International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

A Review of the Impact of Distributed Generation from Solar Energy on the Nigeria Power Distribution Grid.

Inyama Kelechi[1], Onojo, James O[2], Okozi, Samuel O[3]., Joe-Uzuegbu Chijioke K[4].

[1]Electrical and Electronic Engineering Department, Abia State University, Uturu, Nigeria.

[2,3,4]Electrical and Electronic Engineering Department, Federal University of Technology, Owerri, Nigeria.

kcinyama@gmail.com

DOI: https://doi.org/10.55248/gengpi.4.1123.113016

ABSTRACT

The trend towards Distributed Generation (DG) sources has been determined by the dramatically rising power consumption and the ageing of most generating & transmission facilities. DG is still lacking a common definition. The various definitions put out in the literature are discussed in this paper. The DG system must be integrated with the current grid system in order to play a significant role in the current power landscape. In this effort, solar energy sources received more attention. Renewable energy sources now make up a significant portion of the global energy consumption portfolio due to ongoing concerns about climate change. When fossil fuels are replaced by renewable energy technologies in the transportation and power generation sectors, CO_2 emissions could be decreased. Development and promotion of renewable energy supply technologies, as well as demand for renewable energy, are imperative due to certain unfavourable and irreversible externalities associated with conventional energy production. To lower the cost per unit of generation, more power should be produced utilising renewable energy sources. Economic development, population growth, energy prices, climate, and technological advancements are some of the variables that affect energy usage.

Keywords: Renewable energy, Renewable energy sources, Distributed generation, Distribution grid, solar energy

1. INTRODUCTION

Concern over energy security is on the rise in many industrialised and developing nations alike. All people should have access to sufficient, dependable, and reasonably priced electricity, according to Obideyi (2017). An increased degree of energy security is the goal of many nations' energy systems' policies and initiatives on a global scale. The International Renewable Energy Agency (IRENA), 2015 states that this is a response to the need to continuously guarantee energy supply in the face of rising energy demand, rapid energy depletion, and the need to lower the "risk of disruptions and volatility of energy supply and price" associated with conventional sources.

The market for electricity is changing dramatically as it gets closer to becoming a more competitive place. The 'growing pains' of this transformation, which include shifting regulatory regimes, ageing infrastructure, and unstable prices, are prompting energy consumers and electric utilities to reevaluate the advantages of distributed generation (DG) (Pepermans et al 2005).

Utility reorganisations, technological advancements, and new environmental regulations all contribute to the likelihood that distributed generation will become a significant energy source in the near future. Utility restructuring creates energy markets where consumers can select their energy supplier, mode of delivery, and related services. Small, modular power systems that are easily implemented in response to market signals are preferred by market forces.

This reorganisation takes place when:

-Both domestically and internationally, there is an increasing demand for power;

-The cost and performance of small, modular distributed generation technologies have improved significantly.

-Efficiency and environmental performance are now highly valued due to regional and global environmental concerns; and

-Apprehensions about the dependability and calibre of electricity have increased (EIA, 2020).

In general, any technology for producing electricity that is connected into distribution networks near the point of use is referred to as distributed or distributed generation. Medium- or low-voltage grid connections are made to distributed generators. They are usually smaller than 30 MW and are not centrally planned. (Mohammad and others, 2017).

The traditional centralised power production model, in which energy is created in huge power plants and sent to end customers via transmission and distribution lines, is contrasted with the idea of distributed generation (DG) (see figure.1.1). Although central power networks continue to be essential to the world's energy supply, they are not very adaptable to shifting energy demands. Large capital-intensive facilities and a transmission and distribution (T&D) grid are the two main components of central power.

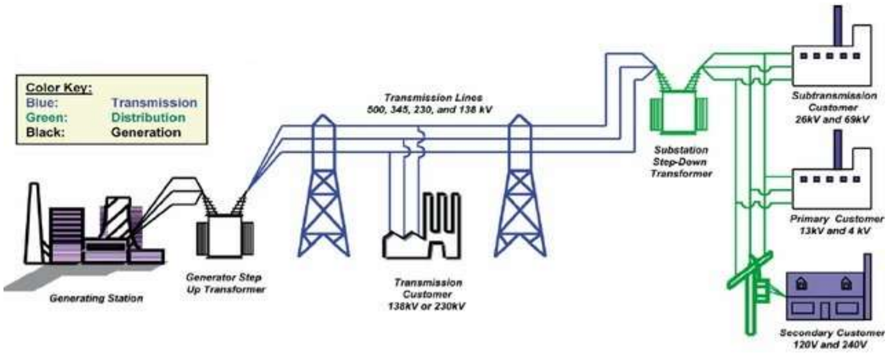
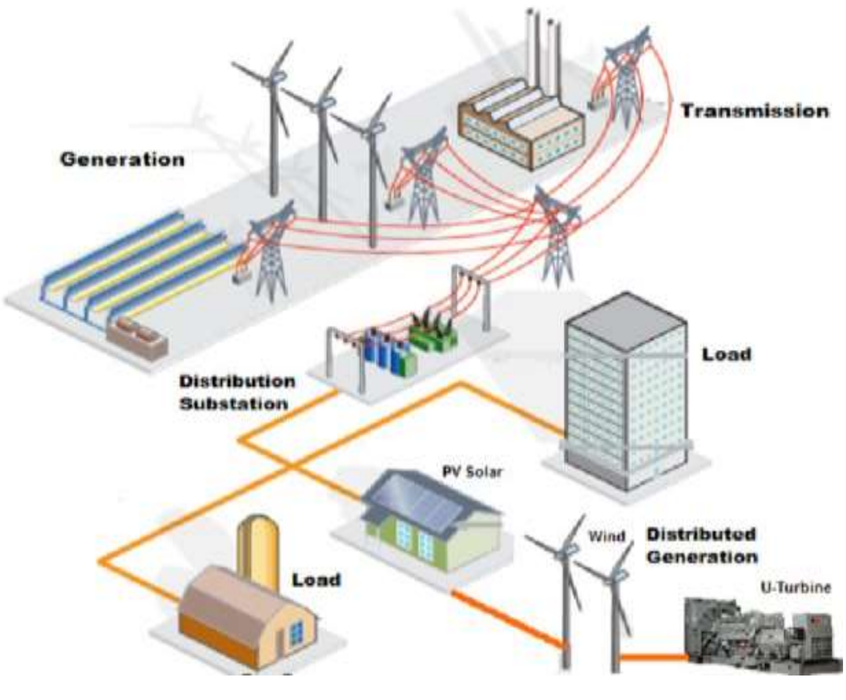


Fig 1.1 An electric power system

A distributed electrical system is one in which lower voltage distribution networks, businesses, residences, and factories are directly connected to tiny and micro generators. Any electricity that is not consumed by the clients who are directly connected is supplied into the active distribution network to satisfy demand in other locations. Any extra generation can be stored using electricity storage systems. Huge power plants and large-scale renewable energy sources, including offshore wind, are linked to the high-voltage transmission network, which guarantees supply quality and provides national backup. Once more, storage can be used to handle various types of generation's varied output. Figure 1.2 below shows a distributed electricity grid of this type.



