp Corporation of Japan started.
Producing commercial PV modules and installing a 242 W PV module on a lighthousewas the world's largest commercial PV installation (Green, M. A, 2001). Crystalline silicontechnologies accounted for about 87% of global PV sales in 2010 (Schott Solar., 2010). Theefficiency of crystalline silicon modules ranges from 14% to 19%. At the same time,mature technologycontinued cost reductions through improvements in materials and manufacturing processes. If themarket continues to grow, enabling several high-volume manufacturers to emerge (B. Mills,Internet., 2007).

2.2.1 Mono-Crystalline silicon

As shown in Fig. 1, monocrystalline silicon cells have the highest efficiency of thethree most common technologies, up to 20%.

2.3 Solar Photovoltaic Electricity

Solar PV electricity is an essential consideration as renewable energy since it has a widerange of end-use applications from utilities to residential rooftops (Energy TechnologyRoadmaps., 2009) and is distributed amongst the major countries of the world (Global MarketOutlook for Photovoltaics., 2010). It is expected to generate 11% of global electricity by 2050 (Energy Technology Roadmaps., 2009).

Figure 1: Worldwide Distribution of PV Electricity (Global Market Outlook for Photovoltaics., 2010)

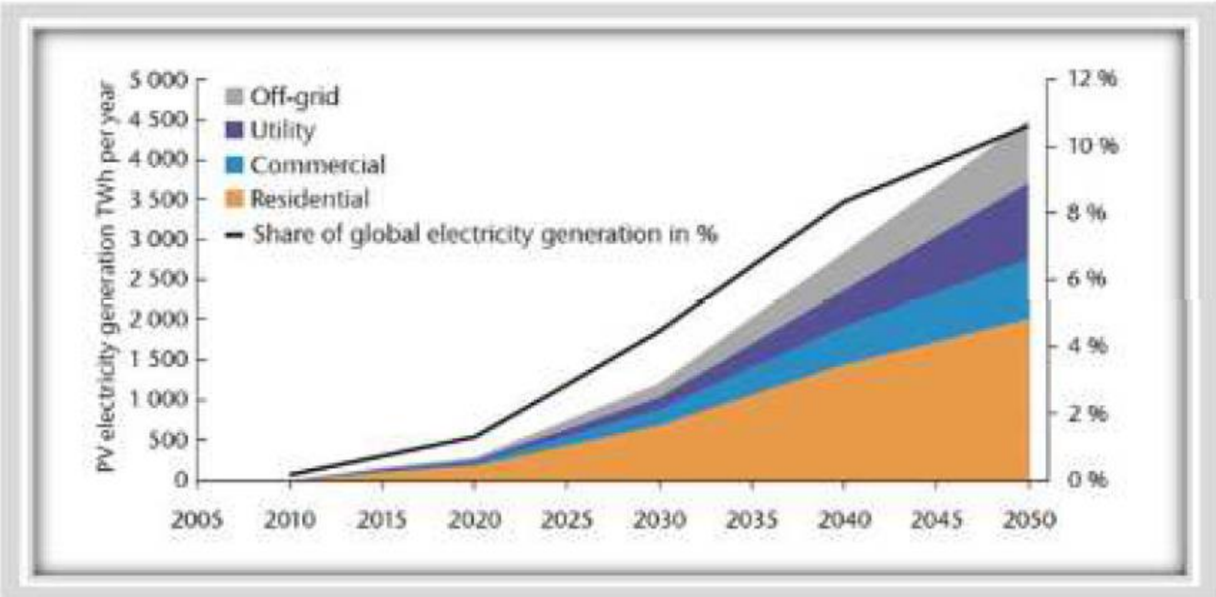

Figure 2: Global Solar PV Electricity Production by End-Use Sector 2010-2050 (Energy Technology Roadmaps., 2009)

III. Photovoltaic system

A photovoltaic (PV) system is a solid-state semiconductor device that generates electricitywhen exposed to sunlight.

