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Recent Trends in the Optimization of Renewable Distributed Generation: A Review

Tendencias recientes en la optimización de la generación distribuida renovable: una revisión

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ABSTRACT

Distributed energy resources, or distributed generation (DG), are the mainstay of modern power systems aiming towards green energy generation via the effective integration of renewable energy sources. DG involvement in traditional power systems comprises the enhancement of power quality parameters, the utilization of renewable sources, cost optimization, and stable and reliable energy generation. The advantages of such a revolutionary approach can be achieved with the optimal sizing and allocation of DG by means of adequate optimization techniques, constraints, and optimized parameters. In this study, a comprehensive review of DG optimization is presented in light of recent developments, and a comparison is carried out based on the adopted optimization techniques, test system, enhanced parameters, and outcome evaluations.

Keywords: energy generation, distributed energy resources, renewable sources, optimization approach

RESUMEN

Los recursos energéticos distribuidos, o generación distribuida (GD), son el pilar de los sistemas energéticos modernos, que tienen como objetivo generar energía verde a través de la integración efectiva de fuentes de energía renovables. La participación de la GD en el sistema eléctrico tradicional abarca la mejora de los parámetros de calidad de la energía, la utilización de fuentes renovables, la optimización de costos y la generación de energía estable y confiable. Las ventajas de un enfoque tan revolucionario se pueden alcanzar asignando el tamaño y la ubicación óptimos de la GD mediante técnicas de optimización adecuadas, restricciones y parámetros optimizados. En este estudio se presenta una revisión completa de la optimización de GD en vista del desarrollo reciente, y se hace una comparación basada en las técnicas de optimización adoptadas, el sistema de prueba, los parámetros mejorados y las evaluaciones de resultados.

Palabras clave: generación de energía, recursos energéticos distribuidos, fuentes renovables, enfoque de optimización

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Introduction

Distributed generation (DG) is different from the centralized generation of electrical energy, which is attributed to an approach that involves generation through small units situated near the end users. DG is also known as dispersed generation, embedded generation, or decentralized generation. Renewable and non-renewable energy resources can be utilized due to their technical, financial, and environmental advantages via the optimal establishing of DG. The qualities of electrical parameters that can be consigned in electrical power systems are real and reactive power losses, voltage stability, the tap setting of a transformer, power factor correction, reliability, fault level, and total harmonic reduction with the assimilation of DG.

Environmental pollution has been minimized by maximizing the use of renewable energy sources. Integrated generation models have been designed as an alternative to centralized generation, which demonstrate the potential of solar photovoltaic systems, wind power generation, biogas, and other natural energy sources. The emission level of hazardous pollutants can also be an objective parameter in a multi-objective function for DG allocation. The challenges of renewable energy amalgamation are the intermittent nature of energy sources, which are highly dependent on meteorological conditions and geographical structures (Saxena *et al.*, 2021).

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Merits of DG planning

For optimal DG allocation, the objective function has been optimized by considering various constraints in order to determine the reliability, stability, and utility of the system. As per the desired level of operation, constraints such as load flow, voltage profile, line losses, transformer capacity, short circuit level, power quality, number, size, and capacity of DG may be a part of a single objective or multi-objective functions. As far as financial objectives are concerned, DG capital, operation, and maintenance costs have been considered for cost reduction and maximization of profit. In this process, the objective function includes revenue besides the expenditure, the penalty factor for constraints violations, the integrated cost parameters, and fixed and variable cost parameters.

The benefits of DG optimization are summarized in Figure 1. The planning of renewable DG in distribution networks has several advantages, and broad classifications are given as per the following highlights.

Technological benefits

DG integration in distribution networks reduces system losses and increases the efficacy, reliability, and optimal dispatch of the system. Moreover, the voltage profile and power factor are also simultaneously optimized with power loss minimization. The objective function may be single-objective or multi-objective and subjected to various equality and inequality constraints. Technological benefits are achieved after optimized DG allocation.

Economic benefits

The demand for electrical energy is increasing day by day, and it is not economic to expand centralized generation due to its various limitations. The incorporation of DG may lead down a path that is cost-effective and provides technological benefits, reducing energy losses and satisfying the energy demand through natural resources project DG as a futuristic approach. Capacity maximization and energy harvesting within the distribution network is also involved in financially optimized systems.

Environmental benefits

The high impact of renewable energy resources in the power network enlightens the pathway towards pollution-free, green energy generation. The maximization of extracted renewable energy is possible through the integration of DG in the distribution system.

The key segments of renewable energy-based DG planning are shown in Figure 2.