Source: researchgate.net

Fig 1.2 An Electricity System with distributed generation

Due to its ability to satisfy the industry restructuring goal of market-driven, customer-oriented solutions while increasing system capacity at a reasonable cost, the non-traditional operating model of DG has generated a lot of interest. These dispersed generation systems provide flexible, dependable, clean, and efficient on-site power options. They can run on a variety of petrol fuels. Customers' perceptions of energy are being altered by the growing array of distributed generating options that independent power producers and energy service providers are offering.

Due to a number of issues, Nigeria's power industry has continued to operate poorly and unreliably, similar to that of many other African nations. These difficulties include excessive transmission and distribution losses, undervoltages, overloading transformers, and insufficient generating capacity. Nigerian power has one of the largest cumulative transmission and distribution losses in the world, according to PricewaterhouseCoopers (PwC) (2016), at 19% of generated power. Since there is a growing demand for energy in Nigeria relative to the supply, transmission and distribution networks are overloaded beyond what is acceptable.

One major obstacle to private investment in Nigeria has been the historically low level of investment in the country's power industry (Onyekwena et al., 2017). With generally low power generation, the power system has issues in meeting its ever-increasing power demand. The nation's initiatives to explore electricity generation from renewable energy sources have been sparked by the growing worry over supply security. It is anticipated that the combined goals of energy supply security and emission reduction will be realised with the advent of renewable energy sources.

The quality and dependability of power supply at different load sites are the final issues that Independent Power Producers (IPPs) and consumers have to worry about. An increased deformation in current and voltage waveform known as harmonics is caused by the widespread use of power electronics in a distributed technology network, such as grid-tied inverters, variable speed drives, computerised processing lines PCs, Uninterruptible Power Supply (UPS), and non-linear electronic devices in power systems (Justus & Arumugam., 2005). Devices that inject harmonic current place a significant load on the power system grid, leading to harmonic voltage distortion. These circumstances can lead to the overheating of motors and transformers, as well as the unreliability of sensitive electronic equipment. Non-linear loads can result in voltage harmonics, which pose a major risk to the power system network's power quality.

Little modular generating sources with capacities ranging from kilowatts to a few megawatts are known as distributed (embedded) generation (DG) schemes. Willem, Bernard, and Munyaradzi (2021) define distributed generation (DG) as small power plants at or near loads that are connected to a grid at the distribution or sub-transmission level. These power plants are typically kilowatts up to 10 MW. By lowering technical losses, enhancing voltage profile, and improving power quality, distributed generation (DG) can make distribution systems more dependable. It avoids the need to invest in the transmission and distribution infrastructure when placed properly, saving money. Additionally, it lessens the requirement for interdependencies, complexity, and inefficiencies in the distribution and transmission processes. 2018 saw Idoniboyeobu and Udoha.

Out of the 206 million people living in Nigeria, only roughly 55.4% have access to electricity through the country's traditional power generation infrastructure, also known as the national grid (World Bank data, 2020). This suggests that 44.6% of the people living there do not have access to power. But the 55.4% of the population that has access to energy does not have the capacity to meet the country's current power needs (NERC, 2021). The nation has serious electricity issues, which have impeded its ability to grow economically. The TCN has poor network and grid coverage throughout the nation, as well as an infrastructure shortfall that occasionally causes system collapses (the first one of this year occurred on January 17, 2022). (Business day magazine, 2022). Additionally, the inability of the GENCOs to deploy the available capacity of the energy they produce and the vandalism of transmission lines are factors that contribute to Nigerians' poor quality of energy service delivery.

The overall issue of insufficient network coverage and a lack of infrastructure in the various zones in which the DISCOs hold monopolies is also shared by them. As a result, the distribution business has had to continuously reduce demand in order to make up for inadequate electrical supply and line losses. In order to produce the required amount of power, the majority of Nigerian homes and businesses currently own one kind or another of fossil fuel-powered energy producing facility. Most power plants' incomplete fuel combustion results in the release of toxic gases that are extremely dangerous to human health.

Renewable energy sources, such as wind and solar power, offer environmentally responsible and sustainable power generation options. When these sources are connected at the distribution level, DISCOs can enhance their ability to provide customers with power that is not reliant on the national grid. But there are certain economic and technical issues that need to be fixed. Harmonic currents are produced at the Point of Common Coupling (PCC) by non-linear loads and the widespread usage of equipment based on power electronics, which could lower the quality of the power. Elevated harmonic distortions can lead to decreased efficiency, shortened component lifespans, and potentially equipment damage (Lumbreras et al., 2020). Thus, the current study examines distributed generation using renewable energy with a focus on solar energy.

2. OVERVIEW

Historically, economies of scale—using generating units as large as possible to reduce the cost per unit of output—have propelled electricity generation in the regulated environment. This trend has reversed recently, and interest in decentralised power generation has increased for a number of reasons. The market for distributed generation is anticipated to be driven by factors like rising environmental consciousness, more stringent government regulations and targets for reducing greenhouse gas emissions, and increased energy demand. (Research Grand View, 2020)

This chapter's goal is to provide a list of relevant works, KPIs, and subjects for comprehending how distributed solar energy generation affects power system distribution.

3. DISTRIBUTED GENERATION

Utilising small-scale technologies, distributed generation—also referred to as dispersed, embedded, or decentralised generation—produces electricity in close proximity to the final consumers of energy. Small modular solar and wind generators, coal generators, hydro, biomass, and geothermal energy sources, among others, are frequently used to provide small-scale distributed generation. The classification of a few of the distributed renewable generators now in use for power generation worldwide is shown in Figure 3.1.

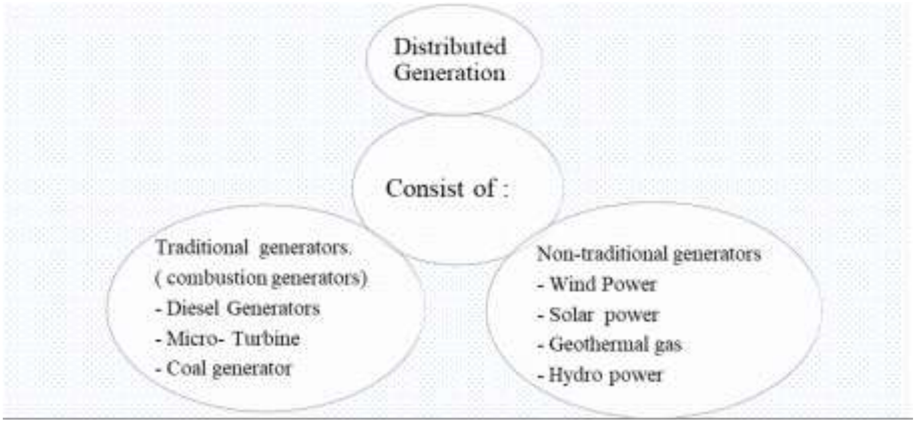


Figure 3.1 Distributed generation classifications

Conversely, Figure 3.2 depicts a more straightforward integration of the grid's current distributed power generation.

