INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH
K. S. Sambaiah, Vol.8, No.3, September, 2018

A Review on Optimal Allocation and Sizing Techniques for DG in Distribution Systems

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Received: 14.12.2017 Accepted:19.02.2018

Abstract- Distributed Generation (DG) offers the reliable and economic source of electricity to consumers. These are connected directly to the distribution system at consumer load points. Integration of DG units into an existing system has significantly high importance due to its innumerable advantages. However, Optimal DG (ODG) allocation and sizing is always a challenging task for utilities as well as consumers. The major objective of ODG allocation and sizing is to improve system overall efficiency with minimum power loss, maximum system security, voltage stability, and reliability. Analytical techniques are performing well for small and simple systems, not suitable for a system with large and complex networks. However, various meta-heuristic techniques are performing better in terms of accuracy and convergence for extensively large and complex networks. A hybrid optimization is a combination of two or more optimization techniques. This technique offers efficient and reliable global optimum solutions for complex multi-objective problems. In this context, a comprehensive literature review of DG fundamentals and the different technical approaches for DG integration into the distribution system are analyzed here. Furthermore, an attempt has been made for comparison of analytical, classical (non-heuristic), meta-heuristic and hybrid optimization techniques with respect to objective function, test system, advantages, and disadvantages. This present study will give in-depth knowledge and acts as a forthright reference for imminent investigators and investors for ODG allocation and sizing in a distribution system.

Keywords: Distributed Generation, Optimal DG allocation and sizing, Meta-heuristic algorithms, Distribution system.

1. Introduction

A longtime scenario witness that traditional power generation methods have dominance over years. In these generating units, conventional type energy resources (fossil fuels) are employed for power generation. Due to an enormous rise in power demand, utilization of conventional type energy resources causes environmental issues. These power generation units release a huge amount of greenhouse gases. Global concern towards reducing habituation on fossil fuel and reduce climate changes, an alternate mode of power generation paradigm has adopted. It is to distribute generation along distribution system. A distribution system is the end point of the power system. It acts as a supply link between bulk power supply area and individual customers with unidirectional power flow. Studies show that about 70% of total power losses in the power system is at distribution side. Small power generating source directly connected to grid or almost near consumer end is called “Distributed Energy Resource (DER)” or “DG”. DG is attractive supplant for centralized power generation. DG units include both renewable and non-renewable sources of energy. DGs have vast techno-economic and environmental benefits. These techno-economic benefits can be achieved by choice of location, size, and type of DG to be installed in Electrical Power System (EPS). ODG allocation and sizing have technical benefits like reduced total system losses, improved voltage profile, voltage stability, loadability, system security, reliability, power quality and economic benefits like low capital cost, replacement cost, operation and maintenance cost, fuel cost, and cost for reliability enhancement. Integration of Renewable Energy Resource (RER) based DGs into distribution system has environmental benefits like eco-friendly (emission-free), free availability, abundant in nature and so on [1-5].

Most commonly used DG systems in the residential sector are solar photovoltaic technology, small wind turbines, fuel cells, natural-gas-fired REs and emergency backup generators typically fueled by diesel or gasoline. However, commercial and industrial sectors use Combined Heat and

Power (CHP), solar PV panels, wind, hydropower, biomass incineration, firing of fuel cells by biomass or natural gas, reciprocating combustion engines, and backup generators fueled by oil type DG systems. Integration of DG units will not guarantee reliability and stability of the system if they are placed at non-optimal locations with different sizes. Instead of improving reliability and maintaining system stability it will affect voltage profile and increase system losses [6]. In the present paper, a vast choice of existing research on analytical, classical (non-heuristic), meta-heuristic, hybrid, and other assorted techniques for ODG allocation and sizing along with objective function, test systems, advantages, and disadvantages are presented.

2. Distributed Generation

Distributed Generation concept has achieved more attention as of its innumerable advantages. So far DG has no uniformity over definition and size across the world. The definition for DG units varies with country and region. For instance, Anglo-American countries habitually use the term ‘embedded generation’, North American countries as ‘dispersed generation’, and Europe and some parts of Asia as ‘decentralized generation’. In the present paper, we considered DG as distributed generation. Electric Power Research Institute (EPRI) defined DG as generation from a few kW to 50 MW. Types of DG units based on generation levels and their respective technology are illustrated in “Table 1” [1,3,7-9]. DG type in terms of real and reactive power injection and consumption capability and respective DG technology is illustrated in “Table 2” [10,71].

