Journal of Engineering Science and Technology Review 17 (4) (2024) 145-163

Review Article

JOURNAL OF
Engineering Science and Technology Review

www.jestr.org

Planning of Radial Distribution System with Distributed Generation-A Review

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Received 14 December 2023; Accepted 7 June 2024

Abstract

This review provides a comprehensive exploration of distributed generatio n (DG) in the context of radial distribution systems, encompassing various DG technologies, current advancements, and their integration challenges. It evaluates the impacts of DG on distribution networks, highlighting diverse applications, drivers, and benefits. A significant focus is on the optimal integration of DG, assessing various optimization techniques, algorithms, and objective functions used to address this challenge. Through a detailed analysis of existing literature, this study identifies that no single optimization method stands out as universally superior. Instead, the research concludes that hybrid optimization techniques, particularly those combining heuristic methods such as genetic algorithms with other approaches, offer the most effective and reliable solutions for the complex task of DG integration. These hybrid methods leverage the strengths and mitigate the weaknesses of individual techniques, providing more robust and dependable outcomes. This conclusion underscores the need for innovative, multi-faceted approaches to optimize DG integration in evolving distribution systems.

Keywords: Distributed Generation (DG), Renewable Energy Sources (RES),Non-Renewable Energy Sources, Optimization Techniques.

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1. Introduction

The increasing demand for electricity, coupled with the limitations and environmental impact of traditional centralized power generation, has highlighted the urgent need for innovative solutions in the energy sector. Traditional power plants, primarily reliant on fossil fuels, contribute significantly to greenhouse gas emissions, exacerbating climate change and presenting substantial environmental and economic challenges. Additionally, the centralized nature of these power systems often leads to inefficiencies, including high transmission losses and vulnerabilities in the grid's reliability and resilience.

In response to these challenges, Distributed Generation (DG) has emerged as a pivotal component of modern energy strategies. DG involves the generation of electricity from decentralized sources, often located close to the point of consumption. This approach leverages a variety of energy sources, including renewable options like solar, wind, and biomass, as well as non-renewable technologies. By integrating DG into distribution systems, there is potential to enhance energy security, reduce transmission losses, and support the transition towards a more sustainable and resilient energy infrastructure.

This review aims to provide a comprehensive overview of DG by:

1) Examining the fundamentals of DG, including an exploration of its various types and current state of technologies.
2) Analyzing the potential advantages and challenges associated with DG deployment, encompassing technical, economic, and regulatory aspects.
3) Exploring the applications of DG in different contexts, including residential, commercial, and community-based systems.
4) Investigating the drivers and benefits of DG adoption, with a focus on economic, environmental, and technical factors.
5) Assessing the impacts of DG on distribution networks, particularly regarding grid stability and integration.
6) Reviewing optimization techniques utilized in DG planning, highlighting the most effective methods for local system optimization.
7) Identifying the best-suited techniques for developing local DG systems, based on an extensive evaluation of current literature and case studies.

On a global level, increasing electrical load demand prompted a remarkable rise in electric power generation capacity. Traditional power generation is currently unable to satisfy the ever-increasing worldwide demand for electricity. Therefore, distribution generation planning is very important issues in the present power generation scenario. Besides, as power plants are typically located far from load centers, power losses, and voltage drops are high [1-3]. In this respect, installing Distributed Generation (DG) units near load centers can contribute to solving these issues. According to the estimations of the U.S. Energy Information Administration [4] it is expected an electricity generation increase by 93% during the period 2010–2040, and that grow will happens at a rate significantly higher than global energy consumption.

Renewable energy sources will contribute greatly to the power generation mix with an estimated growth for that

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doi:10.25103/jestr.174.17

period of 2.8% per annum, to achieve a weight of 24% of total power generation in the year 2040 (Fig. 1).

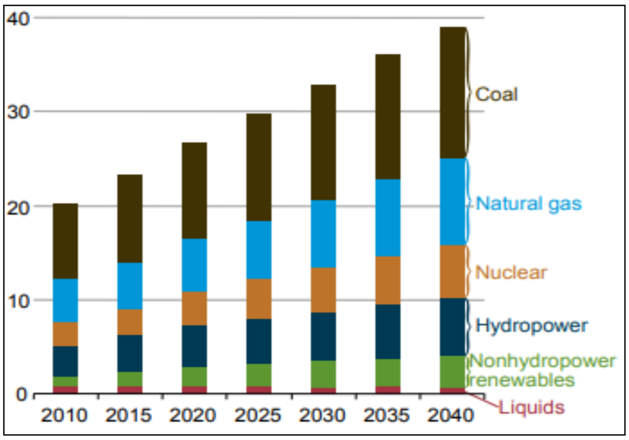


Fig. 1. Evolution of global electricity generation by sources of energy (in trillion kW h).

Traditionally, energy is provided via a centralized power generation system, which is typically composed of a few large-scale generation units and a vast linked network that transports and distributes electricity to homes, businesses, and factories, as illustrated in Fig. 2. In a distributed power generation system, the power flow is unidirectional and the generation units often have huge capacities (such as hundreds of megawatts)[5]. On the other hand, a distributed generation system comprises of small-scale generation units that are directly connected to the distribution network and have capacities that range from a few kilowatts to a few megawatts, resulting in bidirectional power flows [6]. Large capital expenditures, exorbitant transmission costs and losses, the depletion of fossil resources, and growing environmental concerns have recently slowed the growth of centralized systems based on fossil fuel generation [7]. As a result, the power distribution network with a high percentage of DGs from renewable sources is becoming more common.

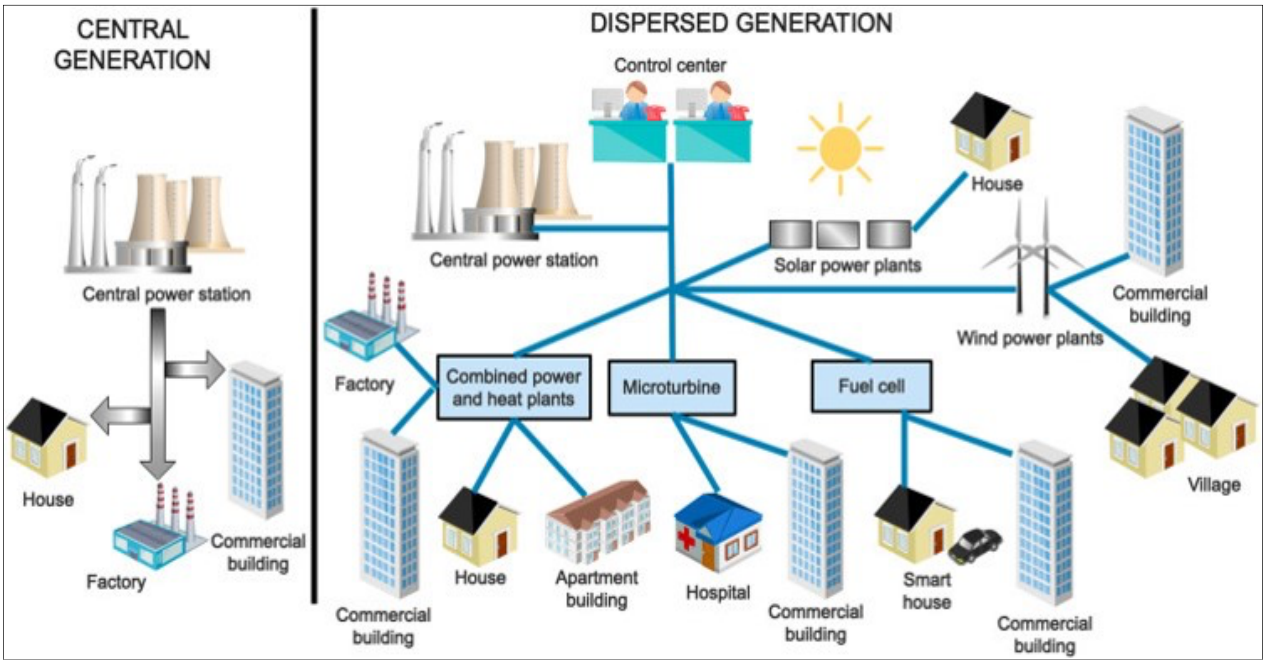


Fig. 2. Central utility of today and distributed technology of tomorrow.