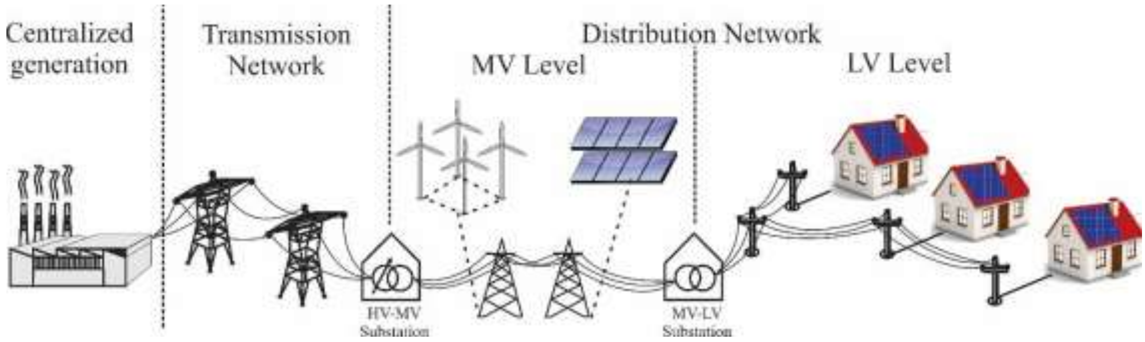


Fig 3.2 The most grid-connected simplified diagram of distributed generation technology (DG) (Freris & Infield, 2008)

An electric power source that is directly connected to the distribution network or to the meter's customer site is known as distributed generation (Bollen & Hassan, 2011). Since the maximum rating is dependent on the local distribution network parameters, such as voltage level, the definition of distributed generation does not determine the rating of the generation source. Introducing categories with varying distributed generation scores is helpful. The table below displays the various categories:

Table 3.1: Distributed generation capacities (El-Khattam & Salama, 2004; Chen J et al., 2022)

Class	**Power Range**
Micro distributed generation	1W – 5kW
Small distributed generation	5kW – 5MW
Medium distributed generation	5MW – 50MW
Large distributed generation	50MW – 300MW

4. TECHNOLOGIES AND APPLICATIONS FOR DISTRIBUTED GENERATION

4.1 Utilising DG

Certain clients currently get all or part of their electricity via distributed generation (DG). The applications for DG technology are numerous and varied. Customers can utilise distributed generation (DG) to supply primary power or lower environmental emissions; some use it to offset demand charges levied by their electric utility. Electric utilities can also use distributed generation (DG) to improve their distribution networks. There are numerous additional uses for DG solutions. A list of those that might be of interest to electric utilities and their clients is provided below.

Constant Power: To enable a facility to generate some or all of its power on a nearly constant basis, the DG technology is used in this application for at least 6,000 hours annually. Significant

DG features for constant power consist of:

-Exceptional energy efficiency,

- Minimal variable upkeep expenses

-Minimal emissions

Nowadays, continuous-power DG is mostly used in industrial applications like food processing, plastics, rubber, metals, and chemical manufacturing. Although it makes up a smaller portion of all industrial usage, the commercial sector comprises industries like pharmacies and grocery stores.

Combined Heat and Power (CHP): Also known as cogeneration or cooling, heating, and power, this distributed generation technology enables a facility to produce all of its own electricity by operating for at least 6,000 hours annually. Steam production, water heating, space heating, and other thermal requirements are met in part by the DG waste heat. This thermal energy can occasionally also be utilised to run specialised cooling machinery. Among the crucial DG attributes for combined heat and power are:

-High thermal output that may be used, which results in high efficiency overall,

- Minimal variable upkeep expenses

-Minimal emissions

Although the high heat demand in this case is not required for Continuous Power applications, CHP characteristics are similar to those of Continuous Power, leading to nearly identical customer profiles in both applications. Similar to continuous power, the majority of CHP installations are in the commercial sector, with industry clients being the primary users.

Peaking Power: To lower annual electricity expenses, distributed generation (DG) is used for 200–3000 hours per year. By balancing site demand, units can be used to delay purchasing electricity at times of high price, reduce demand charges from the utility, or secure reduced rates from power providers. Among the crucial DG properties for peaking power are:

- Minimal install costs

- Fast startup

- Minimal set upkeep expenses

Energy firms can offer peaking power applications to customers that wish to lower their electricity purchase costs during periods of high prices. Due to the very flat load profiles in the industrial sector, DG peaking units are now largely utilised in the commercial sector. Applications in educational institutions, hotels, various retail locations, and certain industrial facilities with peaky load characteristics are the most prevalent.

Green Power: By using DG units to generate its own power, a facility can lower the pollution it releases into the atmosphere. Among the crucial DG attributes for green electricity applications are:

-Minimal emissions

-Superior efficacy

- Minimal variable upkeep expenses

Energy providers could potentially use green power to provide consumers who prefer to buy power produced with minimal emissions.

Premium Power: Distributed generation (DG) is utilised to supply power with greater dependability and/or quality than what is generally supplied by the grid. The expanding market for premium power offers utilities the chance to offer their customers a value-added service. Because customers usually want continuous power for multiple uses, premium power is further divided into three categories:

Emergency Power System: In the event that the primary power source fails, this stand-alone system will automatically supply electricity within a predetermined window of time. The system provides power to vital equipment, the failure of which could endanger public health and safety or cause property damage. A wide range of public meeting places, hotels, schools, and commercial, business, and apartment buildings are among the customers.

Standby Power System: In the event that the primary power supply fails, this standby system supplies electricity to keep the customer's complete facility running smoothly. For customers including airports, police and fire departments, military installations, jails, water supply and sewage treatment facilities, natural gas transmission and distribution networks and dairy farms, this kind of system is essential.

True Premium Power System: This system is utilised by customers who require continuous power without any power quality issues, including fluctuations in frequency, voltage transients, dips, and surges. Such power is not available straight from the grid; instead, it needs to be treated by auxiliary power conditioning equipment in addition to emergency or standby power.

As an alternative, the grid can be used as a backup power source and DG technology as the main power source. Mission-critical organisations including airlines, banks, insurance providers, radio stations, hospitals, and assisted living facilities employ this technology.

The following are crucial DG features for premium power (emergency and standby):

- Fast startup

- Minimal install costs

- Minimal set upkeep expenses

Delay in Transmission and Distribution: Occasionally, positioning distributed generation units (DG) in key places can aid in delaying the acquisition of new transmission and distribution infrastructure, including substations and distribution lines. It is imperative to do a thorough examination of the life-cycle costs associated with the different options and to closely monitor the matters surrounding equipment deferrals.

The following are crucial DG properties for distribution and transmission postponement (when utilised as a "peak deferral"):

- Minimal install costs

- Minimal set upkeep expenses

Electric utilities employ distributed generation (DG) to supply ancillary services, which are interrelated operations required to influence the transfer of power between the buyer and seller, at the transmission or distribution level. DG applications provide advantages over currently used technology in places where the electric industry has been deregulated and ancillary services have been unbundled (such as the United Kingdom, for example). Ancillary services include non-spinning, or supplemental, reserves (operating reserve is not connected to the system but is capable of serving demand within a specific time or interruptible demand that can be removed from the system within a specified time) and spinning reserves (unloaded generation, which is synchronised and ready to serve additional demand). Other possible services include distribution level local area security, which offers backup power to end customers in the event of a system failure, and transmission market reactive supply and voltage management, which employs generating facilities to maintain a proper transmission line voltage. Depending on the services provided and the final structure of the auxiliary service market, many factors may have an impact on the adoption of DG technologies for ancillary service applications (Resource Dynamics Corporation, 2001; National Renewable Energy Laboratory, 2002). Figure 4.1 provides an overview of the various types of applications for DG.