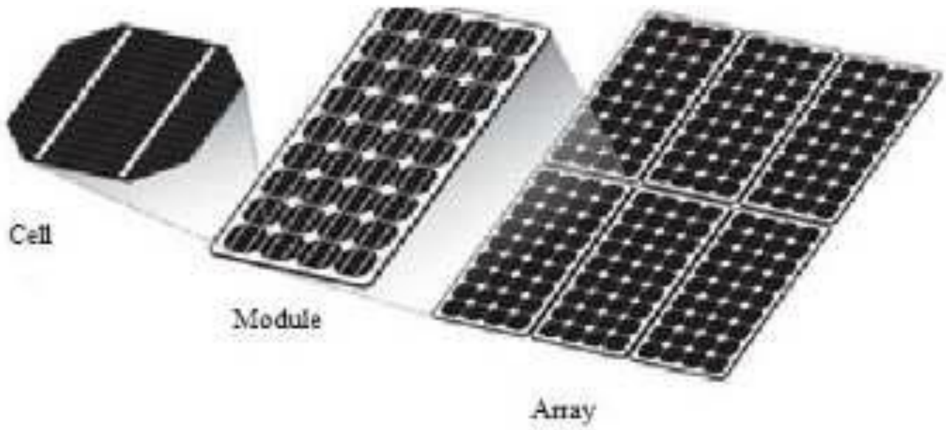

Figure 3*: *PV Cell, Module, and Array.

A typical cell is shown in Figure 3. A photovoltaic module is formed by connecting many solarcells in series and parallel. PV modules are connected in series to get the maximum output voltageand to obtain the maximum output current, and they are connected in parallel. The major challengein using PV power generation systems is to tackle the nonlinear characteristics ofPV arrays. The PV characteristics depend on the level of irradiance and temperature.

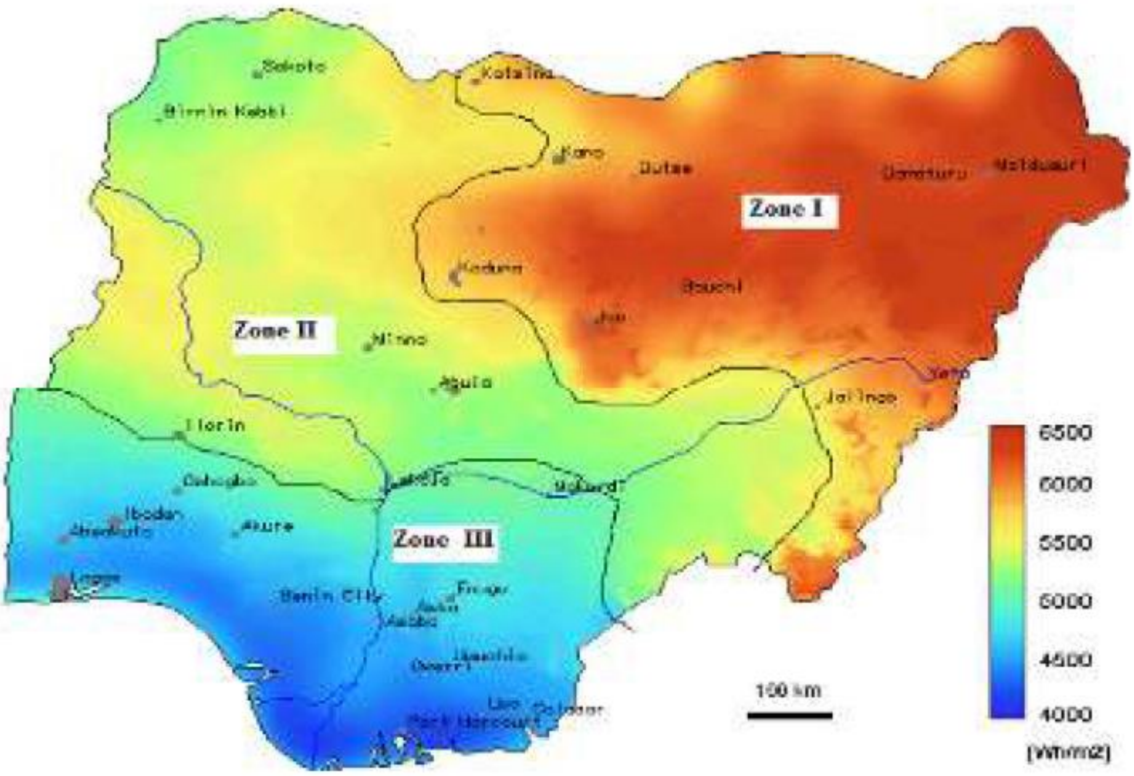

Fig. 4. Solar radiation map of Nigeria (Huldet al., 2005)

