Decentralized and Distributed Power Generation

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Abstract

Distributed energy systems (DES) have significant potential to enhance sustainability of electricity systems. Decentralized generation systems are small-scale power technologies generally ranging between 3 kW– 10 MW located very close to consumers to provide an alternative or enhancement to the centralized or conventional power system. The DGs are connected directly to the distribution system or on the customer side of the meter which significantly reduces the. transmission and distribution losses of the power system. The high consumption of fossil fuels and global commitments to reduction in energy related emissions has generated huge interest in renewable energy resources for use in power generation. This has increased the opportunities of utilizing decentralist generation systems in power generation. The renewable DG systems may be connected to the grid for peak shaving or as a stand-alone system to serve a particular load or an area. Integrating renewable DGs to the power system has many benefits as well as threats if not well coordinated and integrated into the power system. High penetration of renewables can cause several adverse effects on the distribution systems. like voltage rise, reverse power flow, high line losses, creation of harmonics and reduction in voltage quality. Decentralized power systems units should be designed and operated within limits to maintain optimal quality of the power system There is therefore need for optimal sizing and location of renewable decentralized generation (DG) units in the distribution power system for technical and economic benefits. The penetration of renewable decentralized generation systems is considered as a significant contribution to the world energy and environmental crisis

Key words:
decentralized generation, sustainable energy; distributed generation

Introduction

There is need to develop more flexible electricity networks for the purpose of power distribution as opposed to the current practice in centralized power systems where the operators just transmit power and keep the grid stable. A desirable future power grid should have inbuilt flexibility approaches and methods like demand-side response, intelligence, and energy storage. This marks the transformation to distributed generation is which is a new approach in the in the power sector(Lund et al. 2017). There are many definitions for decentralized generation e.g., the Anglo-American often use ‘embedded generation’, while in North America, it is often referred to as ‘dispersed generation’. In Europe and parts of Asia, it is often referred to as ‘decentralized generation’.(Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju 2022; Kabeyi & Oludolapo 2020a). Distributed generation (DG) is proving to be a very important more important future generation system that is rapidly evolving in competitive electricity markets. Distributed generation is generally defined as an electric power generation system within distribution networks or on the customer side of the network (Ackermann et al. 2001; Moses Kabeyi & O. Olanrewaju 2022). The main purpose of distributed generate on is to supply active power to the grid.

Therefore distributed generation does not have to supply reactive power to the power system(Ackermann et al. 2001). The distributed generation units are installed and connected directly to the distribution network or they can be connected to the network on the customer site of the meter(Ackermann et al. 2001). A transmission system is usually operated by an independent institution that is not involved in power distribution and retailing or sale of power to consumers. The distribution network is a low voltage network operated or owned by power retailing or selling companies who deliver power to the consumer meters(Ackermann et al., 2001). Distributed generation units can be owned by independent power producers or by the customers. Distribution companies can only install own distributed sets for different applications. The number of units needed may be determined by whether decentralization is partial or fully implemented. Completely decentralized generation does not need any transmission lines and large-scale centralized power plants but in partial decentralization, distributed generation accounts for a fraction of the local energy demand(Ackermann et al., 2001; Kabeyi & Olanweraju 2022).

Decentralized generation systems are small-scale power technologies generally ranging between 3 kW– 10 MW located very close to consumers to provide an alternative or enhancement to the centralized or conventional power system. The DGs are connected directly to the distribution system or on the customer side of the meter which significantly reduces the. transmission and distribution losses of the power system. The high consumption of fossil fuels and global commitments to reduction in energy related emissions has generated huge interest in renewable energy resources for use in power generation. This has increased the opportunities of utilizing decentralist generation systems in power generation. The renewable DG systems may be connected to the grid for peak shaving or as a stand-alone system to serve a particular load or an area. Integrating renewable DGs to the power system has many benefits as well as threats if not well coordinated and integrated into the power system. High penetration of renewables can cause several adverse effects on the distribution systems. like voltage rise, reverse power flow, high line losses, creation of harmonics and reduction in voltage quality. Decentralized power systems units should be designed and operated within limits to maintain optimal quality of the power system There is therefore need for optimal sizing and location of renewable decentralized generation (DG) units in the distribution power system for technical and economic benefits. The penetration of renewable decentralized generation systems is considered as a significant contribution to the world energy and environmental crisis (Adefarati & Bansal 2016)