2.1. Significance of ODG allocation and sizing

ODG allocation has achieved much importance due to its various advantages. However, integration of DG into an existing system will be a crucial and difficult task. Since DG integration changes the behavior of network from passive to active. Bi-directional power flow eventually rises system loss and affects reliability and operational stability [11]. In [12], DG capacity investment is treated as an attractive choice in distribution system planning. Economically it is not possible to allocate DG on each and every bus which may lead to adverse effects [13]. Planning for DG integration into an existing system requires optimal location, size, type of DG and also network connection [5,14,143]. It reduces total power loss, improve system voltage profile and stability, reliability, loadability, security, power quality, power factor and overall system efficacy. Inappropriate allocation of DG units will distract all aforementioned advantages [9]. Hence it is very important to allocate DG unit in the optimal location with the appropriate size. IEEE 1547 series of standards for interconnection of DG/DER into power distribution system are as summarized in “Table 3” [15]. This collective summary offer a cohesive set of necessities, recommended practices, and guidance for addressing standardized interconnection of DER. Main reasons for extensive use of distributed generation are listed below [7,148]:

- Small generation unit occupies less space.
- Emerging technologies in DG have capacities ranging from 10 kW to 100 MW.
- Widely used past perfected techniques (gas turbines, internal combustion engines), present techniques (wind, solar energy), and future experimenting techniques (fuel cell, solar panel into buildings).
- It reduces the cost of Transmission and Distribution (T&D) expansion since DG units are placed close to customers.
- Consistent availability of natural gas used in DG stations with expected stable prices across the world.
- DG installation involves shorter time with modest risk of investment.
- Flexible cost benefits and reliable.

Table 1. Different DG levels and technology [1,3,7-9]

S. No.	Type	Size	DG technology
1.	Micro DG	~ 1 W < 5 kW	Solar Technology
2.	Small DG	5 kW < 5 MW	Fuel cell, Wind turbine, Biomass…,
3.	Medium DG	5 MW < 50 MW	Geothermal
4.	Large DG	50 MW < ~ 300 MW	Hydrogen Energy system

2.2. Overview of existing DG technologies

Reciprocating internal combustion engines (diesel generators, micro-turbines) are most commonly used conventional DG technology from past decades. However, due to increasing fuel prices and concern towards environment-related issues diesel generator units are restricted to emergency standby [16-18]. Present centralized power generation and future distributed generation is shown in “Fig. 1”. Various DG technologies for renewable and non-renewable energy resources with their techno-economic and environmental benefits are shown in “Fig. 2”.

2.2.1. Non-Renewable DG technology

Reciprocating Engines (REs) are well established and widely used non-renewable DG technologies. According to the US, Environmental Protection Agency (EPA) REs produce over 200 million units per year all over the world. Power generation range of RE is 10 kW to 18 MW. These are typical availability is more than 95 percent in static power generation applications. In REs both diesel and spark ignition configurations are used. RE based CHP systems typically supply both thermal and electric necessities. Micro-turbines are another type of RE. These are simple mechanical assembly, solo shaft, and high-speed devices. Since natural gas is used for ignition in micro-turbines will reduce NO_x emissions over diesel generators. Although micro-turbines have low NO_x emission these are not environmental friendly [16-18]. Apart from all non-renewable DG technologies diesel generators have low cost and high reliability. It is most popular DG technology. Instantaneous start and stop operation will make diesel generator as a dispatchable source. It is very likely suitable for standalone operation.

Table 2. DG type based on power injection and consumption [10,71]

S. No.	DG type	Power Factor	Technology
1.	Real Power injecting DG (P^+)	Unity	Solar PV systems, Micro turbine, fuel cells
2.	Reactive Power injecting DG (Q^+)	Zero	Synchronous Condenser, bank of capacitors
3.	Real and Reactive Power injecting DG (P^+ and Q^+)	0.8 – 0.99 (leading)	Synchronous machines (cogeneration, gas turbine)
4.	Real Power consuming and Reactive Power injecting DG (P^- and Q^+)	0.8 – 0.99 (lagging)	DFIG based wind farm

2.2.2. *Renewable DG technology*

The term ‘Renewable’ is referred as primary, domestic and clean or inexhaustible energy resources. The reason behind the integration of RER based DG units into distribution system is to reduce CO_2, NO_x and other greenhouse gases. Most popular renewable energy-based DG technologies are small/mini/micro-hydro power, solar PV, wind turbines, biomass and fuel cells [19,39,144-147]. In [20], renowned RER based DG technologies are presented. Hydropower constitutes as major percentage of renewable energy all over the world due to its constant availability and huge capacity [21]. Solar energy has received more attention due to its vast availability and non-polluting nature [22-24]. Power generation via renewable energy sources will reduce energy consumption in Spain by 2030 with a special focus on solar PV technology [25]. Wind turbines are another major renewable technology produce clean energy [26,27]. But intermittent nature of solar and wind requires stochastic studies [28]. Biomass is used as another RER. It is produced from organic matters (such as wood, crop waste or garbage) and has potential use as fuel for gas turbines after gasification [29,30]. In [109,140], biogas fueled gas engine as DG is allocated in an unbalanced radial distribution system. Compared with solar and wind green DG technologies fuel cell wouldn’t have geographical limitations and these can be placed at any location in a distribution system. Fuel cell utilizes hydrogen and oxygen produce electricity, heat, and water. Theoretically, fuel cells are much more efficient than conventional power generation [31].