Natural gas is available fairly universally and steady costs can be anticipated. It is frequently utilized as fuel in DG stations. DG plants often demand quicker installation periods with lower investment risk. DG plants produce fairly high efficiency, particularly in coupled cycles and cogeneration (bigger plants). Opportunities for new utilities in the power generation industry are being made possible by the deregulation of the energy market. As it offers a flexible option to select from a large range of cost and reliability combinations, DG delivers excellent values. In Table 1, several generating modes are compared. Be aware that the distributed generation system is a part of the central power system.

Table 1. Detailed comparison of centralised generation and distributed generation (DG)

Aspect	Centralised Generation	Distributed Generation (DG)
Power Generation	The reported range (order of magnitude) is 100 MW–1000 GW [8]; large for reaching economies of scale	Below andupto300MW,withthefollowingcategories[9]: Large: 50–300MW Medium: 5–50 MW Small: 5 kW–5MW Micro: 1W–5 kW
Kind of Technology [10]	Nuclear plant, coal, fuel oil, and gas-based thermal power plants, and hydroelectric plants	Non-renewable: Diesel reciprocating engine, gas reciprocating engine, micro turbine, and combustion turbine Renewable: Solar photovoltaic(PV),solar thermal, wind, low-head hydropower, biomass generation, bio gas generation.

Location	located distant from the load side and typically situated close to the main fossil fuel extraction locations for thermal power plants and water reservoirs for hydroelectric power systems. [11]	Incorporated with customer facilities and closer to the load side
Location of Utility System Penetration	Connected to a high-voltage transmission network, which boosts power before sending it to substations (for further distribution) to reduce line losses. [12]	On-grid DG: Associated with a low-voltage distribution network or client facilities[13] Off-grid DG: Being apart from the utility grid, using customer facilities alone, or using a microgrid system.

Conventional sources include the production of electricity from coal, lignite, diesel, and gas, which account for 49.7%, 1.6%, 0.1%, and 6.1% of the total installed capacity, respectively. With 235.809 GW, or 57.5% of the installed capacity, conventional power sources continue to be the major source of generation [14]. Large hydropower projects, which make up roughly 11.4% of the total installed capacity overall, contribute the second-largest market share. In comparison to prior years, the share of renewable energy has increased, accounting for around 167.750 GW, or 40.7% of total power generation. Renewable energy sources, which make up 15.1%, 10.1%, 2.5%, 1.2%, and 0.1% of the installed capacity respectively, include the production of electricity by solar, wind, biomass, small hydro, and some waste energy. For supplying energy needs in remote and grid-connected locations, solar and wind have been the most well-liked and commonly employed renewable energy sources. Fig. 3 displays the most recent information from the International Renewable Energy Agency (IRENA) for the country-by-country ranking of installed capacity for renewable energy sources.

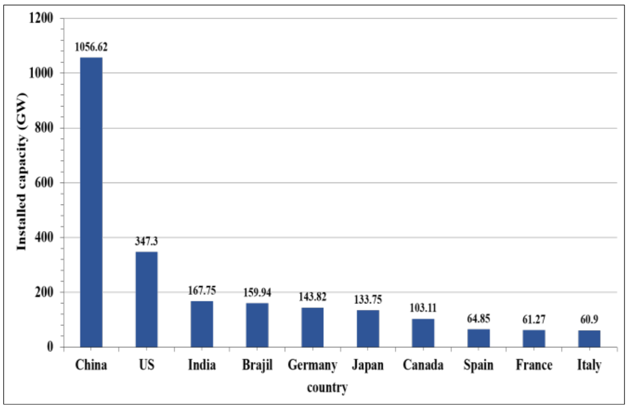


Fig. 3. Renewable energy installed capacity (GW) country ranking.2023

With an installed capacity of 1056.62 GW, China is the world's greatest producer of power from renewable sources, followed by the United States, which accounts for around 247.30 GW, and India, which shared roughly 167.750 GW and ranked third. India, with an installed capacity of 159.94 GW, is in fourth place. With a 60.90 GW capacity, Italy takes the tenth spot.

2. Methodology

The survey was conducted using content analysis. Three screening stages were used to choose the relevant articles for this review. Several platforms, such as IEEE Xplore, Science Direct, Springer Link Google Scholar, Scopus science databases, Web of science, and Research Gate, were used to conduct the first screening of the literature survey between the years 2000 and 2023.The findings indicated that after completing the first screening, the authors discovered 397 articles.

Next, the second screening and evaluation were proceeded using important keywords including distributed generation, renewable energy sources, non-renewable energy sources, optimization techniques and intelligent optimization techniques. The article contents, abstract, and paper title were selected in addition to the keywords in order to locate the appropriate papers. After the second screening, 184 articles in total were found, according to the results. Following that, a third screening and evaluation were carried out using the citation count, review procedure, and impact factor. As a result, 131 articles that had been published recently in books, reputable websites, conferences proceedings, and journals were found. By addressing these objectives and following a rigorous methodology, this study aims to provide actionable insights and recommendations for optimizing the integration of DG into distribution systems, thereby supporting the broader goals of energy sustainability and climate change mitigation.

3. Distributed Generation (DG)

Distributed generation (DG) refers to the generation of electricity from small-scale power sources that are located close to the point of use or within the distribution network, rather than relying solely on large centralized power plants. Depending on the agency, the definition of DG may vary. For instance, the International Energy Agency (IEA) [15] describes DG as a generating facility connected to the grid at distribution-level voltages and servicing a customer directly or supporting a distribution network. A decentralized generation that is smaller than 50-100 MW and typically connected to the distribution network is referred to as DG by the International Council on Large Electric Systems (CIGRE) [16]. The capacity of DG ranges from a few kilowatts to 50 MW, according to other organizations like the Electric Power Research Institute (EPRI) [17]. In a broader sense, a distributed energy resource (DER) is any generation or storage technology that is close to the load centre and has a modular design. Examples of DERs include mini-hydro, wind generators, photovoltaic (PV) systems, diesel generators, fuel cells, batteries, and Demand Side Management (DSM) techniques. In general, distributed generation is defined as "an electric power source directly connected to the distribution network or on the customer site of the meter. “Distributed generation is an alternative for centralized generation. The phrases “distributed generation”, “dispersed generation”, “district generation”, “decentralized generation”, “embedded generation”, “and local generation” and “on site generation” are used interchangeably.

3.1 Different types of DG

According to the active and reactive power supply to the distribution system, DG is divided into the following classes [18]:

3.1.1 DG1 only with active power injection

This kind of DG is connected to the distribution system through power electronic interfaces, typically includes small-scale DG units that operate at a unity power factor. These DG units are characterized by their ability to generate electricity and feed it into the grid without providing reactive power support. Here are some examples of DG technologies that fall into this category: photovoltaic cell, fuel cells, microturbines, batteries, solar systems and biogas, etc.

3.1.2 DG2with active and reactive power injection

This form of DG is based on synchronous machines and operates at 0.80-0.99 leading power factors, like gas turbines and Combined Heat and Power (CHP) units, wind, tidal, wave, geo-thermal, etc.

3.1.3 DG3 with reactive power injection only

These types of DG units provide the necessary reactive power for distribution systems while operating at zero power factor. This category includes synchronous condensors, banks of inductors, banks of capacitors, etc.

3.1.4 DG4 with active power injection and reactive power absorption

Induction generators for wind turbines fall under this category of DG and have a lagging power factor of 0.8 to 0.99. There are various induction generator types available, including fixed-speed, variable-speed, and doubly fed induction generators (DFIG). They take in reactive electricity while also adding active power to the system. Some important variables [19], including the ones listed below, play a role in how DG units are connected to the grid.

- ➢ The kind(s) of DG the system has.
- ➢ The voltage level that will be used to link DG equipment.
- ➢ The generational level that was formerly wired to the grid. The size of the DG linked to the grid;
- ➢ The electrical robustness of the grid at the connecting site.