Design and Construction and Operation

A decentralized power system is based on distributed generation, demand response and energy storage in its design and operation(UNESCAP 2012; Vezzoli et al. 2018). Several recent advances in energy technologies and grid infrastructures have increased the interest in the use of distributed generation (DG) resources for grid electricity generation. The exploitation of distributed generation (DG) for grid electricity subject to technical constraints to extend distribution and transmission networks to some areas as well as the deregulation of the electric power sector. There are many benefits of distributed generation depending on the characteristics of the sources like photovoltaic (PV), diesel engines, wind power systems, type, and characteristics of the loads, availably and access of local renewable resources and power grid network configuration. The benefits can be technical, environmental, social, political, and economic benefits like line-loss reduction, system reliability improvement, local revenue, employment and economic benefits and reduction in environmental pollution. The various benefits can be optimized by optimal sizing, optimal location, as well as optimal configurations (Adefarati & Bansal 2016)

The increasing presence of distributed generation systems based mainly on variable renewable energy sources as well as growing variable load users like, plug-in electric cars connected to the grid and lower voltage points have rendered central power transmission and distribution networks invalid (Zarco-Soto et al. 2021). There is a general shift to small and distributed power plants that use predominantly renewable sources of energy for grid electricity generation in a system that supports a bi-directional flow through transformers(Colangelo et al., 2021). The distributed energy resources (DER), are slowly playing a dominant role in remote and isolated areas. The decentralization. The decentralization of power generation gathered momentum when economies of scale ceased to be a significant factor as a result of innovation and adoption of smart grids. The global annual increase in distributed generation capacity has surpassed the centralized electricity systems which is an indicator of growing demand and use of decentralized generation(Mitrova & Melnikov 2019).

To maximize the use of DER technologies needs the development in a systemic architecture and policy measures that can balance the interests of new players with the existing centralized model players. An optimal combination of DER and centralized generation is one of the most effective and efficient approaches in the energy transition. These requires principles and mechanisms to enable seamless integration of the centralized and decentralized power systems(Mitrova & Melnikov, 2019). The main beneficial effect of distributed generation is the it leads to increase in nodal voltages.

The use of variable loads like electric cars on distribution networks puts significant pressure on need for nodal voltage control using a flexible and resilient grid with abilities beyond mere decentralization of grid power generation (Zarco-Soto et al., 2021). Decentralized generation technologies have resulted in increased viability of small energy systems while more use of information technologies has created to new opportunities in the management of energy infrastructure in a less hierarchical and flexible manner. Decentralization has therefore created higher opportunities in the transition to a more sustainable energy future through application of efficiency measures, reduced emissions, and lower costs.

Sizes of distributed generation Units

In terms of size, The Electric Power Research Institute defines distributed generation as one that ranges from 'a few kilowatts up to 50 MW', while the Gas Research Institute, defines distributed generation as 'typically ranging between 25 and 25 MW while Preston and Rastler suggest size 'ranging from a few kilowatts to over 100 MW'. On his part Cardell defines distributed generation as generation 'between 500 kW and 1 MW'. Since renewable energy is generally produced within decentralized networks, the progress and advances in distribution grid is strongly influenced by progress in smart grid technology (Ackermann et al. 2001)

On the basis of their size, or capacity, distributed generators can be classified as micro, small, medium, and large as summarized in table 6 below.

Table 1. categories of distributed systems based on capacity(Ackermann et al. 2001).

	Category	Capacity
1	Micro	1 watt - <5 kW
2	Small	5kW – <5 MW
3	Medium	5 MW -< 50 MW
4	Large	50 MW- <300 MW

From table 1, it is noted that distributed generators vary in size from as low as 1 watt to 300 MW. Microsystems vary between 1watt and 5kW, small size generators between 5kW and 5 MW, medium between 5 MW and 50 MW and large between 50 MW and 300 MW.

Technologies and Energy Sources for distributed generation

Decentralized generation system (DG) technologies are modular generators used to supply alternative and conventional power as a means of reducing power interruption. These systems have wide ranging limitations, characteristics and strengths. Decentralized technologies can broadly be classified into renewable and non-renewable based on the source of energy and operations. Various technologies used are summarized in table 2.