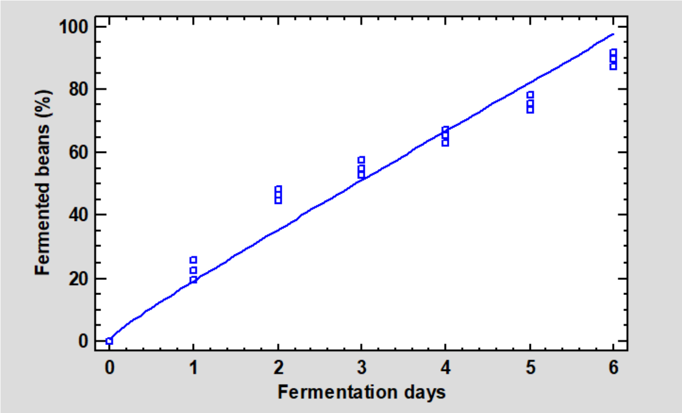

Figure 1. Benefits of DG optimization
Source: Authors

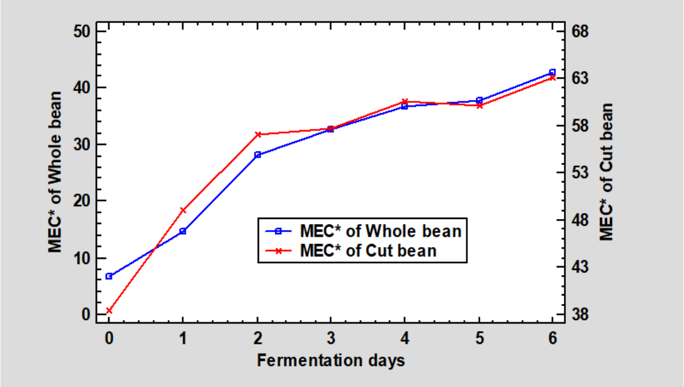

Figure 2. Framework for renewable DG planning
Source: Authors

DG system design

Designing the DG system involves the selection of the energy generation category, the storage technique, and the bus system. Energy generation is broadly categorized based on renewable and non-renewable resources. Solar energy, wind energy, biomass energy, and fuel cells are the main renewable energy sources, whereas combustion is utilized in fossil fuel-based energy extraction (Allan *et al*., 2015).

Despite the intermittent nature of renewable energy, there are numerous stable integrations of distributed energy generation and utilization, in addition to the incorporation of storage devices. Moreover, crop-based energy is also employed in DG.

The different types of bus planning can be categorized as follows:

Bus system with DC

The generated energy is delivered easily to DC load via a DC bus. However, inverter devices may be used to deliver energy to AC loads.

Bus system with AC

This architecture is used to directly supply AC loads through AC buses, while the DC demand is completed by using rectifiers.

Bus system with AC and DC

It is a more complex but highly efficient system to deliver AC and DC supply concurrently. Energy storage is also possible with the help of supply converters.

A categorization of renewable energy sources is presented in Figure 3 (DTI, 2007).

Renewable energy assessment

The assessment of renewable energy is a key component of DG implementation because of the intermittent nature of such resources in comparison with fossil fuel-based generation. To enhance the impact of green energy generation, it is necessary to prepare a framework of renewable energy-based DGs to neutralize the impact of intermittency. The weather conditions, topographical properties, experimental results, data records, soil grade, and seasonal variation are the most important parameters for the analysis involved in the elaboration of the renewable DG framework.

In this vein, biomass energy is dependent on atmospheric conditions, but storage of feedstock can provide continuous energy generation. In turn, wind and solar are unlimited sources of energy but have a high level of intermittency. It is a very difficult task to develop a model that can ensure uninterrupted energy generation.

The intermittency of wind and solar power can be reduced by the following methods (Theo *et al*., 2017):

Experiential meteorological data

Experiential data of solar and wind function can be collected both directly and indirectly by means of visiting the site and consulting published research, meteorological laboratory records, relevant offices, and authorities. The measured metrological data related to solar energy are the irradiance level (hourly, daily, weekly, monthly, seasonal, and global), the intensity, and the power output. Moreover, the wind data collected are the hourly average, the monthly mean, the energy generated per day, and the frequency.