3.2 Advantages of DG

Fossil fuel use is currently the primary source of pollution emissions. Employing ecologically friendly DG units would be promising in the future as a likely strategy to counteract climate change, given that renewable energy sources (RES) make up the majority of DG and the fact that oil reserves are running out [20]. For a better understanding of their economic benefits, one must first weigh the benefits of using DG. In the graphic below, the benefits of employing DG in electrical distribution networks are briefly illustrated.

3.3 Distributed generation technologies

Both the local level and the end-point level are involved in distributed generation [21]. Local power generation facilities frequently use site-specific renewable energy technologies as wind turbines, geothermal energy generation, solar systems (photovoltaic and combustion), and some hydro-thermal plants. These plants are typically more decentralized and smaller than the conventional model plants. They are frequently more reliable, cheaper, and more energy-efficient. Since these local level DG producers frequently consider the local context, they typically produce less energy that is disruptive to the environment than the bigger central model plants. Many of these same technologies can be used by the individual energy consumer at the end-point level with comparable results. The modular internal combustion engine is a common DG technology used by end-users. At this stage, DG technologies can either function as tiny contributors to the power grid or as solitary "islands" of electric energy generation [22]. The majority of studies do agree that without significant structural adjustments, the electrical network can readily absorb distributed generation up to a level of 10% to 15% of the maximum load. However, this will change. Many networks still have penetration levels below this threshold. The DG technologies are divided into two main categories for easier comprehension: non-renewable energy based and renewable energy based technologies in Fig.5. These are compared based on electrical efficiency and overall efficiency in Fig. 6 (a) and Fig. 6(b) for non-renewable energy and in Fig. 7(a) and Fig. 7(b) for renewable energy respectively.

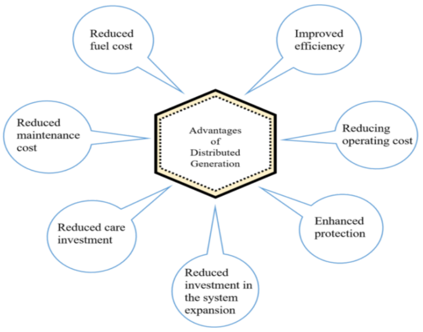
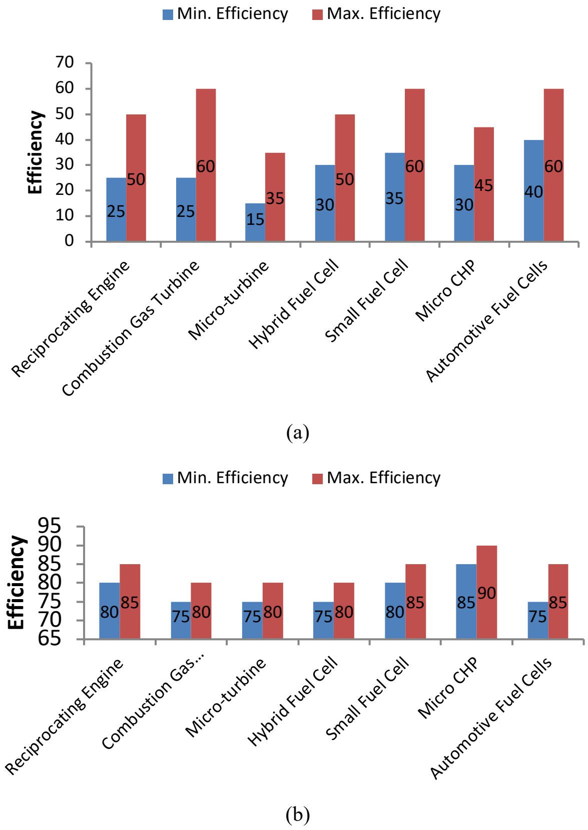


Fig. 4. Advantages of Distributed Generation



(a)

(b)

Fig. 6. (a). Electrical efficiency of Non-renewable energy sources. and (b). Overall efficiency of Non-renewable energy sources.

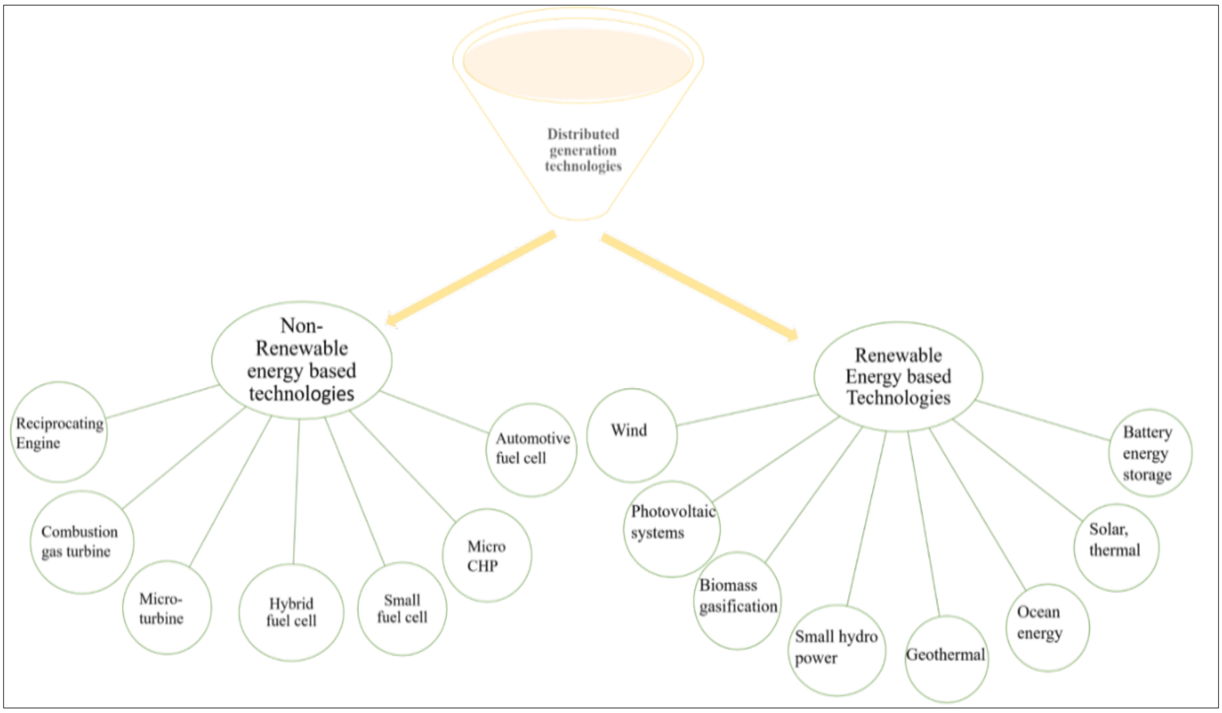
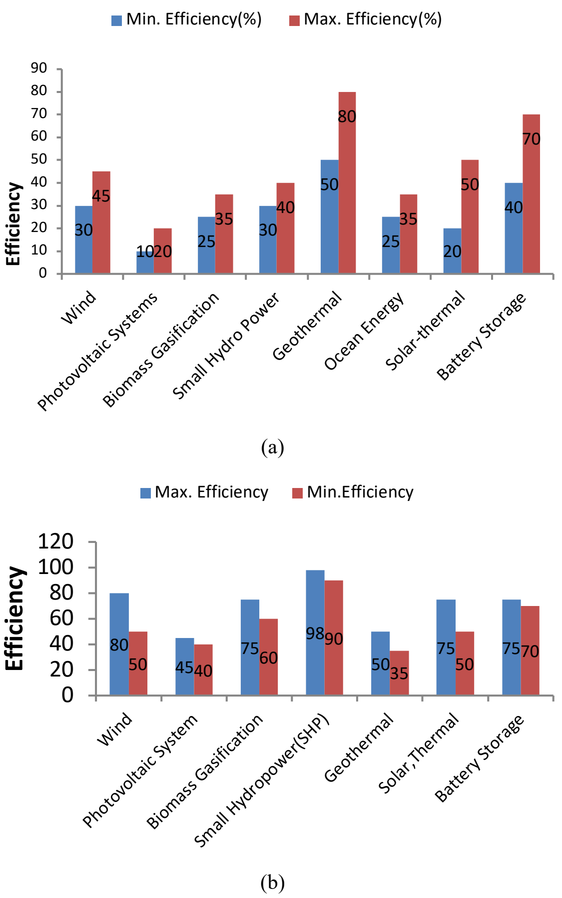


Fig. 5. Distributed generation technologies.