2.3. DG integration benefits

Integration of DG units into an existing system will have technical (reduced line losses, peak shaving, improved voltage profile, stability, reliability, power quality, and overall efficacy etc.), economic (deferment for upgrades, less installation cost with reduced operation and maintenance costs etc.) and environmental (reduced emission of greenhouse gases) benefits [32,33]. In 1999 a report published in the United Kingdom says that 41% of carbon emission will be reduced by using CHP based DG units [7,8].

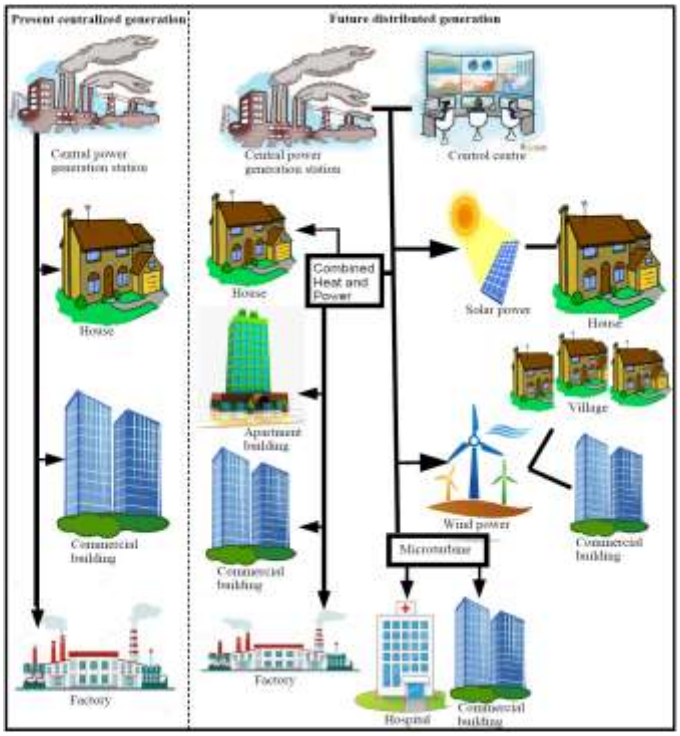

Fig. 1. Present centralized and future distributed generation scenario

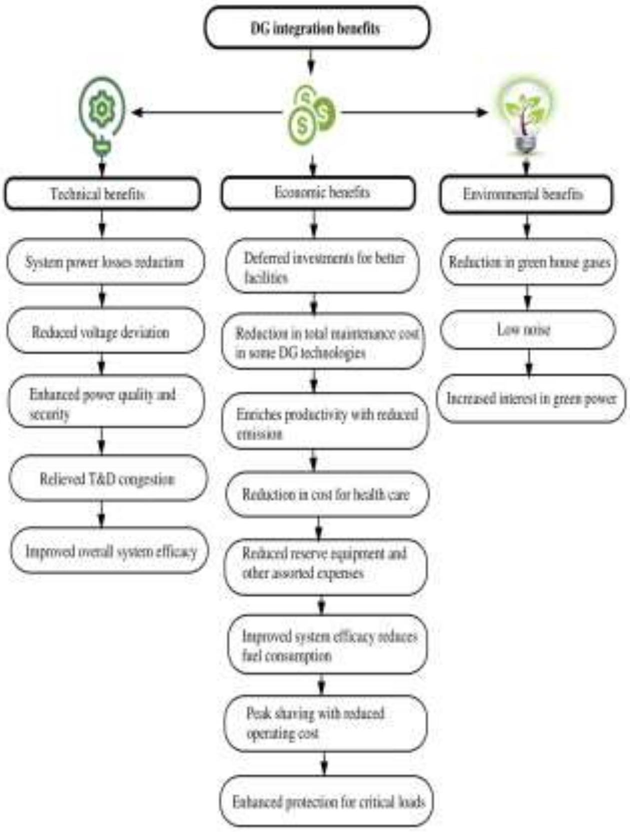

Fig. 2. DG integration benefits

3. ODG Allocation and Sizing Techniques

It is necessary to allocate DG units at the optimal location with suitable size to maximize techno-economic benefits. It results in benefits like minimization of overall system power loss, operation and maintenance cost, and enhancement in voltage profile, power quality, system stability, and reliability. Major technical approaches for ODG allocation and sizing are categorized as follows [7-9,34]:

3.1. Analytical approach
3.2. Classical (Non-heuristic) approach
3.3. Meta-heuristic Optimization approach
3.4. Hybrid approach
3.5. Assorted approaches

All aforementioned technical approaches will have a significant contribution to ODG allocation and sizing in a distribution system. Different approaches employed for ODG allocation and sizing is presented in **Fig.3.**

3.1. Analytical approach:

Analytical methods are performing well for small and simple systems, not suitable for a system with large and complex networks [46]. Analytical methods reviewed in the present paper are as follows:

- 2/3 rule or Golden rule:

It is a popular analytical method used for DG allocation. Here the size of DG is 2/3 capacity of incoming generation is placed or allocate at 2/3 length of the line. This rule is applicable only for uniformly distributed loads [36].