Table 2. Technologies and power plants for distributed generation(Ackermann et al. 2001)

	Technology	Typical Capacity Per Module
1	Combined cycle gas turbines	35 MW -400 MW
2	Internal combustion engines	5 kW -17 MW
3	Combustion turbine	1 MW -250 MW
4	Micro gas turbine	35 kW - 1 MW
5	Stirling engines	2 kW – 10 kW
6	Small hydro	1 MW -100 MW
7	Micro-hydro	25 kW- 1 MW
8	Wind turbines	200 watts -5 MW
9	Photovoltaics arrays	20 watts -100 kW
10	Solar thermal -Central receiver	1 MW -10 MW
11	Solar thermal -Lutz system	10 -80 MW
12	Biomass gasification	100 kW -20 MW
13	Fuel cells- phosphoric acid	200 kW- 2 MW
14	Fuel cells- molten carbonate	250 kW- 2 MW
15	Fuel cells-Proton exchange	1 kW -250 kW

16	Fuel cells-Solid oxide	250 kW- 5 MW
17	Geothermal	5 MW -100 MW
18	Ocean thermal	100 kW- 1 MW
19	Battery storage	500 kW -5 MW

From table 2, it is noted that different technologies and energy sources with different capacity ranges can be selected for use in decentralized generation. The largest units in decentralized generation are combustion engines and gas turbines .

Energy Sources

Renewable

Decentralized technologies that fall under this category include biomass, geothermal power, solar power, small/mini/micro-hydro power, photovoltaic (PV), and wind turbines. The output of the DG technologies is dispatched to the grid based on the request of the utility grid operators or they operate as stand-alone system to serve a particular load or an area(Ackermann et al. 2001).

Nonrenewable

Non-renewable technologies use natural gas, coal and petroleum as energy source to produce electricity which produces significant greenhouse gases (GHGs) emissions, acid rain and petrochemical pollution and global warming and hence non-sustainable. Non-renewable DG technologies are used for power generation and thermal energy for domestic and industrial use through a co-generation arrangement. Prime movers using non-renewable technologies in decentralized generation include reciprocating engines, gas turbines, micro-turbines and steam turbines. (Ackermann et al. 2001)

Distributed Generation Technologies, Characteristics and Applications

Distributed generation occurs at local level and the end-point level. Technologies for local level power generation include wind turbines, solar systems, geothermal energy production, combustion engines, and some hydro-thermal plants which tend to be smaller. and less centralized compared to traditional model plants. These systems tend to be more cost and energy efficient and more reliable. Because the DG producers often consider the local context, they generate less environmentally damaging or disrupting energy compared to larger central power plants (Viral & Khatod 2012).

For end-point level consumers can apply same technologies with similar effects. A frequently used decentralized technology by end-point users is modular internal combustion engine. The decentralized generation technologies can have operated in "islands" of electric energy production or can be connected and this contribute to the power grid. Many researches indicate that the penetration of distributed generation of 10–15% of maximum load is easily be absorbed by the grids without major structural changes with many networks having less than the practical limit. Decentralized technologies can broadly be classified into non-renewable energy and renewable energy based technologies with variations in terms of fuel used, efficiency, size/module, electrical efficiency, installation cost, maintenance cost, reliability, peak shaving, power quality and green power(Viral & Khatod, 2012).

2. Microgrids in and Energy Storage Decentralized Generation

DERs are generally small-scale energy resources located within the utility facilities or at electricity consumers premises as a local supply of energy. The use of DERs can significantly change the traditional power systems which involve generating power in large central power stations and transmitting it over distances using high voltage transmission lines to reach customers at load centres. DER technology can also be used as a means to supply power to rural and remote areas with no transmissions and distribution facilities and also where grid extension is quite expensive to develop. DERs include a variety of technologies (Sandelic et al. 2022).

Since renewable energy sources are characterised by the intermittency and variability, the DGs in microgrids need presence of dispatchable energy source and storage to compensate for their fluctuations. For microgrids to operate in island mode, there is need for seamless transfer to the islanded mode hence the need for integration of energy storage systems (ESS) in microgrids. The use of energy storage (ESS) enable higher degree of flexibility in power generation, supply and use. Application of Large-scale ESS enhances the efficiency of utility grids hence reduced costs of operation cost and related greenhouse gas emissions as well as increased power system reliability(Moses Kabeyi & Oludolapo Olanrewaju, 2022; Moses J. B. Kabeyi & Oludolapo A. Olanrewaju 2022). The advantage of microgrids as compared to the conventional large-scale power plants is that they have ability to respond to load fluctuations in real-time which improves voltage and power quality. Increased penetration of renewable DGs, increases the demand for microgrids in decentralised generation due to their non dispatchable nature. Benefits accruing from of storage in microgrids and other distributed include avoided costs and additional revenue to the utility operator or consumer (Sandelic et al. 2022). These shows that energy storage is an important feature in decentralised power systems for enhanced efficiency, reliability and financial benefits.