(a)

(b)

Fig. 7. (a) Electrical efficiency of Renewable energy sources and (b) Ov erall efficiency of Renewable energy sources.

The emission characteristics of different electric generation systems are summarized in the Table 2

Table 2. Displays Emission Characteristics of Various Electric Generations in (g/kw)

Sr.no	Technology	SO_2	NO_x	CO_2	CO
1	Thermal power plant	6.48	2.88	623	0.1083
2	Micro-gas turbine	0.000928	0.6188	184.0829	0.1702
3	Fuel cell	0	<0.023	635.04	0.0544
4	Photovoltaic	0	0	0	0
5	Wind	0	0	0	0

3.4 DG applications

Depending on the user's specific needs, several DG technologies may be applied. Figure 8. below lists the most prevalent technological application for systems [23–27].

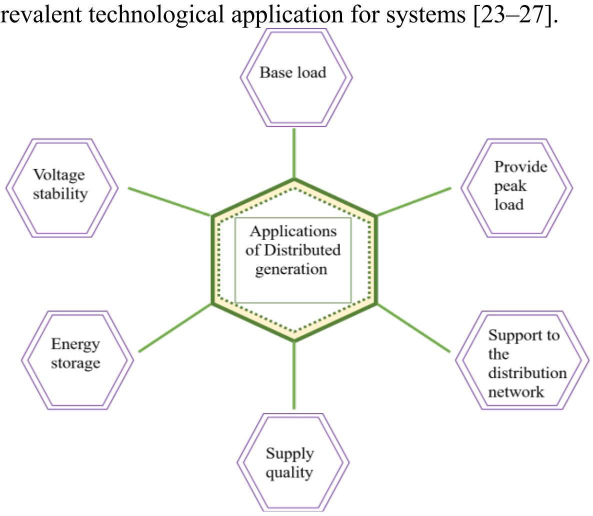


Fig. 8. Applications of Distributed generation

3.5 Drivers and benefits of distributed generation

Environmental, economic, technological, technical, and regulatory drivers, as indicated in fig.9, are the primary factors influencing the expansion of DGs from RES [28–32].

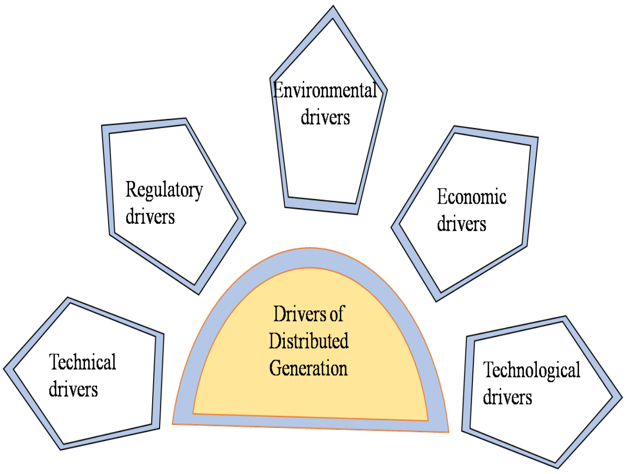


Fig. 9. Drivers of Distributed Generation

3.6 DG Challenges

Distributed Generation (DG) presents several challenges that affect its integration into power systems. These challenges can be categorized into technical, economic, regulatory, and social issues. Here's a comprehensive overview:

The challenges can be listed as follows:

- Reverse power flow: due to the current configuration of the protective circuits being impacted by the connection of DG to the system.
- Reactive power: Asynchronous generators, which are used by many DG systems, do not provide reactive power to the grid.
- System frequency: Supply and demand imbalances are what lead to variations from the system's nominal frequency. The frequency of the system is impacted by the growth in distributed generation, and because these generators could end up as "free riders," controlling them becomes more challenging.
- Voltage levels: The distribution network's voltage profile is altered by the installed distributed generating due to the altered power flow magnitudes. In congested networks with low voltage issues, the voltage profile will typically tend to grow, which is not a problem as would be the case otherwise.
- Protection schemes: As was already noted, the majority of distribution networks are set up as split rings and in radial design. The protection system is created in accordance with the unidirectional flow patterns that are generated as a result. When dispersed generation is installed, the flow is forced to become bidirectional, necessitating the installation of additional safety measures as well as a network resizing (grounding, short circuit, breaking capacity, Supervisory Control and Data Acquisition (SCADA) systems, etc.).

  As a circumstance in which a section of the utility system that comprises both load and distributed resources stays electrified while being separated from the rest of the utility system, islanding protection is a crucial security measure. A DG could be feeding a short circuit, creating the threat of fire or activating a specific area of the network, which could put workers who come into touch with itat risk of dying if they aren't promptly informed that it might be activated. Placing protective devices like transfer switches and electrical or mechanical relays is one method to solve the problem. g. Harmonics injection into the system by asynchronous DG sources which use inverters for interconnection.
- Problems with stability.
- Depending on where the DG units are located, increased fault currents.
- If renewable energy sources are utilised, there will be a high cost per kW generated because these technologies are still in their infancy.
- The use of power electronics to manage SPV wind energy systems causes an issue with power quality [33–35].

The various issues have been clearly identified and discussed; however, the over-voltage issue at various nodes brought on by the addition of DG to the distribution network needs special consideration. It is necessary to analyze this technological issue in order for the distribution network to operate properly.

3.7 Impact of distributed generation

Depending on the kind, DG will have both favourable and unfavourable effects on distribution networks, as shown in Table 3. As a result, power system academics have recently focused a lot of emphasis on the issue of DG planning to get the most out of this emerging power generating technology without endangering the already-existing power system architecture.

Table 3. Impacts of distribution system allocation on DG.

Type of impact	Non- Renewable DG	Renewable DG
Environmental	–	✓
Voltage stability	✓	✓
Reverse power flow	✓	✓
Reliability	✓	–
Deferring upgrades of power system	✓	✓
Reduction of electricity tariff	✓	✓
Reduction of green house gases	–	✓
Cost saving	✓	✓
DG allocation flexibility	✓	–
Loss minimization	✓	✓
Safety	✓	✓
Islanding	✓	✓
Stiffness in distribution bus voltage	✓	–
Islanding response	✓	✓

Distribution systems are created with the presumption that electricity moves from the power system to the load, as was previously mentioned. Therefore, there is likely to be some impact on the total distribution system in terms of power losses, voltage profile, dependability, power quality, protection, and safety if output variations or a reverse flow from generators occur on the grid due to DG. Below is a description of the probable effects of DG [36].

3.8. Factors motivating the DG era

The restructured electrical system, where there is more supply and demand volatility, is drawing a lot of attention to DG installation. The primary drivers of DG era's success [37-38] include:

- In comparison to the usual solution, modularity and compact size allow for more resilient installation in a shorter amount of time.
- Less likelihood of interruption of the power supply due to the advantages of quick and simple maintenance provided by the modular structure.
- A properly positioned and properly constructed DG might significantly reduce system losses.
- Enhances the voltage profile.
- Increases system reliability.
- Reduces system clogging.
- Enhanced power quality.
- Improves the system load capability while making different investments in system improvements.
- Reduces health risks because of an unaltered environment.
- Especially with cogeneration, can produce reasonably high efficiency.
- Efficiency growth brought on the lower fuel prices.
- Wide variety of DG technologies available.
- Excellent scale economies.
- Being able to select from a variety of cost and reliability combinations.
- Because of its modular nature, it can track load variation more precisely.
- Respond to the energy requirements of increasing load.