- Kalman filter:

It is also known as Linear Quadratic Estimation (LQE). Its accuracy depends on the number of samples. It is used for multiple DG allocation with less number of samples. Increase in the number of samples rises computational burden. It is used to determine DG size and an optimal locator index for DG allocation [38].

- Sensitive factor analysis:

Vulnerable node identification technique is sensitivity-based approach for ODG allocation which is carried out by small world network theory software [40]. A loss reduction sensitivity factor method is used for selecting ODG location [41-43]. An analytical approach for solving ODG allocation problem is using loss sensitive factor based on the equivalent current injection. In this method, total power loss minimization is attained without evaluating admittance, the inverse of admittance or Jacobian matrix.

- Iterative methods:

In [44], along with Newton-Raphson method of load flow study, a simple conventional iterative search technique is used for DG allocation. An efficient analytical method proposed for power loss minimization through integrating multiple DG units into a distribution system [35]. These iterative methods consume more time.

3.2. Classical (Non-heuristic) approach:

Various classical optimization methods are performing better than analytical methods for finding a near-optimal solution with better accuracy. Some of methods reviewed in the present paper are as follows:

- Gradient Search (GS):

This characterize is based on minimization and maximization of a given function, gradient descent for function minimization and gradient ascent for maximization. GS ignores fault level constraints while integrating DG unit into meshed network [37,47].

- Non-Linear and Mixed Integer Non-Linear Programming (NLP and MINLP):

NLP is used for minimum DG unit allocation with improved voltage stability in both radial and meshed networks [48]. In [49], multiple DG allocation is preferred for reducing overall power loss and generation cost. MINLP is used to solve time-varying load models by converting discrete probabilistic generation load model to deterministic [50-52].

- Dynamic Programming (DP):

It is one kind of multi-stages sequential decision problem solver. In [53], DP is used to minimize the power loss of the distribution system with enhanced reliability and voltage profile.

- Ordinal Optimization (OO):

It provides a probabilistic framework for minimizing the search space and the computational burden. It gives trade-offs between loss minimization and DG capacity maximization [54].

- Exhaustive Search (ES):

It is a suitable method for time-varying behavior of generation and demand. Studies with load profile are energy based and without load profile is power based. But both DP and ES are not suitable for large systems [55].

- Continuation Power Flow (CPF):

A new methodology was developed based on CPF affirm that DG provides a part of the solution to increasing load demand [56].

3.3. Meta-heuristic approach:

This approach includes swarm-based and evolutionary optimization techniques [7]. Here for convenience, all these optimization techniques are taken as meta-heuristic techniques.

Fig. 3. Different approaches for ODG allocation and sizing

- Genetic Algorithm (GA):

GA belongs to evolutionary algorithms. Since sensitivity analysis is very peculiar hence GA with optimal power flow is considered [57,142]. Placement of DG units will causes Total Harmonic Distortion (THD) which can be reduced by GA using probabilistic planning approach [58]. Improved Non-dominated Sorting Genetic Algorithm – II (NSGA-II) is used for minimum investment cost, loss minimization with minimum voltage deviation and maximum voltage stability [59]. In [101], GA was used to minify costs of network upgrading, power loss, energy not supplied, and energy required by the served customers. An enhanced GA is used in [11] for total power losses reduction. In [103], a modified GA is used for ODG allocation to avoid voltage drop and frequency mismatch in distribution system. In [108], NSGA-II is used to reduce total power loss and imposed costs along with point estimation method for probabilistic approach.

- Tabu Search (TS):

TS algorithm is used to solve optimization problem within reasonable time span [9]. In [101], TS algorithm is used for loss minimization through ODG allocation.

- Bat Algorithm (BA):

It is a swarm intelligence-based algorithm. It was inspired by echolocation (bio-sonar) behavior of micro-bats. This is by varying pulse rates of emission and loudness. It is well suitable for DG integration into a network with mixed loads where reactive power loss is ignored [60].

- Shuffled Frog Leaping Algorithm (SFLA):

It is a population-based optimization algorithm. Optimization is carried by cooperative search metaphor inspired by natural meme-tics. It is used to improve voltage profile with maximum benefits on a 38 – bus distribution system [61]. In [106], modified SFLA is used for multi DG allocation and sizing along with an interactive fuzzy satisfying method.