Microgrids can be classified based on three types: energy arbitrage, reliability, and power quality. Energy from inverter-based microgrids generally responds slowly which, makes, ESS necessary only necessary in mostly critical load designed to have a power quality higher than the utility grid, and is optional for other types of microgrids for such power systems. Studies have shown that ESSs used in microgrids can perform the task of active power balancing and as well as voltage regulation simultaneously. For grid-connected mode, the use of ESS enable load levelling and reduction in power exchange with the network making the system operation more efficient and more flexible. For this reason, ESS improves DER penetration and enhances quality of energy delivery to customers.(Sandelic et al. 2022).

Application od Distributed generation

There is a wide range of applications for decentralized power generation in the power system based on the user's needs. The most common technical applications include

i.) Baseload applications

In base load applications, the Dg system is design and operated in parallel with the distribution network. The system can take or sell part of the energy and uses the network to support the maintenance. The baseload system runs constantly and reduces the consumption of electricity network.

ii.) Peak load application

Decentralized systems can also be predominantly for peak load supply which effectively reduces demand since the cost of power during peak is highest.

iii.) Support distribution network

DGs are also used to support the distribution network sporadically or periodically to cater for large customers or the system which requires power to strengthen the power grid through installing small plants and substation, to avoid or resolve congestions caused by high demands at different times of the year or during the network failures.

iv.) Power Supply quality regulation

Decentralized generation can be applied to improve quality of power by supplying required stabilizing supply to improve the quality by eliminating fluctuations.

v.) Energy storage

Energy storage is a viable technology when the cost of using technology is variable or cases where we have frequent supply interruptions or systems using variable renewable energy sources. As a backup system, it acts as a stand-by supply ensuring the uninterrupted electricity power supply in case of interruptions(Viral & Khatod, 2012).

Results and Discussion

There is a growing trend to develop energy systems that have little or no reliance to fossil fuel sources. This is mainly because of concerns over climate change, air quality, and electrification of remote areas which have most of the 17% of world population having no access to electricity. By deploying power plants as close as possible to end-users and incorporating multiple energy sources and carriers, as well as use of renewable energies, decentralized generation is expected to transform the energy sector towards sustainability. The main challenge remains that the design of distributed energy systems (DES) is a complex problem because of multiple objectives or goals and constraints that should be considered.

Benefits of Distributed Generation

The conventional centralized power grid is being converted to a mixed distributed electrical network by Continuous expansion and deployment of distributed power-generation systems (DPGSs). The level of integration of the DPGS into the grid has a critical role to play in develpnent of a sustainable and resilient electricity systems, particularly with highly intermittent renewable energy resources. To address challenges and, leverage the energy generation, demands from both utility operators and consumers are imposed on the distributed power-generation systems (DPGSs). The modern power grid need flexibility in energy utilization but have significant challenges where the degree of penetration of renewable energy like wind and solar photovoltaics are main sources of power.(Blaabjerg et al., 2017). Decentralized generation is in the distribution system is increasing rapidly due to technological advancement leading to design and manufacturing of efficient DG's components, under increasing uncertainty of the global fossil fuel supplies creating increased demand for locally available energy resources. Decentralized generation helps consumers to meet their load requirements since DG technologies are more efficient and reliable [16, 17]. With deregulation of the power sector, centralized power systems are gradually being replaced by decentralized power systems. [18, 19].

Decentralized technologies are more environmentally friendly than centralized generation. Other benefits of decentralized power generation include reduction of transmission line losses, achieved by proper siting in terms of location and unit sizing, which further improves the environmental balance in decentralized. However, oversizing DG units might force the large units to operate below their optimum efficiency, increasing emissions by fuel based DGs per produced kWh. Other aspects, which make an environmental comparison very difficult are different perceptions regarding the risk of nuclear power stations or regarding the visual impact, noise impact and land requirements of wind turbines, for example(Ackermann et al. 2001).

Application of decentralized generation has economic and technical benefits Distributed. DG facilitate cleaner power production, due to use of renewable energy sources like wind and solar while use of the combined heat and power (CHP) increases overall efficiency and reduces the greenhouse gas emissions. The benefits can be broadly classified into Technical, economic and environmental (Viral & Khatod, 2012).