3.9 Techniques for DG allocation and sizing

The literature has taken into account a variety of goals, including power losses, voltage stability, power quality, etc. to address the problem of DG positioning and sizing in power systems. If the DG of appropriate size is not connected at optimal locations, the system performance in terms of power loss, stability, power quality, and protection may suffer. Therefore, proper DG distribution and sizing are essential for both utility and consumers [39].In order to successfully address this optimization problem while taking these objectives into account, various strategies have been described in thisreview study. There are four different categories of DG allocation and scaling techniques: conventional methods, artificial intelligence-based methods, hybrid methods, and software tool-based plans, as shown in Figure 10.

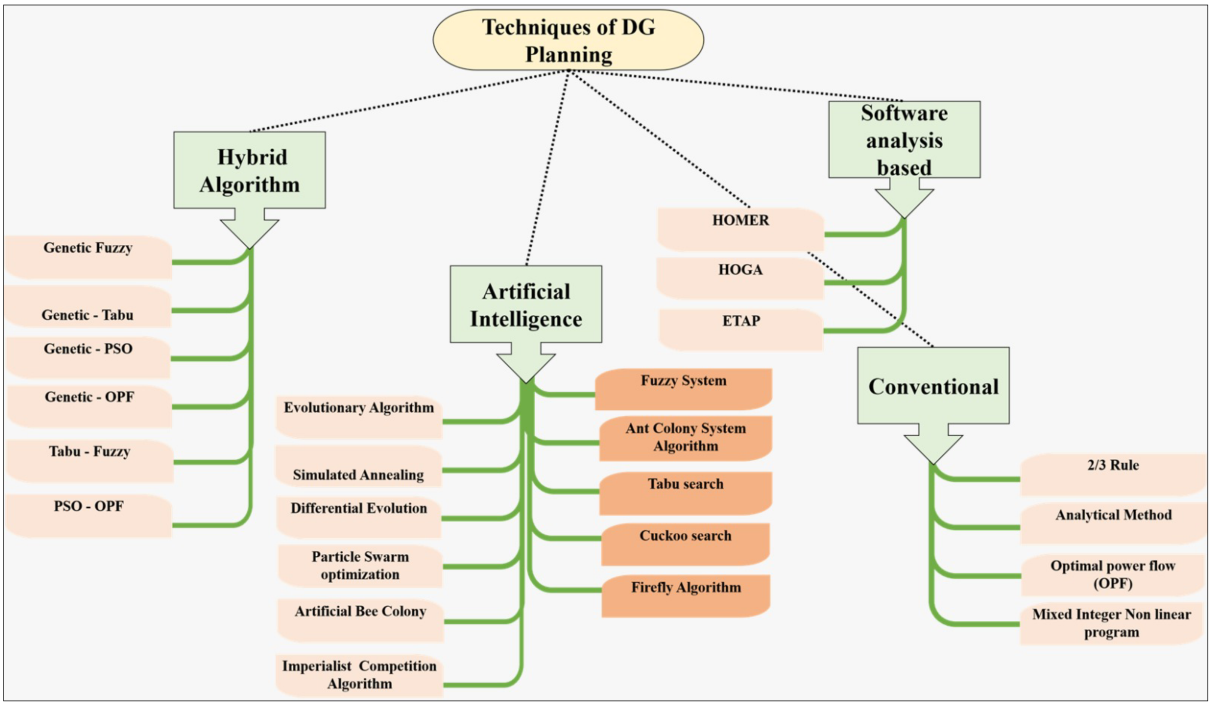


Fig. 10. Techniques of Distributed Generation Planning

3.9.1 Conventional Methods

Traditional procedures, which use iterative, numerical, graphical, and probabilistic methods, are the most time-tested manner of resolving optimization issues. It is a straightforward and precise method for a small distribution network because it uses a nonlinear complex equation to get the ideal solution and is able to solve an objective function. Iterative, numerical, analytical, probabilistic, and graphical construction techniques are used in traditional ways to calculate the proper location and amount of DG in a distribution network.

3.9.2. Artificial / Heuristic Methods

Another strategy for solving the optimization problem that successfully handles many objectives is artificial intelligence. It is also employed to get around the limitations of conventional approaches. AI approaches suggest the meta-heuristic search approach as a method for solving optimization issues as effectively as possible.

3.9.3. Hybrid Methods

Hybrid methods are defined as the combining of two or more methods with increased adaptability and optimization effectiveness. Modern approaches known as hybrid methodologies integrate two or more artificial algorithms to efficiently and quickly handle multi-objective problems. For extensive bus distribution networks, they are able to produce precise results. These methods are becoming increasingly effective at handling complex, non-linear, multi-objective functions.

3.9.4.Software Tools

To address a particular sort of problem, software tools are described using a special computational simulation module. They are only useful for solving clearly stated problems; multi-objective tasks are not suitable for them. Today, computer programs called Photovoltaic-wind, Photovoltaic-battery, Wind-battery, and Photovoltaic-wind-battery are utilized to optimize hybrid renewable energy systems. They are based on a certain mathematical computing technique for simulation, which makes calculations easier. Possibile software tools like HOMER, HOGA, IHOGA, ETAP, etc. can be utilized to solve this issue.

A comparative study with merits, demerits and the field where the above techniques can be applicable is discussed in Table 4.

Table 4. Comparison of Methods.

Methods	**Merits**	**Demerits**	**Major Applicability**
Conventional Methods	Simple to execute Non-iterative and Iterative in nature Solutions available Robust	Inaccurate Computational time high Failing to solve a complicated system	Applicable on small and medium distribution system Deterministic
Artificial Methods	efficient with numbers precise in calculations Several iterations may be considered can be applied to difficult problems	Not as sturdy Several different data sets were required for training Unstable Unsure	Suitable for medium-sized and large-scale distribution networks
Hybrid Methods	Precise outcomes High Robustness Extremely rapid rate of Convergence	In order to validate errors, a lot of test data are needed.	Massive distribution systems Suitable for dynamic modeling
Software-based tools	Utilized for the special computational issues Simple techniques that are easy to employ	Unfit to perform multi-objective functions There are numerous challenges for which there are no practical tools.	Only suitable for a particular class of issues

Table 5. Various analytical approaches/techniques used for optimal planning of DGs.

Ref. Year	**Approach**	**Algorithm**	**Problem formulated as/ Objectives**	**Merits**	**Remarks**	**Type of DG/ Type of ESS**	**Test System**
[40] 2000	Conventional	2/3 rule	Analysis using a "zero point" approach	Loss minimization and can be used to examine the effect of DG on feeder flow.	Effective for a load that is evenly distributed, but the solution deviates from the theory for a load that is more spread and centrally distributed.	Small DG unit produces 3 MW	2 bus system
[41] 2004		Linear differential	Analytical minimize the power loss	Optimal location of DG in radial as well as networked systems ,minimization of power loss ,results were received quickly and without any convergence issues.	DGs only with a unity power factor are taken into account, and DG size is not thought to be maximized. Other aspects including economic and regional concerns may need to be taken into account throughout the process of identifying the best bus for putting DG. These aspects aren't covered in this work.	Wind	A test system for the IEEE 30-bus and a component of it, a 25-kV IEEE 6- bus networked system,
[42] 2009		Classical grid search	In accordance with loss	Determined the ideal DG size and position reduces overall	Iterative strategy Losses	Small DG unit produces 5	Distribution test systems