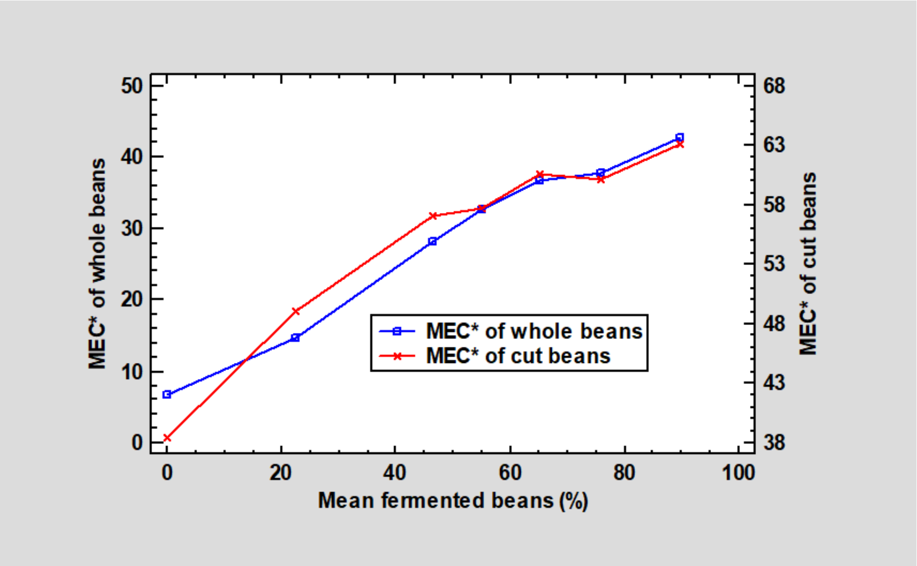

Figure 3. Categorization of renewable energy sources
Source: Authors

Climatic data forecast

It is necessary to forecast reliable metrological information, even in light of the following constraints, which may hamper the assessment:

- The proficiency and resources are limited in a particular area;
- low financial assistance limits the complete, highly accurate seasonal data observation; and
- the failure of an observational system may lead to the absence of regular data recording for a long period.

Load survey

Load demand analysis is mandatory for generation planning and utilization. The nature of the load may be continuous or discrete, while its measurement may be conducted in different time frames or seasons. It consists of analyzing the demand at low, medium, and high levels, and it varies from residential to industrial sectors. Studying the load curve from peak to valley and valley to peak is also required to maintain the consistency between demand and supply.

Optimized DG allocation

A predicted capacity-based solar power plant in an unbalanced power distribution model was recommended. The particle swarm optimization (PSO) technique was used to optimize the size and location to get the plant's capacity and determine its power capacity per day. The process started by modeling the varying load, followed by assuming an unbalanced distribution system, and concluded with the determination of the DG's probable capacity. The optimized parameters were compared to the absence of distributed generation (ADG) (Jana *et al.*, 2020).

A metaheuristic, hybrid-approach PSO coupled with a grey wolf optimization (PSOGWO) approach was implemented to enhance the voltage profile and optimize the real power losses. The photovoltaic and fuel cells and variable capacitor types were selected for the optimization process, and the results were significant for voltage profile improvement and real power losses reduction (Kumar *et al.*, 2020).

A simulation test was conducted on a physical 10 kV Chinese feeder for the execution of the cluster coordinated optimization (CCO) method, which exhibits a dual approach: determining voltage handling capacity of internal constellation reactive generators and employing constellation sovereign optimization. Moreover, complex circuits can be converted into an evident network based on essential observational information and Ohmic parameters, as well as autonomously evaluated for every cluster. The concept of this optimization basically involves choosing a fundamental load among two nearby nodes, and the effectiveness of its outcomes have been demonstrated in comparison with other optimization techniques such as centralized optimization (CO), multiplier-based distributed inter-cluster optimization (MBDICO), and cluster independent optimization (CIO) (Lu *et al.*, 2020).

Heuristic nature-inspired algorithms, namely dragonfly-particle swarm optimization (DFPSO) show prominent results in the enhancement of power losses and voltage profiles. Hybrid optimization techniques exhibit a dual approach: dragonfly for optimizing switching sequences and PSO for DG allocation in view of different scenarios of loss reduction (only active power, only kVAR, or complex power). The outcomes are impressive in comparison without those without DG reconfiguration (WRDG) (Rafi *et al.*, 2020).

It is necessary to optimize a mixed-integer nonlinear programming objective function to increase the penetration level of renewable energy sources in the distribution network. This objective function was solved with the help of a two-stage technique named coyote optimization algorithm (COA) at variable load levels to minimize the energy losses of the system. This methodology started with a load flow analysis, followed by determining the DG location, size, and loss reduction ratio (LRR). Furthermore, a methodology was examined for two types of cases: the IEEE 123-bus benchmark and the Tai power 123-bus system. The test results were compared with those of mixed-integer linear programming (MILP), genetic algorithm (GA), PSO, biogeography-based optimization, (BBO), and grey wolf optimization (GWO) (Chang *et al.*, 2020).