- Artificial Bee Colony (ABC):

It is swarming intelligence-based algorithm which is inspired by foraging behavior honey of bees. It is well suitable for complex problems [62]. A chaotic ABC algorithm is used for allocation of real power DG units on a 38 node and 69 node radial distribution systems (RDSs) [68].

- Particle Swarm Optimization (PSO):

It is swarming intelligence-based algorithm. A wide range of hybrid, modified and improved types of PSO algorithms are used for ODG allocation and sizing problem. It is well-known optimization technique used in time varying load demand systems [63,64,141].

- Cuckoo Search (CS):

This algorithm was inspired by obligate brood parasitism of some cuckoo species. They used to lay their eggs in other host birds' nests. CS algorithm is used for real power loss minimization [65].

- Bacterial Foraging Optimization (BFO):

It is a nature-inspired optimization. It is used to find DG size and a loss sensitivity analysis for the location [66,137].

- Ant Colony Optimization (ACO):

It is a population-based algorithm. In this algorithm, ants find the optimal path from their colony to the food source. It is used for optimal reclosers and DG allocation in a distribution system [67].

- Flower Pollination Algorithm (FPA):

It is an evolutionary algorithm. In [71,94], FPA is used along with vector indexing method for loss reduction and voltage profile improvement through ODG allocation.

- Firefly Algorithm (FA):

This algorithm was inspired by flashing behavior of fireflies. It is used for energy loss minimization with ODG allocation [72].

- Ant-Lion Optimization (ALO):

It is inspired by hunting mechanism of ant-lions. In [73], ALO is used for integrating RER type DG units into the distribution system for loss minimization.

- Oppositional Krill Herd Optimization (KHO):

It is a biologically inspired algorithm. In [75], oppositional KHO is used for integrating RERs into RDS to reduce annual energy losses.

- Intelligent Water Drop (IWD):

It is a population-based algorithm. In [76], IWD algorithm is used for sizing of DG and a loss sensitivity factor for ODG allocation.

- Invasive Weed Optimization (IWO):

It is inspired by colonizing behavior of weeds. In [77], IWO is used for sizing of DG and a loss sensitivity factor for ODG allocation.

Table 3. IEEE 1547 series of standards for DG/DER interconnection [15]

IEEE Standard	Description	Year
IEEE 1547	Standards for Interconnecting DERs with EPSs	2003 and 2014
IEEE 1547 (full revision)	Draft Standard for Interconnection and Interoperability of DERs with Associated Power System Interfaces	2003
IEEE 1547.1	Standard for conformance Tests procedure for Equipment Interconnecting DERs with EPSs	2005
IEEE 1547.2	Application guide for IEEE 1547 Standards for Interconnecting DERs with EPSs	2008
IEEE 1547.3	Guide for Monitoring Information Exchange and Control of DERs with EPSs	2007
IEEE 1547.4	Guide for Design, Operation and Integration of Distributed Resource Island Systems with EPSs	2011
IEEE 1547.6	Recommended Practice for Interconnecting DERs with EPSs Distribution Secondary Networks	2011
IEEE 1547.7	Guide for Conducting Distribution Impact Studies for Distributed Resource Interconnection	2013
IEEE 1547.8	Draft Recommended Practice for Establishing Methods and Procedures that Provides Supplemental Support for Implementation Strategies for Expanded Use of IEEE Standard 1547-2003	2014

3.4. Hybrid approach:

In this approach, a combination of two or more optimization techniques is involved to achieve the optimal solution. In [78], GA based TS is used for optimal allocation of DG in demand side of power system. In [79], a combination of GA and PSO with fuzzy is used for converting the multi-objective problem to a single objective and to reduce iteration count. A combination of Imperialistic Competitive Algorithm (ICA) and GA are performing well for allocation of real and reactive power DG [80]. Transient stability problem can be solved through a combination of PSO and SFLA [81]. In [82], a combination of PSO and Gravitational Search Algorithm (GSA) is used to solve voltage rise problems due to DG integration. In [83], a combination of ACO and ABC algorithms are used for optimal wind DG allocation through appropriate stochastic wind power generation studies. Hybridization of methods will show a better solution for DG allocation problem.

3.5. Assorted approach:

Here miscellaneous or assorted approaches are presented. In [69,70], a backtracking search optimization algorithm is used for studying multi DG allocation with various load models. Pareto Frontier Differential Evolution (PFDE) will produce a worthy solution with a minimum number of iterations [84]. Symbiotic Organisms Search (SOS) algorithm, Quasi –Oppositional Swine Influenza Model-based Optimization with Quarantine (QOSIMBO-Q), Quasi-Oppositional Teaching Learning based Optimization and Supervised Big Bang - Big Crunch (BB-BC) method has better convergence speed [85-88]. Modified Honey Bee Mating Optimization (MHBMO), Modified Bacterial Foraging Optimization (MBFO) and Modified Teaching Learning Based Optimization (MTLBO) will produce superior non-dominated solutions [89-92] and improved harmony search algorithm for loss minimization in [96].