		algorithm.	sensitivity calculations and employing equal current injection	power losses	of energy not calculated	MW	for 12 buses, 34 buses, and 69 buses
[43] 2010		Mixed integer nonlinear programming	Energy and power loss	Different types of DG units for renewable energy have been strategically placed in the distribution system to reduce annual energy loss.	Computationally demanding	Solar ,wind and biomass	Typical rural distribution system
[44] 2011		Multi-objective function	Dynamic programming / voltage profile and power flow	To achieve practical results, this optimization uses time-varying load, while all studies and their requirements are based on cost-benefit analyses.	Methodology that is difficult Unaccounted for energy losses	Medium DG upto 20MW	8 buses test system which is served by a high voltage distribution substation (132-33 kV)
[45] 2013	Conventional	Linear programming	To determine the DG unit's location, size, and power factor for minimizing energy losses	By taking into account the interaction of time-varying demand and various DG output curves, It is simple to adapt energy loss reduction strategies to various types of renewable DG..	Because it is not realistic, it is assumed that the bus voltage does not change significantly after DG insertion.	Solar ,wind and biomass	69-bus radial distribution system
[46] 2017		Optimal power flow (OPF)	Voltage magnitude variations, and ESS integration investment costs	introduces the active distribution network for the first time into the positioning and size issue for the ideal ESS.	Iterative approach; computationally challenging	DG: Solar ESS: battery	A basic grid with 11kV,6 lines and 6 nodes, an 11 kV radial distribution system with 70 buses
[47] 2018		Sensitivity method	Stability of voltage	Increases the margins for system stable voltages efficiently, calculates quickly, and supports real-time application	This method might be easily used in scenarios taking into account load profiles and the creation time-varying patterns of DGs in further works.	PV	IEEE systems with 6, 14, 30, and 57 buses
[48] 2018		Linear programming	Ability to host PV	Successfully increases the distribution system's ability to host PV; quick computation	Complexity increases for huge systems	Solar DG	IEEE 123 bus and a tiny 15. bus, 12.47 kV radial distribution system
[49] 2018		Optimal power flow	Real power loss	Consideration is given to how wind intermittency affects power grids in the fast process for allocating wind electricity.	The study of many important economic issues is not covered in this work.	Wind	34-bus and 70-bus radial test system
[50] 2019		Monte Carlo	Line loss and installation costs for renewable DG units	An improved method makes it easier to employ MCS to model RES and load uncertainty.	Difficult formulation	Wind and PV	The real 135-bus and 201-bus test systems and IEEE 32-bus test system
[51] 2021		Empirical discrete algorithm	Power reduction and voltage sag	Simpler to implement and fewer variables	Future work could analyze the system's economics.	Solar DG and fuel cell	IEEE 34and 123-bus distribution networks
[52] 2000	Artificial intelligence /Heuristic approach	Power Flow Analysis	Using a heuristic iterative search strategy	Easily understood demonstrates how the effective capacity of DG units can be significantly impacted by their right position.	Iterative process produces inaccurate results	Micro DG	Eastern Washington system as a component of the WSCC system as a whole
[53] 2001	Heuristic/ Metaheuristic approach	Tabu search algorithm	The size-search method and the DG allocation algorithm are separated in	The Tabu search algorithm is used nestedly to find the locations and discrete capacity of DGs to minimize the distribution loss.	not taking into account energy losses	fuel cells	Two versions of distribution systems that combine

			order to streamline the solution process				industrial, commercial, and residential loads
[54] 2004	Artificial intelligence techniques	Genetic algorithm	Power flow equations/power loss	Utilizing both discrete and continuous characteristics, they strive to reduce overall actual power losses.	Iterative process accuracy issues when a quality solution is needed	3 MW	30 loads distribution system
[55] 2005	Artificial intelligence techniques	Genetic optimization algorithms	Using exhaustive search, solve a non-convex optimization problem	Optimal size and placement of distributed power units in a grid serving residential properties, Power losses are minimized while the voltage profile is maintained at a reasonable level.	For complex systems, the method might not converge.	PV and CHP	Grid topology in use with information on production and residential load
[56] 2007	Meta heuristic approach	Ant colony optimization	A cost based model	In relation to overall power losses lowering the total cost of operation and the DG investment optimizes the number and position of dispersed generation sources	Reliability of the system is not included in the model.	4MW	9-bus distribution system
[57] 2009	Artificial intelligence techniques	Multi-objective genetic algorithm	Genetic algorithm	Examines how the size and location of a DG are affected by load models. When there are less-than-ideal alternatives, GA may be performed numerous times.	GA and multi-objective optimization combined	-	16and 37-bus distribution systems
[58] 2012	Meta heuristic approach	PSO	multi-objective index-based approach	Optimizing the size and placement of multiple DG units in distribution systems with various load models	Complicated methodology	-	IEEE-34 and IEEE-123 bussystem
[59] 2012		GA	Multi-objective approach	Maximize electricity systems' capacity to handle load	Accuracy issues when a quality solution is needed	-	Test system of 9-bus
[60] 2018		Salp swarm	power quality, operating expenses, and power loss	Shunt capacitor banks and distributed renewable generators are simultaneously and accurately dispersed	The approach might not be able to converge in large systems.	Fuel cell, wind, and PV ESS: electrolysis of water	IEEE 33-Bus system
[61] 2018		Clustering-based approach	Yearly loss of energy, expenditure and voltage improvement	A novel distributed multi-agent technique for simultaneous planning of wind DGs and shunt capacitor banks	Does not assure the best resolution	Wind	IEEE unbalanced test feeders, each with 37 and 123 nodes.
[62] 2018		Ant lion	Total power lost and voltage profile	Remarkable effectiveness in minimizing electricity losses and costs while taking into account various technical constraints while distributing DG units.	There is further work to be done to validate the suggested algorithm's performance on large-scale distribution power networks.	PV, wind	12.6 kV radial distribution system with 69 buses
[63] 2018		Modified shuffled frogleaping (MSFLA)	Voltage sensitivity, overall actual power lost	Comparing the proposed approach to the shuffling frog leaping and modified PSO algorithms, For real power loss minimization	The optimization procedure does not take economic factors into account.	Wind	IEEE-30 bus system
[64] 2018		Moth-flame	Power loss of system, voltage profile, and total yearly operating costs	allocating DGs, take into account the shunt capacitor banks' maintenance and operation expenses.	To demonstrate the superiority of the suggested model, additional DG types, including biomass, hydro-turbines, and fuel cells, can be modelled.	Solar and wind	Systems for DGs IEEE 33-bus and 69-bus, 111-bus with a 12.66 kV rated voltage

[65] 2019		Bird swarm algorithm	Voltage profile and system loss	to reduce line loss and voltage deviation, various types of renewable DG units have been optimally placed	System reliability is not included in the model.	Energy production from biomass and the sun	A 52-bus, 11 kV, realistic radial distribution network in India
[66] 2021		GA	voltage stability, power loss, and phase angle variation	Different system contingencies are created to achieve practical outcomes.	The potential for using the suggested methods in a bigger system could be explored.	Synchronous generator	11 kV-rated 9-bus test systems
[67] 2021		Multi-objective sine cosine algorithm	Power loss, power quality, and emission	DG planning is first time done using a modified multi-objective sine cosine method.	In addition to photovoltaic power, the viability of other forms of renewable energy is not examined.	Photovoltaic	33and 69-bus distribution systems
[68] 2022		Artificial hummingbird algorithm (AHA)	Investment cost, electrical power quality, and emissions	The optimal allocation problem is resolved with a brand-new effective optimizer, AHA.	Enhancing reliability is not taken into account	PV, wind	33-bus and 94- bus test network
[69] 2001	Hybrid approach	GA.	Multi-objective programming / reduces the energy losses costs.	Reduce costs and losses, and rapidly and accurately consider a wide range of planning options in a real-size distribution network scenario	computationally needed	Wind	a section of the real MV Italian network
[70] 2004		Tabu Search-Fuzzy (TSFZ)	Multi-objective fuzzy model for optimum planning	Determines the ideal site and dimensions for future feeders and substations, The model also makes it possible to choose the appropriate reserve feeders (in terms of size and placement) for a particular level of resilience, providing the best reliability at the best price.	Computationally needed	-	Electric utility network in Spain
[71] 2008		Genetic-Fuzzy (GA-FZ)	Model with several objectives: Using a multi-objective genetic algorithm, true Pareto-optimal solutions are discovered, and a max-min technique is used to discover the ideal answer.	Reduction of the financial cost index, which includes investment, DG unit operating costs, and loss-related costs Technical risks (such as the possibility that voltage and loading restrictions may be broken due to load uncertainty) and Economic risks brought on by the ambiguity of the electricity market price	Complexity increases for massive systems	-	9-bus primary distribution network with modifications
[72] 2011		Evolutionary algorithm	The genetic algorithm and "Particle Swarm Optimization (PSO)" are combined in the Modified Shuffled Frog Leaping Algorithm (MSFLA).	Superior DG sizing and location leads to a better voltage profile and less power losses	Not accounting for energy losses Methodology that is difficult	-	IEEE 33-bus system
[73] 2013		Non-dominated Sorting Genetic Algorithm II (NSGAII),	2-Point Estimation Method/ To deal with the optimization problem, a reliable, widely utilized method of multi-objective dilemmas is applied.	When deciding on the size and location of DG units in distribution systems, the total imposed costs, total network losses, customer outage costs, as well as absorbed private investment minimization, were all taken into account along with other technical constraints.	Challenging methods	-	IEEE 37-Bus standard test system
[74]		Affine Power	Determine the	ESSs are distributed according	With a larger	DG: solar ,	A revised