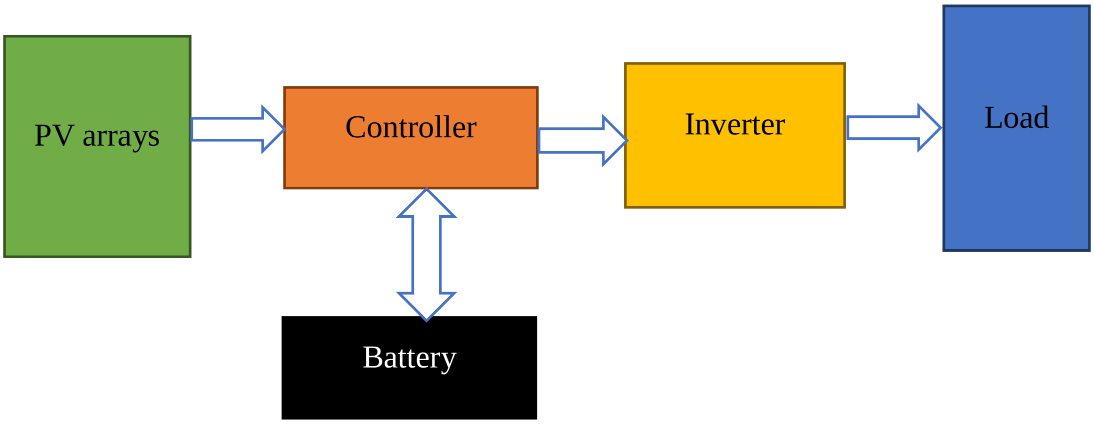

Figure 5: Block diagram of a PV system.

A solar panel is an electrically connected solar photovoltaic module mounted on asupporting structure. A photovoltaic module is a packaged, connected assembly of solar cells. A solar Cell is a device that converts light into electric current using the photoelectric effect.A solar cell isa p-n junction fabricated in a thin semiconductor wafer. Theelectromagnetic radiation of solar energy can be directly converted to electricity through the photovoltaic effect. Being exposed to sunlight, photons with energy more significant than the bandgapenergy of the semiconductor create some electron-hole pairs proportional to the incidentirradiation equivalent circuit of a PV cell, shown in Figure 5.

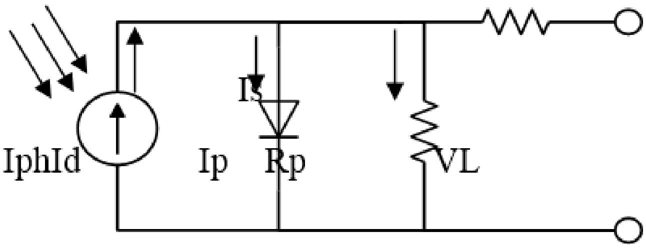

Figure 6: Equivalent Circuit of a Solar Cell

$$Iph - Id - Ip - Il = 0 \Rightarrow Il = Iph - Id - Ip \quad \ldots (1)$$

$$(Vd = Vp) = Vs + Vp \Rightarrow Vd = RsIl + Vl \quad \ldots (2)$$

$$Ip = \frac{Vp}{Rp} = \frac{Vd}{Rp} \quad \ldots (3)$$

The diode current can be expressed as follows.

$$Id = Isat\left(\exp\frac{Vd}{mNsVt} - 1\right). \quad \ldots (4)$$

Where, $Vt = \frac{KT}{q}$ substitute for V_T into Equation (5)

$$Id = Isat\left(\exp\frac{qVd}{mNsKT} - 1\right) \quad \ldots (5)$$

By substituting equations (4) and (6) in equation (2), we have

$$IL = Iph - Isat\left(\exp\frac{qVd}{mNsKT} - 1\right) - \frac{RsIL + VL}{Rp} \quad \ldots (6)$$

I_{Ph}, I_D, I_P, and $I_{sat}$are the PV cell's photocurrent, the diode current, the shunt current, and the reverse saturation current of the solar module, respectively. *Ns* is the number of cells connected in series, VT is the thermal voltage, and *m* is the ideal factor of the diode (1-5(*VT*)). *K* is the Boltzmann constant (1.381×10-23 J/K), and *q* is the electron's charge (1.6021×10-19C). R_S and R_P are the solar module's equivalent series and parallel resistance.

$$Iph = [Isc + \alpha i(T-25)]\frac{G}{Gref} \quad \dots (7)$$

I_{Ph} is the photocurrent at nominal PV standard test conditions (STC) (normally 25°C and 1000W/m^2) for temperature and irradiation. *I*sc is tiny, short-circuit current of the module. *G* and $G_{ref}$are the amounts of actual and nominal irradiation, respectively. *T* is the temperature in Kelvin (K), and $\alpha i$is the current temperature coefficient. The $I_{sat}$and I_{sc}can be obtained according to the following equations:

$$Isc = Isc, ref\left(\frac{Rs+Rp}{Rp}\right). \quad \dots (8)$$

$$Isat = \frac{Isc, ref + (T-25)}{\exp\frac{q(Voc, ref + \alpha v(T-25))}{NsmKT} - 1} \quad \dots$$