Analytical and classical (non-heuristic) approaches are performing well for small and simple systems, not suitable for a system with large and complex networks. However, performances of various meta-heuristic techniques are enhanced. Their high accuracy and faster convergence are suitable for extensively large and complex systems. A hybrid optimization is a combination of two or more optimization techniques. It offers more effective and reliable global optimum solutions for complex multi-objective problems. Different DG deployment methodologies with respect to approach, algorithm, objective function, test system, advantages, and disadvantages are presented in “Table 4”.

Table 4. Different DG Deployment Methodologies

S. No.	Approach	Algorithm	Objective	Test system	Advantages	Disadvantages	Ref
1.	Analytical	Linear differential	Minimize power loss	IEEE 6-bus and IEEE 30-bus test system	This method is effective, instructive and helpful in selecting suitable site for DG placement	DG size is not optimized, omitted economic and geographical factors	[97]
2.	Analytical	Iterative method	Minimize annual energy losses	69-bus distribution system	Integration of dispatchable and non-dispatchable renewable DG units	Power factor of DG units are kept constant which is not possible practically	[98]
3.	Analytical	Exhaustive search with sensitivity factor	Minimize loss considering different DG units	16-bus, 33-bus and 69-bus test system	Less computational time	Sizing and placement is considered only for peak load	[55]
4.	Analytical	Iterative method	Minimize active and reactive power losses	IEEE 15-bus and 33-bus RDS	Size of DG units are depends only on base case load flow	Proposed method is not applicable to unbalanced meshed networks	[99]
5.	Analytical	Power Stability Index (PSI)	Improve voltage profile and stability with loss reduction	12-bus, modified 12-bus and 69-bus RDS	Reduce losses and improves overall system efficacy	Thermal limit of the line not considered	[100]
6.	Analytical	Loss Sensitivity Factor (LSF)	Minimize total power losses	12-bus, 34-bus and 69-bus distribution test system	Analytical method without using admittance (Y_{bus}), inverse admittance matrix (Z_{bus}) or	Phasor current injection methods consider unrealistic assumption like uniformly and centrally	[45]

					Jacobean matrix	increased load profile	
7.	Analytical	Voltage Sensitive Index (VSI)	Minimize real and reactive power losses	A practical 69-bus distribution system	Well maintenance of voltage limits	Applicable for constant impedance and constant current loads	[41]
8.	Analytical	Existing sensitivity methods	Minimize cost of losses and power	33-bus and 69-bus distribution system	Reduces reactive power burden on input side of distribution system	Only considered unity and 0.9 lagging power factors	[42]

Table 4. (Continued)

S. No.	Approach	Algorithm	Objective	Test system	Advantages	Disadvantages	Ref
9.	Classical (Non-heuristic)	Non-Linear Programming	Minimize DG units, power losses and enhance voltage stability margin	34-bus distribution system	Conversion of non-linear programming to mixed integer non-linear programming not essential	Chances of infeasible solution due to convergence problem	[48]
10.	Classical (Non-heuristic)	Mixed Integral Non Linear Programming with probabilistic approach	Minimize energy losses by incorporating loss adjustment factors along with individual generation load factors	A practical 40-node test system	Maintaining voltage limits, feeder capacity maximum penetration limits and discrete size of DG units	Demand for computation	[52]
11.	Classical (Non-heuristic)	Probabilistic approach	Minimize annual system energy losses	A practical 40-node test system	Maximization of investment and penetration limits of DG units	Suitable only for RDS	[51]
12.	Classical (Non-heuristic)	Continuation Power Flow	Improve voltage limit loadability	85-node distribution system	Reliability improvement	System losses not evaluated	[56]
13.	Classical (Non-heuristic)	Dynamic Programming	Minimize the power loss with enhanced reliability and voltage profile	A practical 132/33kV distribution system	Financial and technical benefits	Effect of reactive power not considered	[53]
14.	Classical (Non-heuristic)	Ordinal Optimization	Minimize loss and maximize DG size s	69-node distribution system	Guaranteed solution	High computational burden	[54]
15.	Meta-heuristic	Genetic Algorithm	Minimize costs of network upgrading, power loss, energy not supplied, and energy required by the served	Small portion of distribution system constituted by 142 MV/LV nodes and	Reduced power losses with maximum loadability	For high quality solutions accuracy is low	[101]

			customers	substations			
16.	Meta-heuristic	Genetic Algorithm	Minimize electrical network losses	A 43-node Brazilian actual system	Evaluation of losses, voltage profile based on power flow method and reliability indices by analytical method	Premature convergence	[104]
17.	Meta-heuristic	Enhanced Genetic Algorithm	Minimize total power losses	16-bus distribution system	Simple and straightforward solution	Violation values of constraint not considered	[11]