2017		Flow method and Improved Immune Genetic Algorithm (IIGA)	capital expenditure and cost resulting from voltage fluctuations for ESSs.	to the technical and economic requirements that includes both solarand wind DG.	system, one may investigate the optimal distribution of ESSs.	wind ESS: Na/S battery	version of the IEEE 33-bus that has a significant DG penetration
[75] 2018		PSO, SAPSO	Reduction of energy storage capability, yearly cost, and voltage variation	Presents the best location for hybrid energy storage systems (ESSs) in power distribution networks when combined with distributed solar sources. It takes advantage of the hybrid energy storage system's optimal capacity design.	the system's economics might be examined in relation to the capacity optimization of the storage.	ESS: supercapacitor, battery DG: PV	23 kV IEEE 14-bus test distribution feeder
[76] 2019		(GPSO-BFA)	Costs, dangers, and load loss associated with system operation	Developed a comprehensive set of risk and economics indices to assess risk variables in the setup and allocation of DGs.	Iterative approach	Wind , micro-gas turbine (MT), and solar	69-node American PG&E system. 12.66 kV
[77] 2021		Harris Hawks and Grey Wolf algorithms (HHA-GWA)	Total expense, power loss, and voltage profile	For EVs to reach the adjacent charging station, traffic congestion is decreased	ESS allocation might be taken into account jointly to reduce costs overall.	Solar	System with 33 nodes for radial distribution
[78] 2021		Geographical Information System Multi-Criteria Decision-Making method (GIS-MCDM)	System dependability, RES hosting capacity, and overall yearly running costs	Fulfills both the geographical and climatic requirements for building PV plants simultaneously.	System dependability is not researched.	PV	A system for medium-voltage distribution
[79] 2021		GA and PSO	Network stability	An efficient way for assessing smart grid stability	Voltage flicker, voltage fluctuation, and power quality characteristics may all be problematic	Solar, wind, and diesel	IEEE 33-bus system
[80] 2021		Grey Wolves and Particle Swarms (EGWO-PSO)	Energy cost, emissions, quality of the power and power loss	In order to obtain the lowest cost and emission, assemble the grid by allocating DGs and capacitor banks.	The output of renewable DGs' uncertainty is not taken into consideration	Wind, solar, and gas turbines	IEEE 33- and 69- bus systems
[81] 2022		(BGA) and (BPSO)	Cost of the ESS for investment and operation	It is taken into consideration how load demand varies throughout the year.	Future research could examine the problems with congestion management.	ESS: battery DG: PV	IEEE 24-bus system

Here's a comprehensive tabular literature review on Distributed Generation (DG), with detailed background on its definitions, types, and technological implementations. This table includes critical comparisons and highlights gaps in the current literature up to 2024.

Table 6. Critical Literature Review

Aspect	**Study**	**Key Findings**	**Critical Comparison**	**Gaps in Literature**
Definitions and Overview	[82]	Defines DG and its classifications, focusing on small-scale power generation.	Lays foundational technical definitions but lacks context on modern developments.	Needs integration with smart grid and evolving regulatory frameworks.
	[83]	Discusses economic, technical, and environmental benefits of DG.	Extends to economic and environmental dimensions, but limited on regulatory impacts.	Insufficient focus on emerging market mechanisms.
	[84]	Examines DG's role in enhancing network reliability and resilience.	Highlights reliability benefits but lacks cost analysis and regulatory implications.	Requires further economic viability studies.
	[85]	Reports on global DG trends and their impacts on energy systems.	Provides a broad overview of DG trends but lacks detailed regional analysis.	Need for region-specific studies on DG impacts.
	[86]	Technical guidelines for	Offers technical	More holistic approaches

		DG integration into power systems.	integration guidelines but less on economic and social aspects.	needed for DG integration.
	[87]	Discusses market dynamics influencing DG adoption.	Focuses on market aspects, lacking technical and regulatory perspectives.	Need for interdisciplinary studies on market, technical, and regulatory integration.
	[88]	Highlights DG's role in renewable energy integration and grid modernization.	Emphasizes renewable integration but lacks detailed technological pathways.	Detailed pathways for integrating DG with emerging technologies required.
	[89]	Evaluates regulatory challenges and opportunities for DG.	Discusses regulatory aspects but lacks integration with technical challenges.	More research on harmonizing technical and regulatory frameworks.
	[90]	Analyzes impacts of DG on power quality and system stability.	Focuses on power quality impacts but limited on mitigation strategies.	Development of mitigation strategies for power quality issues.
	[91]	Reviews policy frameworks supporting DG in different regions.	Examines policy impacts but less on technological integration.	Need for studies combining policy analysis with technology implementation.
Types of Distributed Generation	[92]	Discusses solar PV systems, highlighting efficiency improvements and cost reductions.	Emphasizes solar PV's viability but less on integration with other DG types.	Integration strategies for combining solar PV with other DG systems.
	[93]	Analyzes hybrid renewable energy systems, showcasing performance optimization.	Highlights benefits of hybrid systems but lacks implementation challenges.	More focus on real-world implementation of hybrid systems.
	[94]	Reviews wind DG, covering small and community-scale turbines.	Focuses on wind energy, but limited on integration with storage solutions.	Need for comprehensive studies integrating wind DG with storage.
	[95]	Discusses DG based on fuel cells and micro-turbines.	Explores diverse DG technologies but lacks economic analysis.	Economic feasibility studies for emerging DG technologies needed.
	[96]	Reviews microgrid configurations incorporating various DG types.	Emphasizes microgrid benefits but lacks integration with existing grids.	Integration challenges with large-scale grid systems.
	[97]	Examines bioenergy-based DG, focusing on small-scale applications.	Highlights bioenergy potential but less on cost and scalability.	Research on scaling bioenergy DG and cost-effective implementation.
	[98]	Analyzes geothermal DG and its potential for base-load generation.	Focuses on geothermal viability but lacks integration with intermittent DG sources.	Integration strategies with intermittent DG like solar and wind.
	[99]	Discusses multi-generation systems combining heat and power generation.	Explores combined heat and power but limited on integration with renewable DG.	Studies on combining multi-generation systems with renewable DG needed.
	[100]	Reviews mini-grid systems for rural electrification using various DG types.	Emphasizes rural electrification benefits but lacks urban application analysis.	Application studies for both rural and urban contexts needed.
	[101]	Evaluates nuclear-based small modular reactors for DG.	Focuses on nuclear DG, lacking in renewable integration analysis.	More studies on integrating small modular reactors with renewable DG.
	[102]	Analyzes DG using tidal and wave energy for coastal applications.	Highlights niche applications but less on broader integration challenges.	Comprehensive analysis of marine energy DG integration with grids.
Technological Implementations	[103]	Reviews solar PV advancements, including cell efficiency and cost reductions.	Focuses on PV technology, but limited on system integration.	More on integrating advanced PV with grid and storage technologies.
	[104]	Explores the role of energy storage in DG, focusing on battery technologies.	Provides a broad overview but less on specific DG-storage integration.	Detailed studies on integrating storage with various DG technologies.
	[105]	Discusses advancements in wind turbine technologies for DG.	Focuses on wind technology improvements, lacking in hybrid system analysis.	Studies integrating wind DG with other renewable sources needed.
	[106]	Reviews smart grid technologies supporting DG integration.	Emphasizes smart grid benefits but lacks on-ground implementation examples.	Real-world examples and pilot projects for smart grid-DG integration.