The challenges of voltage regulation and power losses were addressed in HV and MV distribution networks (DN) via generalized benders decomposition (GBD), and a simulation test was carried out in the Jinzhai distribution network of China. The effectiveness was examined with global centralized optimization (GCO) and independent optimization (IO). Crest voltage compensation was adopted in order to obtain enhanced results in a master-slave network with the increased precision of the LinDistFlow equation. Unlike other optimization techniques, this one facilitates the complete utilization of the voltage regulation capacity, which reduces energy losses during off-grid generation and yields good results in terms of cost-saving and computational calculation. A multi-objective function was disintegrated into a main universal problem and auxiliary problems in order to generate an iterative process (Chai *et al.*, 2020).

A DG management approach (DGMA) was proposed as a supervisor unit for controlling and optimizing the operations of multiple inverter modules in a power grid in order to operate simultaneously in different dispatch segments. The proposed supervisor unit allows independent and subsidiary services to enable various modes of operation: maximum real power, power factor improvement subjected to connection/disconnection authorization, constant reactive power, and active power (Santos *et al*., 2020).

A two-stage data-driven distributed robust optimization (DDRORO) model was implemented to overcome the challenges of intermittency in renewable source integration given the lack of informative characteristics as compared to robust and stochastic optimization approaches. Green energy generation and profit maximization were accomplished by increasing the penetration level of renewable energy. Consequently, in comparison with the other stochastic optimization (SO) models, cost-saving reached 20% via the optimal sizing and allocation of DG (Fathabad *et al*., 2020).

The PSO method was studied in a 22 kV distribution system (DS) in Thailand to reduce the system energy losses caused by the inappropriate allocation of DG. Additionally, the concept of load transfer was used, and, to this effect, the tie-switch location was identified through this nature-inspired optimization algorithm. A comparison of results demonstrated reduced energy losses and a voltage profile increase of 40,38 and 6,59%, respectively, which took 3,13 h (Karaaom *et al*., 2020).

To enrich the generating capacity of DG and smoothen voltage fluctuations, reactive power optimization was modeled via the general algebraic modeling system approach (GAMSA), although the utilization capacity of DG was reduced. The recognized multi-objective function (considering the voltage variant, the real power losses, and the DG capacity) was converted into a single objective function, which was subjected to various constraints such as power balance, balanced node, line power, node voltage, DG output, and reactive power compensation. The variations in active power, reactive power, and node voltage irrespective of load demand were demonstrated in optimized results (Wang *et al*., 2020).

Compared to the absence of DG optimization (WDG), the importance of DG planning and allocation was justified with the help of the PSO approach in view of its enormous advantages, which include improved voltage profiles, reliability, and power quality. This was carried out in the Basuki Rahmat Surabaya feeder by using a graphical user interface system. Voltage and current-based injection matrices were used for power flow analysis, and the particle swarm optimization technique was then demonstrated with suitable results (Saidah *et al*., 2020).

Cost minimization and voltage regulation were achieved by trivial alteration using a moth search optimization technique called corrected moth search optimization (CMSO). A multi-objective function was developed via the optimal placement of DG and shunt capacitors while concurrently optimizing and controlling the tap position of grid transformer. The results were also presented in comparison with other established optimization techniques such as the harmony search algorithm (HAS), the fireworks algorithm (FA), and the dynamic node priority list-genetic algorithm (DNPLGA) for the IEEE 33 and 118 test systems at different load conditions (peak, normal, and light) (Singh *et al*., 2020).

A qualitative merging of genetic algorithm (GA) and ant colony optimization (ACO) resulted in a restructured algorithm dubbed genetic ant colony optimization (GACO), an approach that exhibited reduced energy losses and improved voltages. Load flow analysis was completed via the forward-backward method, and the newly developed technique was implemented with a faster convergence and free from local optima tracking. The results obtained were compared to those of renowned metaheuristic optimization techniques, which resulted in better voltage levels, average iterations (AI), reduced losses, and a faster convergence rate (Yang, 2020).