Technical benefits

Technical benefits include peak load shaving ability, good voltage profile, system loss reduction, better continuity and higher system reliability and enhanced quality. With high power losses in a number of developing countries to the range of 15–20% of total power generation, system losses will be reduced to well under 10%. Loss reduction is influenced by the choice of placement and size of the DG. The major technical benefits are:

Reduction inline losses
Improvement in voltage profile
Higher overall energy efficiency.
Higher system security and reliability
Improved power quality
Reduction in transmission and distribution (T & D) congestion

Economic Benefits

The economic or financial advantages include savings in fuel, transmission and distribution costs, low wholesale and retail electricity prices. These benefits are listed as follows

i.) Deferred facility upgrades and expenditures
ii.) Lower operation and maintenance costs.
iii.) Higher productivity
iv.) Lowe health expense due to improved environment
v.) Lower fuel costs as a result of higher generating efficiencies
vi.) Lower or reduced reserve requirements and their related costs.
vii.) Reduced operational costs resulting from peak shaving
viii.) Higher security for critical loads.

Environmental benefits of decentralized generation

Use of decentralized technologies provides ancillary benefits to society more than the large centralized power generation because studies show that widespread application of decentralized generation technologies significantly reduces emissions: For British analysis showed that domestic combined heat and power technologies have potential could reduce carbon dioxide emissions by 41% in the year 1999 while similar studies in for Danish power system showed that widespread use decentralized generation technologies could reduce emissions by 30% between 1998 and 2001 besides increasing energy sources diversity.

Renewable energy technologies like wind turbines, solar photovoltaic panels, and hydropower, do not use fossil fuels hence are clean while fuel cells, micro turbines, and some internal combustion cleaner natural gas which can be substituted further by biomethane which is renewable(Moses Kabeyi & Oludolapo Olanrewaju 2022; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju 2022a, 2022b). Diversity of energy sources and technologies insulates the economy from price shocks, supply interruptions, and fuel shortages affecting any specific type. Other environmental benefits are low and low emission levels and greener power. (Viral & Khatod 2012).

2.1. Challenges of decentralized generation (DG)

Distributed power-generation systems (DPGS) have a significant role in modern power systems with wind and solar photovoltaics (PVs), being important renewable energy sources for decentralized power systems. However, large-scale adoption of decentralized systems poses challenges as a result of several inherent characteristics. (Blaabjerg et al. 2017)

Distribution networks are often designed for a different purpose than transmission networks. Distribution systems are not usually designed for the connection of power generation devices, e.g. connection of distributed generation leads to a change in the fault-current, thus the need to redesign local fault protection system. Distribution networks usually have a radial or loop design, and not a meshed design like transmission networks meaning power flow in distribution networks is usually unidirectional with little or no redundancy. Additionally, high voltage lines, like transmission lines or urban distribution lines, have low resistance compared to low voltage distribution networks lines. The effect of line resistance in transmission lines or urban distribution networks, is small, since its specific magnitude is generally much less than the reactance. Reactance is the most important parameter for voltage drop and line losses. Distribution line resistance induces significant proportion of the voltage drop along the distribution lines as well as of the line losses. This implies that connecting distributed generation can have significant influence on the local voltage level. The low voltage ends of distribution systems are generally not connected to Supervisory Control and Data Acquisition (SCADA) systems making data gathering needed for the control of the distribution system and DG units difficult(Ackermann et al. 2001)..

Medium-sized and small DG technologies often use asynchronous generators or induction generators mainly because they are significantly cheaper than synchronous generators. These asynchronous generators, have different operational characteristics e.g. synchronous generators are directly grid-connected but the asynchronous generators cannot provide reactive power and require reactive power from the grid during the start-up process and at operation. The disadvantages of grid-connected asynchronous generators can be addressed by various technical options e.g. capacitors and power electronic converters, micro systems like photovoltaic modules, fuel cells, batteries, and micro hydro turbines connected via an interface (converter) to the grid since these micro-systems produce direct current. Modern power electronic interfaces convert D.C. current to an A.C. voltage and active/reactive current at desirable required frequency. The use of power electronic converters comes with 'new control issues and new possibilities' to grid integration e.g. they are used for voltage control in the distribution network with possible emergency of control problems e.g. power fluctuations or oscillations in the distribution networks although such cases are rare. Most distribution network operators rely on commonly used interconnection standards regarding the connection of DG resources to achieve a secure network operation with many of the standards being based on recommendations by ANSI and IEEE. Most of these standards however do not distinguish between medium-sized CCGT power stations and micro-PV systems with cases of owners of the DG unit (s) and the distribution network operator disagreeing over appropriate interconnection standards(Ackermann et al. 2001)..