	[107]	Analyzes microinverter technology for solar DG systems.	Highlights microinverter benefits but less on broader system integration.	Integration of microinverters with other DG and grid technologies.
	[108]	Reviews combined cooling, heat, and power systems in DG.	Focuses on combined systems but limited on renewable energy integration.	Need for studies combining cooling, heat, and power with renewable DG.
	[109]	Examines energy management systems for optimizing DG operations.	Discusses EMS benefits but lacks integration with diverse DG types.	Integration of EMS with various DG technologies for optimized performance.
	[110]	Reviews advances in hydrogen-based DG technologies.	Highlights hydrogen DG potential but lacks integration with renewable sources.	Studies on integrating hydrogen DG with renewable energy systems.
	[111]	Discusses blockchain technologies for DG transactions.	Explores blockchain benefits but limited on technical integration aspects.	Need for practical implementation studies of blockchain in DG systems.
	[112]	Analyzes advancements in DG communication technologies for smart grids.	Focuses on communication technologies but less on economic impacts.	More research on economic impacts of advanced DG communication technologies.
Applications of Distributed Generation	[113]	Evaluates the economic viability of residential rooftop PV systems.	Emphasizes economic benefits for households, less on broader applications.	Broader evaluation of DG impacts across various sectors needed.
	[114]	Reviews DG benefits in community microgrids for improved energy access.	Highlights social benefits for communities but lacks urban focus.	More studies on DG applications in both rural and urban settings.
	[115]	Discusses business models for DG in community energy systems.	Focuses on business models, less on technical challenges.	Research on combining business models with technical and regulatory aspects.
	[116]	Reviews DG applications in industrial microgrids.	Emphasizes industrial benefits but lacks residential and community integration.	Integration studies for industrial, residential, and community DG applications.
	[117]	Examines DG's role in disaster resilience and recovery.	Highlights DG for disaster resilience but less on everyday applications.	Need for studies balancing disaster resilience with regular DG operations.
	[118]	Analyzes DG applications for grid modernization and resilience.	Focuses on grid modernization but limited on local level impacts.	Detailed studies on local impacts of DG on grid modernization needed.
	[119]	Discusses DG for off-grid applications in remote areas.	Highlights off-grid benefits but lacks on-grid integration strategies.	Research on strategies to integrate off-grid DG with main grid systems.
	[120]	Reviews DG applications in urban microgrids.	Focuses on urban benefits but less on integration with traditional grid.	Need for studies on integrating urban DG with existing grid infrastructures.
	[121]	Discusses DG for improving energy security in developing regions.	Highlights energy security benefits but less on technological challenges.	More focus on overcoming technological and regulatory barriers in developing regions.
	[122]	Evaluates economic and environmental impacts of DG in smart cities.	Emphasizes smart city benefits but lacks detailed cost analysis.	Comprehensive cost-benefit analysis for DG in smart cities needed.
	[123]	Reviews DG's role in reducing urban carbon footprints.	Highlights environmental benefits but limited on practical implementation.	Practical implementation strategies for urban DG to reduce carbon footprints needed.
Optimization Techniques for DG Planning	[124]	Reviews analytical methods for optimizing DG placement.	Provides deterministic insights but limited on handling complex problems.	Research on combining analytical with heuristic and simulation methods needed.
	[125]	Evaluates heuristic methods, particularly genetic algorithms, for DG optimization.	Highlights robustness of heuristic methods but lacks integration with other approaches.	Integration of heuristic with simulation-based optimization methods required.
	[126]	Analyzes simulation-based methods for optimizing DG operations.	Focuses on simulation benefits but less on real-world applicability.	Studies on real-world application of simulation methods for DG optimization needed.
	[127]	Reviews stochastic optimization techniques for DG planning under	Emphasizes uncertainty handling but lacks practical implementation.	Practical studies on applying stochastic optimization in real DG

		uncertainty.		scenarios needed.
	[128]	Discusses multi-objective optimization methods for DG placement and sizing.	Highlights multi-objective benefits but limited on integration with heuristic methods.	Need for studies combining multi-objective with heuristic optimization techniques.
	[129]	Evaluates machine learning techniques for optimizing DG operations.	Focuses on ML benefits but lacks integration with traditional methods.	Research on combining ML with traditional DG optimization techniques needed.
	[130]	Reviews metaheuristic optimization methods for DG systems.	Highlights metaheuristic flexibility but lacks comparative analysis with other methods.	Comparative studies of metaheuristic with other optimization methods required.
	[131]	Discusses big data analytics for DG optimization.	Emphasizes big data benefits but lacks integration with traditional optimization.	Studies on integrating big data analytics with traditional DG optimization methods.

This table synthesizes critical findings from a wide range of sources on distributed generation, providing a robust foundation for understanding current trends, technological advancements, and optimization strategies in DG. It highlights gaps and areas needing further research, especially the integration of DG with modern grid technologies, interdisciplinary approaches combining market, technical, and regulatory perspectives, and real-world validation of optimization techniques.

4. Result and Discussion

4.1 Increased Adoption and Technological Advances

The literature reveals a significant trend towards the adoption of distributed generation (DG) technologies across diverse sectors. Innovations in solar photovoltaics, wind turbines, and combined heat and power (CHP) systems are driving this trend. Advancements in energy storage, especially battery technologies, are further enabling more effective integration of DG into existing distribution networks.

4.2 Shift Towards Renewable Energy Sources

There is a growing emphasis on renewable energy sources for DG, motivated by environmental concerns and policy support. Solar and wind power are the most prevalent, with their technological maturity and declining costs making them increasingly viable for widespread deployment.

4.3 Emphasis on Smart Grid Integration

Integrating DG with smart grid technologies is emerging as a key area of focus. Smart grids offer enhanced control, real-time monitoring, and improved resilience against grid disturbances, making them ideal for managing the intermittent nature of renewable DG sources.

4.4 Development of Hybrid Optimization Techniques

A notable trend in the literature is the development of hybrid optimization techniques combining heuristic, analytical, and simulation-based methods. These techniques are gaining traction due to their ability to address the complex, multi-objective nature of DG planning and integration.

4.5 Implications for Future Research

Future research should focus on validating hybrid optimization techniques in real-world settings, exploring their applicability to various scales and contexts of DG integration. Additionally, more studies are needed on the socio-economic impacts of DG to ensure that the benefits of these technologies are equitably distributed.

5. Conclusion

This review comprehensively examines distributed generation (DG), focusing on its foundational principles, integration complexities, and impacts on distribution systems. It discusses various DG types such as solar, wind, and combined heat and power systems, noting their distinct benefits and integration challenges. Technological advancements have bolstered DG's efficiency and reliability, but they have also introduced new complexities in terms of grid stability and power quality. The review emphasizes DG's potential benefits, including enhanced energy efficiency, reduced transmission losses, and improved grid resilience. However, these advantages are tempered by challenges like the need for sophisticated control systems, increased grid management complexity, and significant infrastructure investments. Understanding these factors is crucial for maximizing DG's benefits.

A critical aspect of the review is the optimal integration of distributed generation (OIDG), highlighting significant advancements in OIDG research. Various optimization techniques have been explored to address DG integration, yet no single method consistently proves superior due to the diverse and complex nature of DG systems. Each DG type, with its unique characteristics, poses different integration challenges that a single optimization approach may not effectively address. The review advocates for hybrid optimization approaches, which combine the strengths of multiple techniques to manage the multifaceted challenges of DG integration more effectively. Hybrid methods offer a robust and reliable solution by leveraging the complementary strengths of different optimization techniques, thus mitigating the weaknesses of individual approaches. Looking forward, the review suggests focusing on developing advanced hybrid optimization algorithms that can adapt to evolving DG technologies and integration needs. Collaboration among researchers, policymakers, and practitioners is essential to advance DG integration strategies, enhance distribution network resilience, and maximize efficiency and sustainability. In conclusion, while considerable progress has been made in OIDG research, adopting hybrid optimization methods is crucial for more reliable and effective DG integration, paving the way for improved energy distribution solutions that benefit all stakeholders

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