A multi-objective modified symbiotic organism search algorithm (MMSOSA) was executed for the optimization of the capacity and placement of renewable DG, with the purpose of achieving cost minimization (the cost of electricity for yearly purchases, the yearly expenditure, and the cost of operation), voltage regulation, and annual energy loss reduction at various load levels (constant, residential, commercial, and industrial) subjected to various constraints such as the power balance equation, the node voltage limit, and the DG capacity limit. Hourly demand variation and the total voltage deviation (TVD) curve were also significant for the improved results. Moreover, the results were quite impressive as compared to multi-objective symbiotic organism search (MOSOS) and the non-dominated sorting genetic algorithm-II (NDSGA) (Saha *et al*., 2020).

The frequency regulation of a DG was carried out with the help of the moth swarm optimization technique, in which a series of PI-PD controllers were used through the incorporation of renewable energy-based sources (such as solar photovoltaic and wind power) and energy storage devices along with an electric vehicle. PI works in the primary stage and PD in the secondary one. Such a cascaded operation reduced the steady-state error of the system in comparison with conventional PID controllers, which may lead to an unstable transient response. For the execution in MATLAB and SIMULINK, the gain and time constant parameters of solar photovoltaic, wind power, fuel cell, and diesel engine generators, the electric vehicle, and the battery storage were taken as the nominal parameter of DG (Khamari *et al*., 2020).

A battery storage architecture was proposed for the effective integration of distributed solar photovoltaic systems in order to avoid the intermittency of renewable energy sources. The flexibility of the grid, regardless of faults (circuit scale fault, substation scale fault, and generation plant scale factor), has also been understood to cause disturbances. Numerous types of battery storage architectures were identified based on different types of working principles: In-building Distributed Storage Architecture, Circuit/Distribution Storage Architecture, Substation/Microgrid Storage Architecture, Generation Plant Storage Architecture, and Utility/Grid Storage Architecture. As an outcome, grid resilience was maximized by optimizing the combination of battery storage systems to increase the penetration level (PL) of renewable energy (Confrey *et al.*, 2020).

A mathematical apprehension technique was proposed to enhance power and voltage quality via the amalgamation of DG in power distribution. This operation was carried out with the help of a flexible multi-level switch. The loading frequency and the power handling capability of the feeder were considered for the effective assimilation of DG through equalization. Moreover, a control framework for a PI controller and a steady-state converse model were developed in order to optimize the different modes of a flexible multi-level switch (Yu *et al.*, 2020).

The coordinated scheduling of renewable DG with the constraints of a futuristic smart grid was presented, and such a combination was focused on sorting out the disturbance caused by the intermittency of renewable energy sources. Firstly, renewable virtual sources were considered for the procedural implementation, and then the obtained characteristics were simulated in order to design the framework of the strategy. The recommended model showed potential regarding the use of pumped storage energy in order to minimize the intermittency of renewable energy generation. Effective forecasting was achieved with source shedding with the purpose of maximizing profits (Dong *et al.*, 2020).

A novel filter was used for the prediction of distributed solar power generation, in which the geographical proximity of the energy system affects the observations. Moreover, the intermittency in cloud formation and propagation was considered for the model at a resolution of 1 minute. This bi-level methodology consists of estimating PV power and measuring the lower frequency of the sampled data (Alam *et al.*, 2020).

A dumping cost to evaluate soil contamination was proposed along with a new framework for delivering the electrical energy at a unitary power factor level in order to minimize distribution energy losses. Consequently, the cost required for power congestion management was also reduced, thus enhancing the level of futuristic smart city power projects (Parida *et al.*, 2020).

The voltage regulation of a distribution system was improved with the use of solar PV DG as a reactive element that was independent from information exchange and feedback assessment. The backward/forward sweep algorithm was used while considering the irradiance level of solar energy and ambient temperature (Ammar *et al.*, 2019).

The cost of acquiring land is increasing day by day for the installation of a solar PV system as DG. An appropriate method was recommended by the authors for solar PV installation so that land could be utilized in a better way. The unusable land near the railway track area, water storage land, and highways could be used while offering remuneration to the owner instead of purchasing new land. A geographic information system was also developed to get the details of such lands having the appropriate irradiation level of solar energy. (Asanov *et al.*, 2019).

The increased risk power failure of renewable DG due to the intermittency of the climatological and atmospheric conditions has been highlighted with the proposal of an adaptive forecaster subgroup assortment strategy for enhancing the forecast. In this two-level approach, a binary genetic algorithm was used for selecting the characteristic, and a regression-based vector was applied to calculate the suitability level of the estimator. The accuracy was enhanced by 58,4% in comparison with the real prediction method (Eseye *et al.*, 2019).