The advances in renewable energy technologies and developments in the power system infrastructures have created opportunities for power utilities in to exploit distributed generation (DG) for electricity generation. The development and utilization of DG resources electricity generation is subject to the deregulation of the electricity sector and technical constraints in the extension of the transmission and distribution networks to some areas(Moses Kabeyi & O. Olanrewaju, 2022). Power system planners, regulators and the policy makers have derived significant benefits from integration of decentralized generation units into the power distribution networks(Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju 2022). The benefits derived are functions of the DG units' characteristics, load characteristics, availability of local renewable resources and network configuration. The various benefits are technical, environmental and economic e.g. line-loss reduction, reliability improvement, economic benefits and environmental pollution optimization. The benefits of decentralized generation can be optimized if all the decentralized units are optimally sized, located and configured to the power system (Adefarati & Bansal, 2016; Kabeyi & Olanweraju, 2022).

High penetration of renewables can cause several adverse effects on the distribution systems. like voltage rise, reverse power flow, high line losses, creation of harmonics and reduction in voltage quality. High penetration of decentralized generation significantly affects the system dynamics. Analysis of DG interconnection is made complex, due to wide variety of technologies applied and the typical configuration of distribution networks designed to operate with unidirectional power flows. The various limitations include;

i.) Causes reverse power flows as a result of connecting DG in the system which can cause malfunction of system protection circuits as they are configured at present.
ii.) Many decentralized generation systems apply asynchronous generators which do not supply reactive power to the grid
iii.) Decentralized generation systems may cause significant deviations from the system nominal frequency due to unbalances between power supply and demand. An increase in the amount of distributed generation may affect the system frequency with a possibility of these generators becoming “free riders” which makes process of control more complicated.
iv.) There is a tendency for *installed* distributed generation to change the voltage profiles of the distribution networks as a result of changes in the magnitude of power flows. The voltages profile tends to rise which is beneficial in congested networks with low voltage problems, as would be in the contrary.
v.) Many distribution networks are configured in radial form, at split rings which generates unidirectional flow patterns, hence the protection systems are so designed accordingly. However, distributed generation changes the flow into bidirectional, which requires new safety equipment and resizing the entire network i.e. short circuit, grounding, breaking capacity, Supervisory Control and Data Acquisition (SCADA) systems and many other critical features.
vi.) It is important to put in place islanding protection security which a portion of the utility system containing both load and distributed resources remain energized but isolated from the utility system. In this case, a decentralized generation system some certain segment of the network, which can cause death to workers coming in contact with it if not advised timely of the possibility energizing. One option is to place protective equipment like relays i.e. electronic or mechanical and transfer switches.
vii.) There is injection of harmonics into the system by asynchronous decentralized generation sources which apply inverters for interconnection.
viii.) Decentralized generation is associated with stability challenges
ix.) There are higher fault currents depending on the location of decentralized units
x.) There is a challenge of power quality with use of power electronics to control the SPV wind energy technologies

Over voltage at different nodes resulting incorporation decentralized generation in the in the distribution network needs some special attention and should be addressed to ensure proper operation of the distribution network.

Impact of Distributed Generation

Distribution power systems are designed in a way that allows power to flow from the power system to the load. Output fluctuations or reverse flow from generators is likely to influence overall distribution system in terms of voltage profile, power losses, reliability, power quality or protection and safety. Potential impacts of DG are;

Power Losses

Decentralized generation causes significant impact in electric losses because of its proximity to the load centers. DC is allocated in a way that reduces power losses just like capacitor capacitors are located to minimize losses. DG units' impact on both active and reactive power, while the capacitor banks only impact in the reactive power flow. For feeders with losses, strategically located DGs could significantly reduce losses. Optimum location is one that guarantees minimum losses when the DGs are located there(Viral & Khatod, 2012).

Voltage profile

Power distribution is normally controlled or regulated by tap changing at substation transformers and use of voltage regulators and capacitors on the feeders. This voltage regulation assumes that power flows by circulating from the substation to the loads. Therefore, distributed generation introduces meshed power flows that can interfere with the normal regulation practices. Voltage regulation is usually based on radial power flows, hence inappropriate decentralized generation (DG) will cause low or over-voltages in the network. Decentralized generation on the other hand can yield positive impacts in distribution system by enabling reactive compensation for voltage control, reduce losses, contribute to frequency regulation and act as spinning reserve in main system fault cases. Incompatibility of DG with the voltage regulation in radial power flows can cause over voltage and under voltage (Viral & Khatod, 2012).

Power Quality

Power quality is the degree to which power characteristics comply with the ideal sinusoidal voltage and current waveform. Network operators should guarantee a specified minimum short-circuit capacity to protect the system from degradation in power quality. Distributed generation has a healing effect on power systems hence a significant contribution to quality of power supply. Additionally, for systems with difficulty in voltage support, distributed generation generally leads to a rise in voltage in the network(Viral & Khatod 2012).