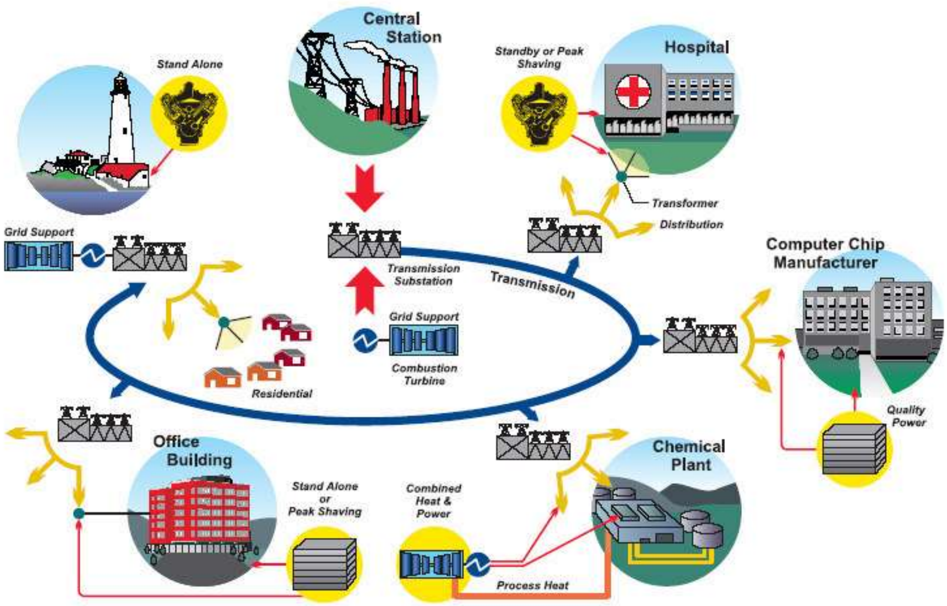


Fig 4.1. Summary of DG applications (EPA, 2022)

4.2. DG Technologies.

Reciprocating engines: This direct-drive technology was created over a century ago and is currently in high demand for a wide range of uses. The engines are sized from less than five and more than

5,000 kW, and their fuel source is either waste gas, natural gas, or diesel. The goals of development continue to be lowering pollution levels and increasing efficiency. Reciprocating engines are mostly employed in cogeneration applications, backup power, and peaking power applications.

Microturbines: Currently only offered by a select few manufacturers, microturbines are a novel and developing technology. Other manufacturers with versions ranging from 30 to 200 kW are attempting to break into this growing market. Microturbines are very pricey at the moment, however they promise minimal emission levels. For manufacturers, securing fair prices and proving dependability would be significant challenges. Since microturbines are relatively new to the market, the majority of installations are done so to test the technology.

Industrial combustion turbines: These well-established technologies come in a variety of powers, from 1 MW to more than 5 MW. In addition to having low emissions and low construction costs, they typically have low electric efficiency ratings. The goal of development work is to make this readily accessible technology more efficient. The main uses for industrial combustion turbines are cogeneration and peaking electricity.

Solar panels, also referred to as photovoltaic (PV) panels, are widely accessible for usage in both residential and commercial settings. Panels can be combined to create systems of any size, with units starting at less than 5 kW. They require little upkeep and emit no pollution.

They can, however, be very expensive. The current economic constraints to the widespread deployment of PV systems must be removed with the help of less costly components and improvements in the production process. At the moment, photovoltaics are mostly utilised to create green power and in isolated areas without grid connections.

Fuel cells: These devices have extremely low pollution levels in addition to being incredibly efficient. Just like a battery, a fuel cell functions. By electrochemically mixing hydrogen and oxygen without burning, it generates electricity. But in contrast to a battery, which needs to be recharged or eventually run out of energy, a fuel cell is continuously supplied with fuel and an oxidant to generate electricity. The electrochemical reaction produces heat and energy without a flame, resulting in clean water as the end product ("cold combustion"). Since a single fuel cell only produces less than one volt, multiple fuel cells are typically "stacked" on top of one another to maximise power output. An electrolyte separates the two electrodes of a simple fuel cell. Fuel (such as hydrogen or natural gas) is given to one electrode (the anode). Air is only pumped into the cathode, the second electrode, to supply it with oxygen. The few fuel cells in use today offer superior power. Fuel cells are available in various varieties. These days, the most widely available type of fuel cells on the market are proton exchange membrane ones. They offer the highest energy density per volume rate, and since the automotive sector is adapting them for use in transportation, their prices are anticipated to drop quickly.

Wind turbine systems: There are numerous manufacturers currently offering wind turbines, which vary in size from less than 5 to more than 1,000 kW. They offer a reasonably priced (in comparison to other renewables) method of producing electricity, but they are not suited for continuous power needs because they depend on the erratic and unpredictable wind. The goal of this work is to combine battery storage devices with wind turbines to supply electricity while the turbine is not in use. Energy firms and isolated areas without grid access are the main users of wind turbines for renewable energy.

5. RENEWABLE GENERATION

Renewable Energy Sources (RES) offer environmentally beneficial and sustainable power generation options, such as wind and solar power. The increased use of renewable energy sources (RESs) is a result of the growing global energy demand and the depletion of fossil fuel supplies. The growing environmental impact of energy technologies and the fact that RESs are now mature technologies are other significant factors that have significantly influenced the development of RESs. Using clean and renewable energy resources to shift the paradigm of energy supply is necessary in order to have accessible sustainable energy systems that can eventually replace conventional ones (Edenhofer et al., 2011).

Hydro, wind, and solar energy are examples of renewable energy sources that are excellent, pollution-free, and widely available virtually everywhere in the world. These elements have combined to make renewable energy sources the renewable technology with the quickest rate of growth worldwide (Weedy et al., 2012).

Due to their special advantages—such as the presence of fuel cells, high reliability, ease of allocation, low maintenance, and lack of noise and wear due to the absence of moving parts—photovoltaic (PV) and wind generation are currently playing a significant role in Nigeria as renewable generation sources applications (Obar et al., 2021).

The most significant use of today is the integration of renewable generation resources into the power system grid, surpassing traditional centralised dispatch generation in interest. The numerous advantages of employing RES in distributed generation (DG) power systems are driving this trend (Muruganantham et al., 2017).

5.1 Types of Renewable energy sources

There are two main categories of renewable generation: rotating machine DG and inverter based DG. Since the generated voltage in DG systems can be either DC or AC, inverters are typically employed after the generating process to adjust the voltage and frequency to the nominal values (Gungor et al., 2013). (Jinwei, He & Li, Yunwei Ryan, 2011). As a result, it needs to be rectified to convert it from AC to DC and back to AC with the nominal characteristics. Some of the currently available technologies for renewable generation are covered in the following pages. These include geothermal and renewable generators, wind turbines, hydropower, biomass, and photovoltaic systems/solar power.

Renewable energies are those that come from the sun directly (like thermal, photochemical, and photoelectric energy) or indirectly (like wind, hydropower, and photosynthetic energy stored in biomass) or from other naturally occurring movements and mechanisms of the environment (like geothermal and tidal energy). These energy sources are constantly renewed by nature. Below is a summary of renewable energy sources in Figure 5.1. These renewable energy sources are converted into useable forms of fuel, heat, and electricity through the use of renewable energy technologies. Over the past five years, the markets for renewable energy, including transportation, heating, and electricity, have experienced rapid growth. Rapid advancements in both older technologies, like hydropower, and newer ones, like wind and solar photovoltaic, have led to a boom in technology adoption that has lowered costs and opened up new options.