A case study of wind power generation in DG to meet the demand of rural America was analyzed. In this context, 2015 separates the pre-wind and the post-wind eras. A graphical presentation was included showing the variation in the development of residential, commercial, and industrial customers over the last five years of the span. Along with this, wind speed, atmospheric temperature, and load demand were also taken into account (Madala *et al.*, 2019).

A simulation test was carried out to investigate the survival of wind power generation as distributed energy sources during the abnormal conditions of a power failure. A seven-scenario system (without DG, downstream, mid-way, upstream, and four types of wind power generation) was adopted to validate the results (Gumilar *et al.*, 2019).

Due to the progression of large heat pump projects, many countries are required to advance in the traditional grid system, which offers the possibilities of renewable energy sources. For the effective integration of heat pumps with wind power generation in the distribution network, a mathematical model was presented with the purpose of maximizing profits and reducing costs (Cui *et al.*, 2019).

Wind power generation in DG has been used for voltage profile enhancement, loss reduction, and ecological benefits in the distribution network. A power control curve optimization approach was adopted for the speed regulation of a windmill rotor. The optimized parameters were energy losses and voltage quality (Eltamaly *et al.*, 2019).

A multi-objective function of DG size and allocation optimization was considered regarding the operating, capital, environmental, wind, and light abandonment costs, which were subjected to voltage, current, equation flow, and DG capacity constraints. This was carried out with the implementation of the particle swarm optimization method in wind turbine, solar PV, and gas fueled micro turbine generators (Ma *et al*., 2019).

The reliability of the radial distribution network could be increased by facilitating DG integration in the formation of multiple energy sources. PSO and the gravitational search algorithm (GSA) were used to obtain the optimal allocation of single and multiple DG. The reliability of the system was calculated in terms of numerous indices. The outcomes were evaluated in the IEEE 33-bus system for the various DG categories and compared to different metaheuristic approaches. The results were more significant in real and reactive power injection than in real power injection. The annual cost of energy losses (AELS) was better in comparison with GSA, PSO, the iterative algorithm (IA), and the krill herd algorithm (KHA) (Parihar *et al*., 2021).

The optimal allocation and sizing of renewable energy-based DG could be found with the use of two different approaches in the same distribution network, namely the PSO and weighted-sum multi-objective (WSMO) approaches. The impact of optimal DG allocation was evaluated in the presence of harmonics distortion and validated in the IEEE 33-bus test system. In this strategy, a bi-level objective function was converted into a single objective function, and PSO was then applied. This approach demonstrated reduced energy losses, enhanced voltage profiles, and better reliability in the distorted distribution network. The results were compared with a GA, a multi-objective GA (MOGA), the analytical method (AM), and the backtracking search optimization algorithm (BSOA) (Parihar *et al*., 2022).

Power quality parameters were also enhanced by incorporating a fuzzy logic controller (FLC) with hybrid optimization approaches. A hybrid optimization approach was proposed which integrates the features of the ant lion optimization algorithm (ALOA) and PSO. The multi-objective function was optimized in the presence of a training dataset offered by FLC, which resulted in optimized DG allocation. Such a process was evaluated in terms of load flow in the IEEE 33 test system. The results showed significant improvements stemming from the use of hybrid optimization techniques for different renewable energy-based power generators across a wide range of power factors. Said results were evaluated in comparison with those of ALOA and the proposed technique without FLC (Samala *et al*., 2020b).

Another hybrid optimization approach was proposed by integrating the grasshopper optimization algorithm (GOA) and cuckoo search (CS) for the enhancement of various parameters of a distribution network in the presence of DG. This technique was evaluated in the IEEE 33 and 69 test systems under half load, full load, and overload conditions. The results were compared to those obtained via salp swarm optimization (SSO) and the lightning search algorithm (LSA) (Suresh *et al*., 2020).

Comparative assessment

An comparative assessment of renewable DG optimization is given in Table 1. The analysis was carried out in terms of the DG optimization technique, the test system, the parameters evaluated, and the optimized outcomes. The Table provides an insight into the literature on DG allocation in distribution networks.

Research gap

After assessing the planning and optimization of renewable DG systems, it was concluded that the intermittency of renewable energy resources is not properly considered in order to establish a stable and reliable distribution system. The integration of energy storage systems and demand response schemes are also under-evaluated during optimal power dispatch. The utilization of energy storage devices can reduce the intermittent nature of natural resources, although the overall cost is increased. It is known that energy saving is also regarded as energy generation, so the end-user can shift their demand as per the demand response scheme. Load shifting from peak to valley hours enhances the quality of optimal power dispatch to reduce the system losses and imbalances between demand and supply. Consequently, battery storage and demand response integration are necessary for renewable DG planning in order to increase the impact of natural energy sources and coordination between distribution companies and consumers.