Excess Voltage

In cases where decent raised generation connections are concentrated on a specific line, power flow gap among feeder lines widens due to back-flow from the DG. This difference may cause deviation in the voltage profile from the correct range. The voltage control for the distribution substation lines is done using a programmed timer or line drop compensator (LDC). Often, a single distribution transformer is equipped with multiple feeder lines with voltage adjustment being done in a block.

Voltage fluctuation

Sudden change in output of a decentralized system is likely to cause fluctuation in voltage of the local line system and this fluctuation can cause over or under voltage at the customer's receiving point. Several concerns arise when generating systems that depend on natural conditions, such as wind power or solar photovoltaic generators, are interconnected to the power systems. (Adefarati & Bansal 2016).

Reliability

The objective of all power systems is to deliver electricity in economical and reliable manner. It is necessary to plan and maintain reliable power systems due to severe economic impact it has on utility and its customers. Generally, reliability analysis and evaluation techniques for the distribution systems are less developed compared to the generation side because distribution outages are localized and less costly compared to generation or transmission level outages. Studies on customer outage data of utilities indicate that the largest individual contribution of supply failure is due to distribution system failure. Integration of decentralized generation to distribution system significantly increases the reliability of the power supply. The decentralized systems can act as a back-up system or as a main supply and can be operated. during peak load periods to avoid additional charges.

System planners and operators apply reliability indices as a tool to improve quality of service to customers. They are used by planners to determine the generation requirements for transmission, and distribution capacity additions. These ensure a robust system that can withstand possible failures with no catastrophic consequences. Therefore, reliability indices are reasonable and logic way to judge the performance of power systems(Viral & Khatod 2012).

6.4. Various Planning Methodologies and Their Comparison in DCs

The various benefits of decentralized generation can only be maximized when optimal sizes of DG units are established and correctly located in distribution systems. The main challenge in decentralized generation for a long time has been optimal sizing and location of units in power systems. Various approaches that can be applied include;

i.) Analytical methods and approaches
ii.) Meta-heuristics.
iii.) Use of artificial intelligence
iv.) Application of genetic algorithm (GA) hybrid methods
v.) Others.

Factors to consider in the analysis are minimization of power losses, voltage profile improvement, effect on reliability and quality of power (Viral & Khatod, 2012).

6.5. Measures to Promote Decentralized Generation

The main drivers for decentralised generation are the need to use more clean and sustainable nature of renewable resources compared to the polluting and limited fossil traditionally used in power generation. State and governmental commitment advance broader integration of renewable energies and enforcement of the clean environmental agenda to mitigate greenhouse gasses emissions and combat climate change are other factors in increasing adoption of decentralised generation Renewable portfolio standards require electricity providers to supply a specific amount of electricity from renewable DGs. The use of public benefit funds raised by levying on electricity rates provide funding to promote decentralised generation and use of renewable energy. Application of Output-based environmental regulations which set emission limits to encourage power producers to increase efficiency and control air pollution are other important measures. Development and enforcement of interconnection standards are technical solutions and technical requirements that facilitate growth of decentralised generation. The developed standard specifies how specify how utilities should treat decentralised systems as well as design and operational requirements(Kabeyi 2022; Kabeyi & Oludolapo 2020b)

Net metering rules enhance the operation of prosumers by specifying how they should be compensated for net power supplied to the utility grids and simultaneously pay for power consumed from the grid when they cannot generate enough for own use. To achieve these function, accurate metering for electricity demanded by consumers. Is critical. The feed-in tariff is another policy measure adopted to promote renewable energy development by guaranteeing sufficient long-term payments for electricity locally supplied the grid from DGs. Payments may be in the form of electricity sales and payments for renewable energy certificates. It is important to have cost efficient Feed-in tariff policies that are e cost-efficient to enable rapid deployment of renewable energy and decentralized generation systems that will benefit the entire society including consumers, prosumers and utilities Globally, the implementing feed-in tariffs is a successful experience to realise economic development and renewable energy targets. Through property assessed clean energy policy, the cost of increased energy efficiency or renewable energy installations is refunded to residential properties borrowers. This encourages property owners to invest in renewable energy improvements. Financial measures applied to encourage development of decentralized generation and use of renewable energy sources include access to grants, loans, rebates, and tax credits to invest in renewable energy(Kabeyi, 2012; Sandelic et al. 2022).

6.6. Technologies for Decentralised Generation

Decentralised generation employs various technologies ranging from the conventional conversion technologies like reciprocating engines to non-conventional technologies like fuel cells. The various technologies are summarised in table 3.