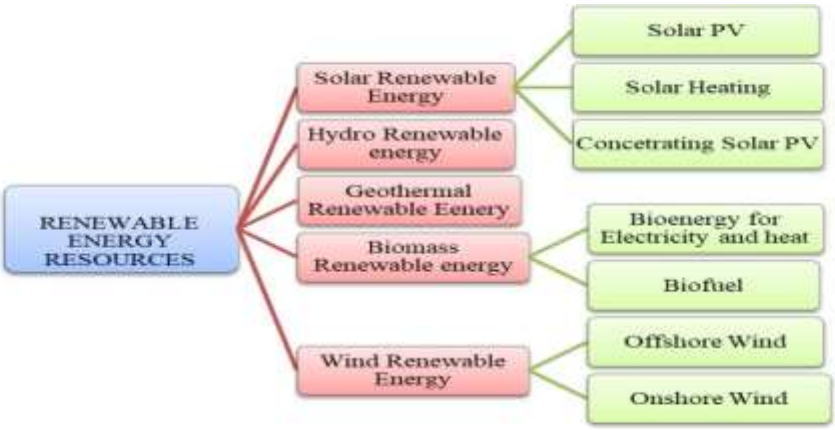


Fig 5.1 Overview of renewable energy sources

5.2. Possibilities for producing renewable energy in Nigeria and Africa

Despite having an abundance of renewable energy resources to cover all of its needs, the African continent's potential is yet unrealized (Fadaeenejad et al., 2014). An opportunity for renewable energy generation on the continent has been provided by growing concerns about carbon emissions and sustainable development.

Hydro power

Using the gravitational pull of falling or flowing water to create power is known as hydro energy. It is the most prevalent renewable energy source that can be found almost anywhere on Earth. It depends on the gravitational potential of high water, which is raised by sunlight from the seas. Most hydropower facilities are located in large dams with strong gravitational pull. There are neither direct nor indirect byproducts from their power generation. It is thought to produce fewer greenhouse gases as an energy source. Roughly 20% of the electricity produced worldwide and 88% of the renewable energy is derived from this power source. As its capacity is dependent on yearly rainfall levels, distribution, and the amount of water entering the river upstream, hydro energy is vulnerable to seasonal droughts. Given that Nigeria's abundance of big rivers and waterfalls has been properly utilised, hydropower may be the most widely used power source for the production and delivery of electricity in the nation. The overall hydropower output of the nation is 14,750 MW, of which 11,250 MW comes from large hydropower and 3,500 MW from small hydropower. Nigeria has a large hydropower potential; from 1999 to 2004, it supplied more than 38.5% of the nation's total electricity power. However, only around 1930 MW—or 14% of the nation's total usable hydropower—have been used, accounting for more than 30% of the installed capacity linked to the grid. There are two significant hydroelectric plants in the nation: the 160 MW Kainji Dam and the 96.4 MW Jebba Dam, which is situated on the River Niger, some 82 km downstream of the former. The rivers Kaduna, Benue, and Cross River have the ability to generate energy as well; together, they might have a capacity of roughly 4650 MW.

By contrast, the Mambillla River has the capacity to produce roughly 2330 MW. Even though the nation generates hydro energy from its major rivers, lesser rivers could also be used to power modest hydro projects.

However, large loans are linked to hydropower projects in the region, resulting in extremely high levels of foreign debt. Large-scale hydro projects are fraught with accusations of corruption since they require substantial sums of money (Kusre et al., 2010).

Wind Power

Wind energy refers to the utilisation of wind as a viable source of energy for power generation. The disparity in temperature at the surface of the Earth determines this. This is frequently the case since the earth's characteristics vary depending on the temperature at which the Sun shines. Typical wind power equipment includes windmills and turbines that produce electricity, as well as drainage pumps and wind turbines for water abstraction. Since the average wind strength of a wind turbine at a given site varies, total energy efficiency cannot be fully achieved by taking that area's wind strength into account. Wind energy has one of the fastest growth rates in the global renewable energy market since it is clean, abundant, inexpensive, renewable, and ecologically beneficial by nature. From 7600 MW in 1997 to 318,117 MW in 2013, the global installed capacity of wind power has steadily grown over the last several years. The 2013 figure is greater than the 263,126 MW in 2011, the 198,001 MW in 2010, and the 158,975 MW in 2009.

Wind energy has promise in Nigeria, where average wind speed is 3.0 m/s across most of the country. Wind speeds vary from 3.88 m/s to 9.39 m/s in the North-West, 1.77 m/s to 4.5 m/s in the South-West, 2.46 m/s to 5.36 m/s in the North-Central, and 3.30 m/s to 4.65 m/s in the South-South. Even if wind energy is viable in Nigeria, the nation's wind power output is still growing because no wind farms are supplying electricity to the national grid. In the nation, small-scale wind turbines have been created and put to use for experimentation, small-scale enterprise electrification, battery charging, and water pumping. With an estimated 10 MW of output capacity, the nation's only large-scale onshore wind turbine is situated in the Rimi Local Government Area in Katsina state. The 5 kW wind energy system erected in Sokoto (Sayyan Gidan Gada) and the 1 kW wind power turbines installed in Bauchi (Kedada) and Katsina (Goronyo) for water pumping are examples of small-scale wind turbines in the nation. Gross energy output is still in its early stages, and wind energy's enormous potential and generation capabilities have not yet been completely realised. Shaaban and Petinrin (2014) claim that the nation has not yet fully explored its wind energy potential, which might raise living standards for all of its residents—especially those who live in rural areas.

However, because wind energy is expensive and unreliable, its development has been sluggish.

Biomass Power

The process of producing electricity from biological materials, chemicals, or organisms, such as trash, wood, and alcohol fuels, is known as biomass energy. Wood chips and dead trees are examples of biomass that can be utilised to produce heat and power. During combustion, this waste frequently turns into fuel. Organic fossil fuels are not included in biomass as an energy source, but they do exist and can be utilised as fuel for cars in a variety of ways. Modern biomass energy sources include electric power plants. There are various ways to convert biomass into electricity. Direct combustion of biomass material, such as wood or farm waste, is the most widely used approach. Other methods include anaerobic digestion, pyrolysis, and gasification. Gasification is a process that creates synthetic gas with a useful energy content from biomass or materials derived from fossil fuels. Typically, less oxygen is used in this process than is needed for the biomass to burn completely. Pyrolysis heats biomass quickly to create bio-oil in the absence of oxygen. Organic debris would be broken down by anaerobic bacteria, producing renewable natural gas in the absence of oxygen. Various techniques for producing heat or power can convert biomass feedstocks into different fuels, such as liquid biofuels or biogas.

Nigeria has an abundance of biomass resources, such as wood, shrubs, and fodder, as well as agricultural waste and byproducts from industrial and municipal processes.

According to Olanrewaju (2019), Nigeria's potential for biomass and bioenergy is projected to be at 200 billion kg/year and 2.58 billion GJ (61.67 Mtoe), respectively. This amounts to around 51% of the nation's total energy consumption in 2015.

Nigeria uses 80 million m3 (4791.7 kg) of fuelwood year for cooking and other household uses, with an energy content of 6.0 x 109 MJ. Currently, just 5% to 12% of this energy content is used for household activities, namely cooking. Between 1989 and 2000, the total energy consumption of primary fuelwood and charcoal was anticipated to be between 32-40%, with a nationwide demand of 39 million tonnes for the year 2000. Ninety-five percent of the fuelwood consumed worldwide came from the cassava processing and household cooking sectors.