(9)

The $I_{sc,\ ref,}$ and $V_{oc,\ the\ ref}$is the module's short circuit current and open circuit voltage at STC, whereas $\alpha_v$is the open circuit voltage temperature coefficient. Usually, these values are evaluated by the manufacturer. The output voltage and current of the module will be as follow:

$$IL = [Isc + \alpha i(T-25)]\frac{G}{Gref} - Isat\left(\exp\frac{qVd}{mNsKT} - 1\right) - \frac{ILRs+VL}{Rp} \dots (10)$$

3.2.1 Working principle of solar cells.

A typical silicon PV cell comprises a thin wafer of ultra-thinphosphorus-doped (N-type) silicon on top of a thicker layer of boron-doped (P-type) silicon.Anelectrical field is created near the top surface of the cell where these two materials are in contact,called the P-N junction. When sunlight strikes the surface of a PV cell, this electrical fieldprovides momentum and direction to light-stimulated electrons, resulting in a flow of currentwhen the solar cell is connected to an electrical load.

3.3 Types of PV Systems

PV systems can be elementary, consisting of just a PV module and load, as in the directpowering of a water pump motor, which only needs to operate when the sun shines. However,when a whole house should be powered, the system must be working day andnight. It also may have to feed both AC and DC loads, have reserve power, and even includea backup generator. Depending on the system configuration, we can distinguish three maintypes of PV systems: stand-alone, grid-connected, and hybrid. The basic PV system principlesand elements remain the same. Systems are adapted to meet requirements by varyingthe type and quantity of the essential elements. Depending on the system configuration, we candistinguish three main types of PV systems: stand-alone, grid-connected, and hybrid. The basicPV system principles and elements remain the same. Systems are adapted to meet requirements by varying the type and quantity of the essential elements.

3.4 Status of solar energy development in Nigeria

For decades, solar thermal has constantly been enjoying very high-level utilization by ruraldwellers for agricultural processing purposes, including drying of agricultural products such as
grains, cassava (tuber so marsh), yam flakes, meat, fish, fruits, kernels, drying of manure, hide and skins, cooking and frying of agricultural products which are not preserved or sold raw.Other areas of solar energy utilization include heating and lighting animal pens, water and irrigation pumping, and food and vaccine storage (Yohanna and Umogbai., 2010). In addition, solar energy has also found wide usage in Nigeria, viz: solar street lightings, solarrefrigerators, solar cookers, solar-powered water pumps, etc.; different applications exist in theform of solar thermal and solar PV.

3.4.1 Existing Nigerian solar energy targets and Policies

Nigerian solar energy targets are basically for electricity generation. Tables 1 and 2 summarize.
Solar targets in the electricity sectors. Nigeria aims to produce 9.74%, 18%, and 20% of itselectricity from renewables by 2015, 2020, and 2030, respectively. As a result, solar energy isexpected to produce 1.26%, 6.92%, and 15.27% of the electricity consumed in Nigeria by 2015,2020, and 2030, respectively.

Table 1 Nigeria solar energy electricity target summary (Dioha&Emodi, 2019)

Licensee	Capacity (MW)	State	Geopolitical Zone
Quaint Global Nigeria Limited	50	Kaduna	North-West
Nigeria Solar Capital Partners	100	Bauchi	North-East
AnjeedKafanchan Solar Limited	10	Kaduna	North-West
Lloyd and Baxter LP	50	Abuja	North-Central
KVK Power Pvt Limited	50	Sokoto	North-West
Pan-African Solar	54	Katsina	North-West

Table 2 Nigeria solar energy application future target summary (Dioha&Emodi, 2019)

Activity/Item	2015	2020	2030
Solar PV home systems (SHS)	5	10	15
Solar PV water pumping	50	1000	5,000
Solar PV community services	45	500	3,000
Solar PV refrigerator	20	500	2,000
Solar PV Street and traffic lighting	100	1000	10,000
Solar PV large-scale PV plants (1 MW capacity)	80	990	9990
Solar thermal electricity (1 MW capacity)	300	2136	18127

3.3.1 Stand-alone systems

Stand-alone systems depend on solar power only. These systems can consist of PV modulesand a load only, or they can include batteries for energy storage. When using batteries, chargeregulators are included, which switch off the PV modules when batteries are fully charged andmay switch off the load to prevent the batteries from being discharged below a specific limit. Thebatteries must have enough capacity to store the energy produced during the day to be used at night and during periods of poor weather. Figure 5 shows schematic examples of stand-alonesystems; (a) a simple DC PV system without a battery and (b) an extensive PV system with both DCand AC loads.