Table 3. Available DG Technologies.

	Type	Fuel/ Energy	Size (kW)	Electrical efficiency % (based n LCV)	Overall efficiency (%)	Installation cost	Maintenance cost ($/kW)
1	Reciprocating engines	Diesel, gas or natural gas	3–6000+	30–43	80–85	500–845	-0.005–0.015
2	Combustion gas turbine	Gas or diesel	0.5–30,000+	21–40	~80–90	400–900	0.004–0.010
3	Micro-turbine	Bio-gas, propane or natural gas	30–1000	14–30	80–85	1200–1700	0.0018–0.015
4	Hybrid fuel cell	Ethenol, H_2, natural gas or propane	400–20,000	35–55	~80–85	4000–5000	0.0019–0.0153
5	Small fuel cell	Ethenol, H_2 natural gas, or propane	1–300	30–50	~80–90	4000–5000	0.0019–0.0153
6	Micro CHP	Heat space or water Ethenol, H_2	1–10	30+	~75–89	500–845	-

7	Automotive fuel cells	natural gas, PEM, phosphoric acid or propane	30–60	30–55	80–90	4000–5000	0.0019–0.0153

From table 3, it is noted that different technologies can be selected for use in distributed generation. They include fuel cells turbines and microturbines and reciprocating engines with fuel cells being the most efficient and microturbines being the most inefficient. The reciprocating engines and microturbines are the cheapest to install while fuel cells are the most expensive per unit power output.

6.7. Renewable Sources for Distributed Generation

Renewable sources play an important role in decentralized generation since most locally available sources of energy are in the form of renewable energy. The characteristics of these renewable energy sources used in distributed generation are summarized in table 4.

Table 4. Renewable energy-based sources

	Type of technology	Energy sources	Size (kW)	Electrical efficiency	Overall efficiency (%)	Installation cost
1	Wind	Wind	0.2–3000	NA	~50–80	-
2	Photovoltaic systems	Sun	0.02–1000+	NA	~40–45	4500–6000
3	Biomass gasification	Biomass	100–20,000	15–25	~60–75	1500–3000
4	Small hydro-power (SHP)	Water	5–100,000	NA	~90–98	10,000–13,000
5	Geothermal	Hot water and steam	5000–100,000	10–32	~35–50	-
6	Ocean energy	Ocean wave	100–1000	-	-	-
7	Solar, thermal	Sun and water	1000–80,000	30–40	~50–75	-
8	Battery storage	-	500–5000	NA	~50–75	100–200

From table 4, it shown that different renewable sources of energy can be used in decentralised generation. The sources of energy include solar using solar photovoltaics and solar thermal, biomass using gasification technology, geothermal and battery storage.

Conclusion

Decentralized generation systems are small-scale power technologies generally ranging between 3 kW– 10 MW located very close to consumers to provide an alternative or enhancement to the centralized or conventional power system. The DGs are connected directly to the distribution system or on the customer side of the meter which significantly reduces the. transmission and distribution losses of the power system. The high consumption of fossil fuels and global commitments to reduction in energy related emissions has generated huge interest in renewable energy resources for use in power generation. This has increased the opportunities of utilizing decentralist generation systems in power generation. The renewable DG systems may be connected to the grid for peak shaving or as a stand-alone system to serve a particular load or an area. Integrating renewable DGs to the power system has many benefits as well as threats if not well coordinated and integrated into the power system. High penetration of renewables can cause several adverse effects on the distribution systems. like voltage rise, reverse power flow, high line losses, creation of harmonics and reduction in voltage quality. Decentralized power systems units should be designed and operated within limits to maintain optimal quality of the power system There is therefore need for optimal sizing and location of renewable decentralized generation (DG) units in the distribution power system for technical and economic benefits. The penetration of renewable decentralized generation systems is considered as a significant contribution to the world energy and environmental crisis

The main drivers for decentralised generation are the need to use more clean and sustainable nature of renewable resources compared to the polluting and limited fossil traditionally used in power generation. State and governmental commitment advance broader integration of renewable energies and enforcement of the clean environmental agenda to mitigate greenhouse gasses emissions and combat climate change are other factors in increasing adoption of decentralised generation. Renewable DGs offer several benefits like energy sustainability, being emission free, and energy security]. Policies and regulations used to support investments in renewable DGs, are renewable development and reinforcement of portfolio standards, use of public benefit funds for renewable energy, application of output-based environmental regulations, development of standards interconnection, application of net metering, attractive feed-in tariffs, and tax incentives.

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