A contemporary example of biomass exploitation in the nation, the megawatt-biomass gas turbine facility in Ebonyi State uses plant husks to generate electricity, aiding in the state's rapid development. The mills will receive roughly two megawatts of energy from the five megawatts that will be produced, while the Oferekpe waters will utilise 1.5 megawatts, with the remaining energy flowing to nearby villages. Power pallets are a cutting-edge device that produces renewable energy from garbage, or biomass. These devices, which have the appearance of tiny generators, come in 10kW/25KVA and 20kW/38KVA capacities and can produce power by turning woody biomass into heat and electricity. The country's biomass supply has significantly decreased over time, in part because of the increased demand for wood in the furniture and construction sectors. Forage, grasses, and shrubs may yield an estimated 200 million tonnes of dry biomass, which can be converted into 2.28 x 106 MJ of energy. Due to the fact that most rural residents rely primarily on wood for shelter and fuel for burning, there is an annual loss of about 350,000 hectares of forest and vegetation compared to a significantly lower annual afforestation rate of 50,00 hectares. If this act of continuously felling trees is allowed to continue, it would eventually cause soil erosion and the encroachment of the desert. Fuelwood use needs to be discouraged by the introduction of acceptable and reasonably priced solar stoves in order to solve this issue. It will enable improved combustion and lower the amount of wood used. Additional benefits include shorter cooking times and a well-organized smoke exit channel. Another factor contributing to the nation's declining biomass availability is the shrinkage of land caused by rising sea levels, floods in the south, and droughts in the north. Without a question, biomass is an important renewable energy source, but in sustainable production, it needs to be understood thoroughly. Nigeria should utilise its plentiful biomass resources, including rice, sugar cane husk, oil palms, forests, and city trash, to produce biogas. Sugar manufacturers are able to utilise their waste and leftover cane within their nation. On the other hand, waste biomass can be used by paper mills and packaging plants in Malaysia and South Africa to provide process steam. When this energy is used as liquid fuel for cooking rather than wood fuel, greenhouse gas emissions can be greatly reduced.

Biomass-to-energy facilities face numerous obstacles, in contrast to their advantages. According to Perlack et al. (2005), biomass fuels have poor energy densities and can be prohibitively expensive to acquire and transport.

Solar Power

The definition of solar energy is the utilisation of sunshine to produce power. It is dependent upon the Sun's core's nuclear fusion power. We can get energy from the Sun in two different ways: directly and indirectly. Photovoltaic (PV) technology is used in the natural process, while water is heated and boiled in sunlight to provide power. The concentration of solar energy (CSP) is the name given to the latter technique. sun power is primarily defined as the process of producing electricity by harnessing sun energy. Nevertheless, the Sun is the main source of all renewable energy sources, with the exception of geothermal and tidal energy. Nigeria is a country of roughly 924 km^, with an average yearly incident solar energy of 1831.06 kWh and an average irradiance per unit area of 5.535 KWh/m2. The extreme north of the nation experiences nine hours of sunshine every day, while the southern region experiences only 3.5 hours. The government receives around 4.85 x 1012 kW/h (3.8 x 1023 kW/s) of solar energy each day with an average of 6 hours of sunlight per day. This is equal to the energy produced by roughly 1.082 million tonnes of oil per day.

These figures demonstrate that a sizable quantity of energy can be produced and used from the enormous solar radiation accessible to counteract the epileptic energy supply, which results in the absence of economic growth. In Nigeria, there are several ways to take advantage of solar energy. One such method is to use solar photovoltaic cells for electrifying rural areas. Other devices that can use solar energy include heaters, water pumps, cookers, and crop dryers. In Nigeria, the use of solar energy is increasing, particularly for irrigation, refrigeration, water pumping, street lighting, rural electricity, showering communication stations, etc. For instance, the National Agency for Science and Engineering Infrastructure (NASENI) has established a fully functional solar PV manufacturing factory with an annual power generation capacity of 7.5 MW in the outskirts of Abuja. The plant's capacity will be upgraded (Business Day magazine, 2023). In order to support renewable energy and the expansion of micro, small, and medium-sized businesses, the government of Delta state signed a Memorandum of Understanding with Yutal Li Nigeria Limited in 2016 to build a 100 MW solar power plant (Independent Magazine, 2018).

6. PHOTOVOLTAIC SYSTEM (PV)

An electric energy source is created from solar light using a photovoltaic system. In this technology, solar cells made of semi-conductive materials are utilised to convert photons' self-contained energy into electricity when the cells are exposed to sunlight. To produce the most power, the cells are arranged in a moving or fixed array that continuously tracks the sun. These systems produce no emissions, making them environmentally friendly. With the exception of solar light, they are simple to operate and require no additional fuel. However, they require huge locations and a substantial initial investment (Houda and Rachid, 2021).

Photovoltaic modules and photovoltaic inverters, along with the necessary installation and protection gear, are the essential parts of PV systems. Solar energy is converted into DC current by photovoltaic modules, and the generated energy is then adjusted by a photovoltaic inverter so that it may be fed into the public grid. Protection and measurement devices supply the AC voltage to the electrical grid. Although there are inverters for outdoor installation, where they must not be exposed to direct sunlight, photovoltaic inverters are typically found indoors. Inverters are appropriate for a network-connected photovoltaic system because they generate high-quality AC current at the appropriate voltage.

Africa is home to numerous large-scale solar power installations, including ones in South Africa and numerous other African nations. The greatest potential for solar power technology in Africa may lie in its ability to provide power on a smaller scale, which can then be utilised to help with daily needs like small-scale electrification, desalination, water pumping, and water purification. Solar power technology can supply energy to large populations and has been used to generate power on a large scale in developed nations.

6.1 PV Systems Connected to the Grid

Grid-connected photovoltaic systems are typically deployed to improve the voltage profile of the network and lower power losses inside the electric grid. This isn't always the case, though, as these systems may have a number of detrimental effects on the network, particularly if they have a high penetration level (Estifanos et al., 2021).

Three broad categories of PV system setups that are connected to the grid have been established:

-A massively centralised photovoltaic grid.

- PV grid systems with medium-sized strings and several strings.

- Modular PV grid system on a small scale.

6.1.1 Big, centralised photovoltaic grid system

Large PV systems with high power outputs up to several megawatts typically employ it. In this configuration, many PV modules are linked in parallel to a single DC bus, and a single big inverter is attached to each string of PV modules that are serially strung. Figure 6.1 displays the block diagram of such a setup.

The centralised topology has the following benefits:

- Low price

-Maintenance ease

-Very strong and effective.

All central inverter topologies have the following primary drawbacks:

-High harmonic content, low power factor, and poor dependability.

-During inverter outages, the breakdown of the central inverter results in total loss of generation.

-The necessary DC wiring lowers safety and raises expenses;

-Segments of the PV modules at their MPP cannot be operated separately. Therefore, a mismatch between sections (due to partial shading, for example) may drastically lower the system's overall output.

- An extension or flexible system design cannot be realised due to the high power range.

String inverters and module integrated or orientated inverters are two solutions that can get around these problems.