Table 4. (Continued)

S. No.	Approach	Algorithm	Objective	Test system	Advantages	Disadvantages	Ref
18.	Meta-heuristic	Modified Genetic Algorithm	Minimize cumulative average daily active power losses	30-node distribution network	Avoids voltage drop, frequency mismatch, flickers and THD	Limited number of constraints considered	[103]
19.	Meta-heuristic	Genetic Algorithm	Improve voltage profile and reduce power losses	A 114-bus mixed urban and rural 11kV in UK	Security constrained optimization will increase system security and reliability	Considered only generator power factor	[111]
20.	Meta-heuristic	Genetic Algorithm	Maximize DG capacity	A 11kV RDS with 69-nodes	Efficiently allocate required number of DG	Considered only deterministic sources	[112]
21.	Meta-heuristic	Genetic Algorithm	Minimize real power losses	16-bus and 37-bus distribution system	Suitable for load models like residential, commercial and industrial loads	Requires multiple runs	[114]
22.	Meta-heuristic	Adaptive Genetic Algorithm	Minimize power losses and maximize node voltage deviation	IEEE 33-node and 52-node Indian practical distribution network	Better convergence	Self compared algorithm	[117]
23.	Meta-heuristic	NSGA-II	Minimize power loss and short circuit levels	IEEE 34-node test system	Suitable for load and generation variability models	Effectiveness of reactive power not considered	[113]

24.	Meta-heuristic	NSGA-II	Minimize cost and enhance reliability	21-bus, 100-bus and 300-bus test systems	Less computational cost	Problem with comparison	[115]
25.	Meta-heuristic	NSGA-II	Minimize power losses and maximize the net present value related to wind turbine investment over a planning prospect	A 11.4kV 84-bus RDS	Suitable for stochastic nature of load demand	Violating voltage limits	[116]
26.	Meta-heuristic	NSGA-II	Maximize annual saving in cost and improve power quality	69-node and 89-node test systems	Reduced THD and voltage distortion	High computational burden	[118]
27.	Meta-heuristic	Tabu Search	Minimize cost of power, energy losses and total required reactive power	33-bus and 69-bus RDS	Suitable for real and reactive power DG allocation	Thermal limits not considered	[119]

Table 4. (Continued)

S. No.	**Approach**	**Algorithm**	**Objective**	**Test system**	**Advantages**	**Disadvantages**	**Ref**
28.	Meta-heuristic	Tabu Search	Minimize Investment and Operation (I&O) cost and maximize reliability	54-bus system	Suitable for multistage distribution system	Difficult in trade-offs from the solution set	[120]
29.	Meta-heuristic	Particle Swarm Optimization	Improve voltage stability margin	41-bus distribution system	Effective analysis of voltage profile and stability	Complicated methodology	[64]
30.	Meta-heuristic	Adaptive Particle Swarm Optimization	Minimize total electrical energy losses, cost of generation, emission and bus voltage deviation	86-bus Taiwan power company system	Suitable for stochastic nature of wind generation and load demand	Correlation between DG units not considered	[121]
31.	Meta-heuristic	Particle Swarm Optimization	Minimize energy cost and losses	A 11.4kV 84-bus RDS	Suitable for stochastic nature of load demand	Violating voltage limits	[122]
32.	Meta-heuristic	Modified Particle Swarm Optimization	Minimize overall cost, power losses and improve voltage stability	33-bus test system	Suitable for short time DG planning problems	Effectiveness of reactive power not considered	[123]
33.	Meta-heuristic	Particle Swarm Optimization	Minimize active power losses, improve voltage stability and	IEEE 33-bus and an actual realistic 94-bus	Suitable for real and reactive power DG allocation	Violating voltage limits	[124]

			balancing current in system sections	Portuguese RDS			
34.	Meta-heuristic	Particle Swarm Optimization	Minimize real power loss	IEEE 33-bus and 69-bus RDS	Coordination and control of different DG units	Low voltage magnitude	[126]
35.	Meta-heuristic	Particle Swarm Optimization	Minimize power loss and improve voltage profile	Modified IEEE 16-bus and IEEE 30-bus system	suitable for capacitor allocation	Near optimal solution	[127]
36.	Meta-heuristic	Particle Swarm Optimization	Minimize real power loss, maximize branch current capacity and voltage deviation	51-bus RDS	Considered technical, economic and environmental aspects	Effectiveness of reactive power not considered	[128]
37.	Meta-heuristic	Ant Colony Optimization	Minimize loss, improve voltage profile and feeder load balancing	IEEE 33-bus test system and a Tai-power 11.4kV distribution system	Suitable for real and reactive power DG allocation	Limited number of constraints considered	[125]