Conclusions

A comprehensive evaluation of recent trends in DG optimization is demonstrated in this paper, with its massive benefits subject to various constraints. These enormous benefits are associated with power quality, economic, and atmospheric parameters. The literature was reviewed based on optimization techniques, methodology, test system, optimized parameters, type of generation, enhanced outcomes, and compared approaches. The optimization techniques can be classified as classical, nature-inspired, and hybrid approaches depending on their methodology. Moreover, these techniques could be compared in terms of their convergence time, available literature, the dimensions of their objective function, and the complexity of their implementation. DG has the potential to exploit the dissemination of renewable energy sources in order to meet the present challenges as it contributes to safe environmental conditions. Moreover, the integration of a battery storage system can reduce the intermittency of renewable energy sources. Demand response is also an important aspect of the modern power grid. Renewable energy-based DG, battery storage, demand response, capacitor banks, and electric vehicles could be used for optimal power dispatch in distribution networks.

Table 1. A comparative analysis of DG optimization

Reference	Optimization technique	Test system	Evaluated parameters	Optimized results	Renewable DG	Non-renewable DG	Compared approaches	DG size (DGS)	DG location (DGL)	System losses (SL)	Voltage profile	Total cost (TC)	Calculation time (CT)	Fitness value (FV)	Power factor (pf)	Reliability
Lu *et al*. (2020)	CCO	IEEE 123	SL (MW)	0,8319	✓		CO, CI, MBDICO			✓	✓		✓			
			Vmax (p.u.)	1,05												
			CT	16,69												
Chang et al. (2020)	DFPSO	IEEE 33, DG=1	DGL	29		✓	WRDG	✓	✓	✓	✓					
			DGS (kW)	830												
			SL (kVA)	135,44 + j 83,69												
		IEEE 33, DG=2	DGL	29, 24												
			DGS (kW)	830, 340												
			SL (kVA)	118,40 + j 81,6												
		IEEE 33, DG=3	DGL	29, 24, 20												
			DGS (kW)	830, 340, 720												
			SL (kVA)	116,7 + j 80,44												
Chang *et al*. (2020)	COA	IEEE 123	SL (kW)	18,2081	✓		MILP, GA, PSO, BBO, GWO			✓	✓		✓	✓		
			LRR	77,01												
			V (p.u.)	0,9939 – 1,0023												
			FV	0,2299												
Chai *et al*. (2020)	GBD	HV and MV DN	SL (MW)	0,6877, 0,0273, 0,0463, 0,055	✓		GCO, IO			✓	✓	✓			✓	
			TC (Yuan)	333,1												
Santos *et al*. (2020)	DGMA	IEEE 13	SL, p.f.	Near to the reference vaue	✓					✓					✓	✓
Fathabad *et al*. 2020	DDDRO	IEEE 33	TC (K$)	17 015	✓		SO					✓				
Karaaom et al. (2020)	PSO	22 kV DS	SL (MWh)	36,38		✓	WDG			✓	✓					
			Vrise (p.u.)	0,97												

Reference	Optimization technique	Test system	Evaluated parameters	Optimized results	Renewable DG	Non-renewable DG	Compared approaches	DG size (DGS)	DG location (DGL)	System losses (SL)	Voltage profile	Total cost (TC)	Calculation time (CT)	Fitness value (FV)	Power factor (pf)	Reliability
Wang *et al.* (2020)	GAMSA	IEEE 33	DGL	4, 5, 6, 11, 25	✓		WDG		✓	✓	✓					✓
Saidah *et al.* (2020)	PSO	IEEE 33	DGL	25		✓	WDG	✓	✓	✓	✓					
			DGS (MVA)	9.5												
			SL (kW)	1.56												
Singh *et al.* (2020)	CMSO	IEEE 33	DGL	13, 25, 30		✓	HAS, FA, DNPLGA	✓	✓	✓	✓	✓				
			DGS (MW / MVAr)	1,459, 0,987, 1,795												
			PL	60.65%												
			SL (MW)	0,1964												
			TC (USD)	64820												
		IEEE 118	DGL	33, 38, 52, 71, 80, 96, 109												
			DGS (MW / MVAr)	2,910, 3,225, 2,677, 4,414, 2,276, 2,159, 4,642												
			SL (MW)	1,4622												
			TC (USD)	478 229												
Yang (2020)	GACO	IEEE 33	SL / kW	139,4715		✓	ACO, GA			✓	✓		✓			
			AI	17,4												
Saha *et al.* (2020)	MMSOSA	IEEE 69	DGL	24, 26, 62	✓		MOSOS, NDSGA	✓	✓	✓	✓	✓				
			DGS (kW)	540,250, 1 325,5												
			SL (kWh)	299 850												
			TC ($)	783 670												
			TVD	5 666												
Parihar *et al.* (2022)	WSMO, PSO	IEEE-33	DGS (kW)	2 588,4	✓		AM, MOGA, BSOA, GA	✓	✓	✓	✓	✓				✓
			DGL	6												
			Improved V %	4,18												
			PDG cost ($/Hr)	52,01												
			AELS ($)	54 499,46												