3.3.2 Grid-connected systems

Grid-connected PV systems have become increasingly popular for building integratedapplications. As illustrated in Fig. 7. They are connected to the grid via inverters, which convertthe DC power into AC electricity. In small systems installed in residential homes, theinverter is connected to the distribution board, where the PV-generated power is transferred to the house's electricity grid or AC appliances. These systems do not require batteriessince they are connected to the grid, which acts as a buffer intransporting an oversupply of PV electricity. At the same time, the grid also supplies the house with electricity in times ofinsufficient PV power generation. Large PV fields act as power stations from which all thegenerated PV electricity is directly transported to the rid. They can reach peakpowers of up to several hundred MWp.

3.3.3 Hybrid systems

Hybrid systems consist of a combination of PV modules and a complementary method ofelectricity generation, such as a diesel, gas, or wind generator. A schematic of a hybrid system is shown in Figure 8. To optimize the different methods of electricity generation, hybridsystems typically require more sophisticated controls than stand-alone or grid-connected PVsystems. For example, in the case of a PV/diesel system, the diesel engine must be started when the battery reaches a given discharge level and stops again when the battery reaches an adequatestate of charge. The backup generator can only recharge batteries or supply the load.

Figure 7: Hybrid systems (GehrlicherSolar., 2010)

3.4 Inverter

The Inverter is an electrical device that converts direct current (DC) to alternate current (AC). The inverteris used for emergency backup power in a home. AC power is used mainly for electrical devices thatconsume AC energy, like lights, radars, radios, motors, and other devices.

3.5 Maximum PowerPoint Tracker

To achieve sound solar isolation, irrespective of the intermittent nature of solarenergy, tracking the best available power is imperative. This can be achieved using paneltracking and soft tracking. The panel tracking device involves the physical movement of the PVarray through the East-West trajectory from sunrise to sunsetto maximize solarrenewable energy. In soft tracking, there is no need for any physical hardware to extract theavailable solar energy during the sun hours. Instead, it is accomplished using software that tracks the panel's maximum power point.

Challenges of Solar Energy in Nigeria

- Variability and intermittency of radiation
- Lack of awareness and information
- Government policy and incentives
- Insecurity of solar plant infrastructure
- Competition with land uses

Counter Measures

- Favorable government policy
- Consistent awareness creation
- Cost reduction measures
- Mitigate political and regulatory investment risk.
- Establish and enforce quality standards for solar energy equipment.

Advantages of a PV System

Photovoltaic systems have several merits and unique advantages over conventional power generation technologies. PV systems can be designed for various applications andoperational requirements and used for centralized or distributed power generation.PV systems have no moving parts, are modular, easily expandable, and even transportable insome cases. Energy independence and environmental compatibility are two attractive features ofPV systems. The fuel (sunlight) is free, and operating PV systems create no noise or pollutionin general; PV systems that are well-designed and adequately installed require minimal.Maintenance and have long service lifetimes.

Disadvantages of a PV System

The high cost of PV modules and equipment (compared to conventional energysources) is the primary limiting factor for the technology. Consequently, the economic value ofPV systems has been realized over many years. In some cases, the surface area requirements for PVarrays may be a limiting factor. Due to the diffuse nature of sunlight and the existing sunlight-to-electrical energy conversion efficiencies of photovoltaic devices, surface area requirements forPV array installations are 8 to 12 m^2 (86 to 129 ft^2) per kilowatt of installedpeak array capacity.

IV. Conclusion

Nigeria is endowed with solar and other renewable energy resources that can contribute significantly to the country's residential and industrial energy needs. This study reviews the renewable energy potential in Nigeria and gives an overview of the past, present, and future of solar energy in Nigeria. Solar, biomass, and hydroelectric power have the most significant potential, while wind and geothermal energy potential are only available in some parts of the country. It also reveals the appropriateness of generating electric power using renewable solar energy. PV systems contain modules, inverters, converters, energy storage, and electrical and mechanical equipment to generate AC and DC power. Generally, PV systems are classified into three types: grid-connected PV systems, stand-alone PV systems, and hybrid PV systems. Designing and sizing PV systems is the most crucial stage in a PV project. The most common failures affecting PV system performance are junction box failures, bypass diode failures, and broken glasses. Inverter problems can be classified into manufacturing, design, control, and electrical component failures.

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