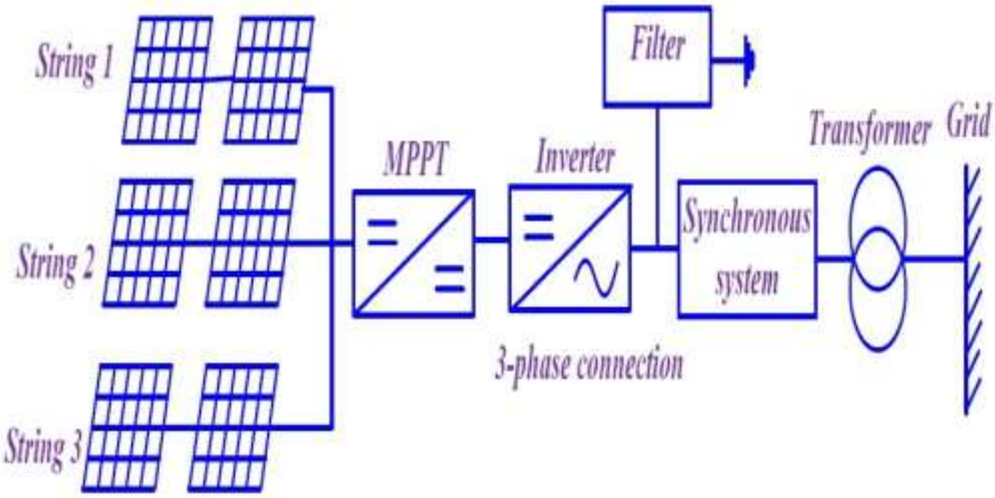


Fig 6.1 Central-plant inverter.

6.1.2 PV grid systems with several strings and medium-sized strings

String configuration: As illustrated in Fig., each string is connected to a single inverter with a power rating of 2-3 kW and a voltage range of 150-450 V. 6.2.2.

Multi-string configuration: To track MPP, each string is linked to a DC/DC converter. As shown in Fig 6.3, a DC bus is then used to link each DC/DC converter to a single inverter.

The primary benefits of these setups are:

Enhancement of the system's dependability

-Reducing partial shading losses because every string has its own MPP.

-Increasing the system's versatility by allowing for the addition of new strings.

These systems' primary drawbacks are higher expenses and losses.

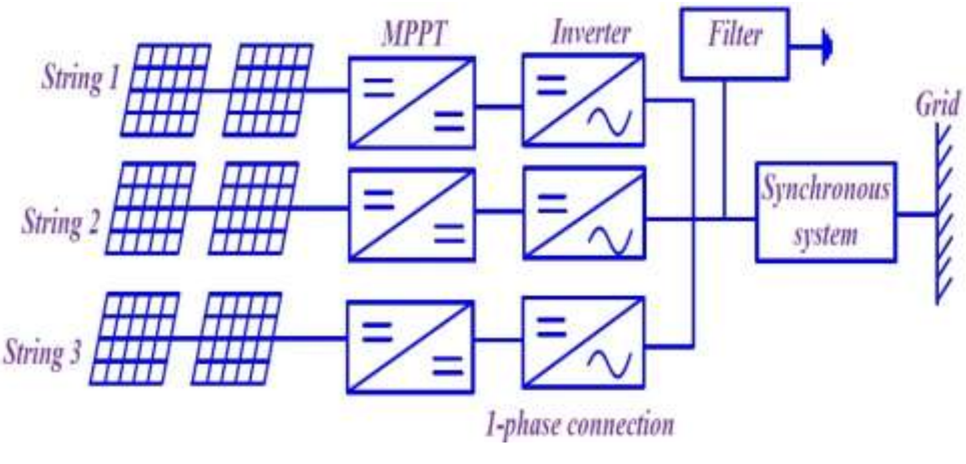


Fig 6.2 String inverter.

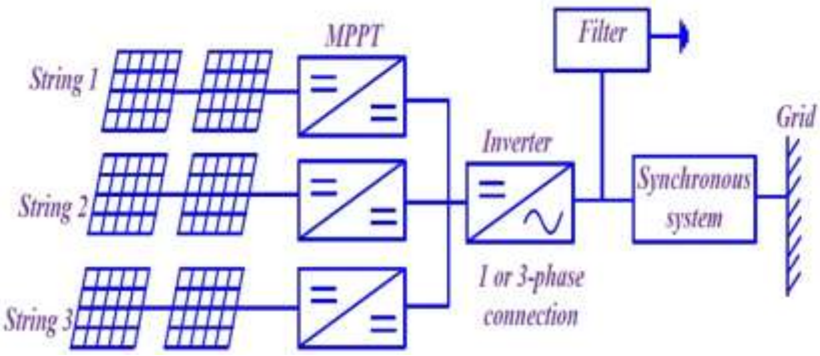


Fig 6.3 Multi-string inverter.

6.1.3 Modular photovoltaic grid on a small scale

This topology uses a DC/DC converter and MPPT to link a single tiny inverter to its PV module. The grid-connected inverter has a synchronisation system and harmonic filter installed. This topology, which is the newest, is known as "AC modules" as, as Figure illustrates, an inverter is included into every module. 6.4%. Nevertheless, only low power applications (up to 500W) are appropriate for this design. The small-scale configuration systems offer a number of benefits, including:

- Maximum productivity without any shading issues.

-Mitigating partial shading losses.

-Installation and maintenance costs are minimal when DC wiring cables are not used.

-The most flexible system design possible, featuring appealing "plug and play" features for installs.

-Longer lifespan and increased reliability.

-The ability to communicate via smart power lines.

-Enhanced oversight for malfunctioning modules.

-It is accessible to all users of public, commercial, and residential structures.

-Sharing to lower the public network's maximum load demand and prevent the need to build large power plants.

The system's very minor drawbacks include the inverter's difficulty of maintenance, which can be mitigated by replacing it with a less expensive, low-power alternative. The industry for home applications uses small scale inverters extensively because of the aforementioned benefits.

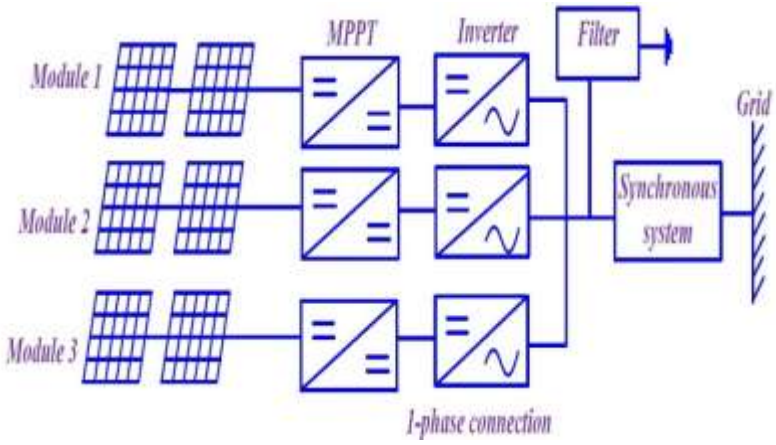


Fig 6.4 Modular-integrated inverter.