Reference	Optimization technique	Test system	Evaluated parameters	Optimized results	Renewable DG	Non-renewable DG	Compared approaches	DG size (DGS)	DG location (DGL)	System losses (SL)	Voltage profile	Total cost (TC)	Calculation time (CT)	Fitness value (FV)	Power factor (pf)	Reliability
Parihar *et al.* (2021)	PSO & GSA	IEEE 33, DG=1 (Injects P)	DGS (kW)	2 605	✓		IA, GSA, PSO, KHA etc.	✓	✓	✓	✓	✓				✓
			DGL	6												
			improved V %	4.35												
			AELS ($)	52 597												
		IEEE 33, DG=3 (Injects P & Q)	DGS (kW)	3 150												
			DGL	6												
			improved V %	6,19												
			AELS ($)	76 774,6												
		IEEE 33, DG=3 (Injects P & Q)	DGS (kW)	859,2, 1 031,6, 605,3												
			DGL	24, 30, 14												
			Improved V %	10,07												
			AELS ($)	101 477,8												
Samala *et al.* (2020b)	ALOA+PSO+FLC	IEEE-33 (PV=2, u.p.f)	DGS (kW)	385, 2 154	✓		PSO, ALOP+PSO	✓	✓	✓	✓	✓	✓		✓	
			DGL	32, 7												
			TC ($)	12 062												
		IEEE-33 (WT=2, u.p.f)	DGS (kW)	951, 696												
			DGL	31, 17												
			TC ($)	8 496												
		IEEE-33 (PV=2, p.f.=0,85 lag.)	DGS (kW + KVAr)	924 + j1223, 665 + j710												
			DGL	32, 14												
			TC ($)	8 037												
		IEEE-33 (WT=2, p.f.=0,85 lag.)	DGS (kW + KVAr)	993 + j1667, 606 + j913												
			DGL	8, 30												
			TC ($)	8 038												
Samala *et al.* (2020a)	ALOA+PSO	IEEE-33	DGL	5, 17, 31	✓	✓	ALOA, GSA	✓	✓	✓	✓		✓			✓
			DGS (MW)	0,4571, 0,2478, 0,9987												
			SL (MVA)	1,5257												

Reference	Optimization technique	Test system	Evaluated parameters	Optimized results	Renewable DG	Non-renewable DG	Compared approaches	DG size (DGS)	DG location (DGL)	System losses (SL)	Voltage profile	Total cost (TC)	Calculation time (CT)	Fitness value (FV)	Power factor (pf)	Reliability
Suresh *et al.* (2020)	GOA+CS	IEEE-33, half load	DGL	2		✓	SSO, LSA, GA	✓	✓	✓	✓	✓	✓	✓		✓
			DGS (kW)	1 716												
		IEEE-33, full load	DGL	24												
			DGS (kW)	926,99												
		IEEE-33, 150% load	DGL	24												
			DGS (kW)	926,99												
		IEEE-69, half load	DGL	17												
			DGS (kW)	1930,7												
		IEEE-69, full load	DGL	6												
			DGS (kW)	1990,7												
		IEEE-69, 150% load	DGL	12												
			DGS (kW)	1890,6												
Jana *et al.* (2020)	PSO	IEEE 34	DGS (kW)	58,928	✓		ADG	✓	✓	✓	✓					
Kumar *et al.* (2020)	PSOGWO	IEEE 33	DGL	6	✓		ADG	✓	✓	✓	✓					
			DGS (MW)	2,576												
			SL (kW)	103,966												
		IEEE 33	DGL	30		✓										
			DGS (MVAr)	1,25												
			SL (kW)	143,6												
		IEEE 69	DGL	61	✓											
			DGS (MW)	1,869												
			SL (kW)	83,9013												
		IEEE 69	DGL	61		✓										
			DGS (MVAr)	1,328												
			SL (kW)	152,4												

Source: Authors

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