7. CONCLUSION

An overview of definitions of distributed generation (DG) and the parameters that must be taken into account when integrating DG to distribution power systems for the benefit of customers and utilities has been provided in this paper. In Nigeria and most of Africa, solar energy systems are a more practical option for distributed power sources. Installing distributed generation (DG) correctly will benefit the environment, the installed system, and the utility and consumers financially. Even though distributed generation (DG) has the potential to be a significant factor in meeting future energy needs, its introduction and use are now being constrained by a number of operational, financial, and technical issues. Financially speaking, distributed generator technology needs to advance to reduce cost per kWh and focus on end-use applications where they can outperform centralised generators.

REFERENCES

Bollen M. and Hassan F. (2011). Integration of Distributed Generation in the Power System, . New Jersey: Wiley-IEEE Press.

Chen J., Sun B, Li Y., Jing R., Zeng Y and Li M. (2022). An evaluation method of distributed generation credible capacity based on island partition. Energy Reports. Volume 8, November 2022, Pages 11271-11287

Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Seyboth, K., Kadner, S., Zwickel, T., Eickemeier, P., Hansen, G., Schlömer, S., von Stechow, C. and Matschoss, P. eds., (2011). Renewable energy sources and climate change mitigation: Special report of the intergovernmental panel on climate change. Cambridge University Press.

El-Khattam, W. and Salama, M. (2004) Distributed Generation Technologies, Definitions and Benefits. Electric Power Systems Research, 71, 119-128. https://doi.org/10.1016/j.epsr.2004.01.006

Estifanos Abeje Sharew, Habtemariam Aberie Kefale and Yalew Gebru Werkie, (2021). Power Quality and Performance Analysis of Grid-Connected Solar PV System Based on Recent Grid Integration Requirements. *International Journal of Photoenergy*, vol. 2021, Article ID 4281768, 14 pages, 2021. https://doi.org/10.1155/2021/4281768

Fadaeenejad M, Saberian A. M., Fadaee M and AbKadir M. Z. A (2014). The present and future of smart power grid in developing countries. Renewable and Sustainable Energy Reviews 29:828-834. DOI: 10.1016/j.rser.2013.08.072

Freris L. and Infield D. (2008). *Renewable Energy in Power Systems.* Chichester: John Wiley & Sons.

Grand View research (2020). Distributed Energy Generation Market Size, Share & Trends Analysis Report By Application. Retrieved from https://www.grandviewresearch.com/industry-analysis/distributed-energy-generation-industry

Idoniboyeobu, D.C., Udoha E.E. (2018). Impact of Distributed Generation from Solar Energy on Power System Distribution in Nigeria. IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 13, Issue 2

IRENA. (2015). Second Ministerial Roundtable: 'The Role of Renewable Energy in Energy Security.

Jinwei, He & Li, Yunwei Ryan. (2011). An accurate reactive power sharing control strategy for DG units in a microgrid. 551 - 556. 10.1109/ICPE.2011.5944604.

Justus Rabi B., and Arumugam R., (2005). Harmonics Study and Comparison of Z-Source Inverter with Traditional Inverters, American Journal of Applied Sciences 2 (10): 1418-1426.

Kusre, B.C. & Baruah, Debendra & Bordoloi, P. & Patra, S.. (2010). Assessment of hydropower potential using GIS and hydrological modeling technique in Kopili River basin in Assam (India). Applied Energy. 87. 298-309. 10.1016/j.apenergy.2009.07.019.

Lumbreras, David & Galvez, Eduardo & Collado, Alfonso & Zaragoza, Jordi. (2020). Trends in Power Quality, Harmonic Mitigation and Standards for Light and Heavy Industries: A Review. Energies. 13. 5792. 10.3390/en13215792.

Mohammad J., Ali A., Mahmoud F. & Moeini-Aghtaie M. (2017). Designing a regulatory framework for efficient integration of distributed generation technologies. Turkish Journal of Electrical Engineering and Computer Sciences 25(5):4117-4130

Muruganantham, B., Gnanadass, R. and Padhy, N.P. (2017). Challenges with renewable energy sources and storage in practical distribution systems. *Renewable and Sustainable Energy Reviews*, *73*, pp.125-134.

National grid collapses for the first time in 2022. (2022, January 18). Business day magazine. [Online]. Available: https://businessday.ng/energy/power/article/national-grid-collapses-for-the-first-time-in-2022/

National Renewable Energy Laboratory. (2002, October). The Impact of Air Quality Regulations on Distributed Generation. Retrieved from http://www.nrel.gov.

Nigerian Electricity Regulatory Commission (NERC). (2021). Renewable Energy Sourced Electricity. Retrieved from: https://nerc.gov.ng/index.php/home/operators/renewable-energy

Obar, E. A., Touati, A., & Rabbah, N. (2021). Embedded generation using shared solar. *E3S Web of Conferences*, *229*. https://doi.org/10.1051/e3sconf/202122901026

Obideyi Oluwatoni (2017). Integrating Renewable Energy into Nigeria's Energy Mix: Implications for Nigeria's Energy Security. Master's Thesis, Faculty of Landscape and Society Department of International Environment and Development Studies, Norwegian University of Life Sciences.

Onyekwena C., Ishaku J. & Akanonu P.C. (2017). Electrification in Nigeria: Challenges and Way Forward. Centre for the Study of the Economies of Africa (CSEA) Abuja, Nigeria

Osinbajo launches Africa's largest solar cell plant in Nasarawa (2023, March 28). Business day magazine. [Online]. Available: https://businessday.ng/news/article/osinbajo-launches-africas-largest-solar-cell-plant-in-nasarawa/

Pepermans G., Driesen J., Haeseldonckx D., D'haeseleer W. and Belmans R. (2003). Distributed Generation: Definition, Benefits and Issues. Faculty Of Economics And Applied Economic Sciences Center for Economic Studies Energy, Transport & Environment, Katholieke Universiteit, Leuven.

Perlack, Robert & Wright, Lynn & Turhollow, Anthony & Graham, R. & Stokes, Bryce & Erbach, Donald. (2005). Biomass as Feedstock for A Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply. Biomass as Feedstocks for a Bioenergy and Bioproducts Industry: the Technical Feasibility of a Billion-ton Annual Supply. 72. 10.2172/885984.

Power Generation: Delta, Foreign Investors Signs MoUs (2018). Independent Magazine [online]. Available: https://independent.ng/power-generation-delta-foreign-investors-signs-mous/

PricewaterhouseCoopers (2016). Powering Nigeria for the future. The Power Sector in Nigeria, 2016

Resource Dynamics Corporation. (2001). Assessment of Distributed Generation Technology Applications. Retrieved from http://www.distributed-generation.com

United States Environmental Protection Agency. (2022). Distributed Generation of Electricity and its Environmental Impacts. Retrieved from https://www.epa.gov/energy/distributed-generation-electricity-and-its-environmental-impacts

U.S. Department of Energy (2016). Demand Response and Energy Storage Integration Study.

U.S. Energy Information Administration (EIA). (2020). Modeling distributed generation in the building sectors.

Weedy, B.M., Cory, B.J., Jenkins, N., Ekanayake, J.B. and Strbac, G., (2012). Electric power systems. John Wiley & Sons

Willem Lukas V., Bernard B. & Munyaradzi J.C. (2021). Managing the Impact of Embedded Generation on Distribution Networks using Autonomous Smart Inverters: a South African Perspective. 2021 International Conference on Electrical, Computer, Communications and Mechatronics Engineering. (ICECCME).

World Bank data (2020). Access to electricity. (% of population). Retrieved from https://data.worldbank.org/indicator/EG.ELC.ACCS. ZS?locations=NG