Table 4. (Continued)

S. No.	**Approach**	**Algorithm**	**Objective**	**Test system**	**Advantages**	**Disadvantages**	**Ref**
38.	Meta-heuristic	Ant Colony Optimization	Minimize interruption costs	A 47-node test system	Reliable method for switch relocation	Parameter tuning	[129]
39.	Meta-heuristic	Ant Colony Optimization	Minimize I&O costs	A 34.5kV 23-node and a 10kV 201-node test system	Less computational time	Difficult parameter tuning	[130]
40.	Meta-heuristic	Ant Colony Optimization	Minimize real power losses	IEEE 14-bus and IEEE 136-bus test system	Less computational time	Effectiveness of reactive power not considered	[131]
41.	Meta-heuristic	Ant Colony Optimization	minimize the total operational, power purchase, customer interruption penalties, Transformers maintenance and the switching costs	IEEE 118-bus distribution test system	Interval based study for stochastic load modeling	Voltage stability and load balancing	[132]
42.	Meta-heuristic	Bat Algorithm	Minimize loss	IEEE 33-bus distribution system	Stochastic nature of solar irradiance is studied and losses reduced	Effectiveness of reactive power not considered	[60]

43.	Meta-heuristic	Artificial Bee Colony	Minimize loss	33-bus and 69-bus feeder system	Effective in handling complex problems	Converge towards local minima	[62]
44.	Meta-heuristic	Artificial Bee Colony	Minimize total cost	IEEE 30-bus, 33-bus and 45-bus system	Tested for both radial and meshed networks	Limited load sharing capability	[133]
45.	Meta-heuristic	Cuckoo Search	Minimize real power loss and improve voltage profile	38-bus and 69-bus distribution test system	Free from parameter tuning	Effectiveness of reactive power not considered	[139]
46.	Meta-heuristic	Cuckoo Search	Minimize real power loss and enhance voltage stability	IEEE 33-bus, IEEE 69-bus and 119-bus test system	Considered alternate methods for same objective	Effectiveness of reactive power not considered	[138]
47.	Meta-heuristic	Bacterial Foraging Optimization	Minimize the total power loss and improve voltage profile	IEEE 33-bus, and 69-bus RDS	Simple and quick losses minimization	High computational burden	[66]
48.	Meta-heuristic	Bacterial Foraging Optimization	Minimize cost	25-node and 23-node test system	Less parameter tuning	Standard test systems not considered	[134]

Table 4. (Continued)

S. No.	Approach	Algorithm	Objective	Test system	Advantages	Disadvantages	Ref
49.	Meta-heuristic	Bacterial Foraging Optimization	Minimize power losses	IEEE 34-bus and IEEE 85-bus RDS	Simple and quick losses minimization	Low voltage magnitude	[135]
50.	Meta-heuristic	Bacterial Foraging Optimization	Minimize power loss, THD and investment cost	34-bus RDS	Less computational time	Self compared algorithm	[136]
51.	Meta-heuristic	Improved Multi Objective Harmony Search	Minimize total loss, cost and maximize net annual savings	15-bus, 69-bus and 118-bus system	Better computational efficiency	Voltage stability not considered	[95]
52.	Meta-heuristic	Improved Multi Objective Harmony Search	Minimize power losses and improve voltage profile	33-bus and 69-bus test system	Superior performance in both uniform convergence and diversity	Not suitable for constraint optimization	[102]
53.	Meta-heuristic	Intelligent Water Drop	Minimize total line losses	IEEE 10-bus, 33-bus and 69-bus radial system	Easy to implement and obtain feasible solution near optimum with less	Problem with voltage deviation	[76]

					computation time		
54.	Meta-heuristic	Flower Pollination	Minimize loss and improve voltage profile	15-bus, 34-bus and 69-bus RDS	Improved voltage profile	Thermal limits not considered	[71]
55.	Meta-heuristic	Flower Pollination	Minimize cost and maximize net savings	15-bus, 69-bus and 118-bus RDS	Discrete capacitor ratings considered	Thermal limits not considered	[93]
56.	Meta-heuristic	Firefly Optimization	Minimize real and reactive power loss	IEEE 33-bus distribution test system	Improved voltage profile	Only suitable for single objective	[72]
57.	Meta-heuristic	Ant Lion Optimization	Minimize loss	15-bus, 33-bus, 69-bus and 85-bus test systems	Perform better at lagging power factors	Effectiveness of reactive power not considered	[73]
58.	Meta-heuristic	Cat Swarm Optimization	Minimize real power loss and maximize reliability	16-bus, 34-bus and 69-bus RDS	Better computational efficiency	Effectiveness of reactive power is ignored	[74]
59.	Meta-heuristic	Oppositional Krill Herd Optimization	Minimize annual energy losses through RERs	33-bus, 69-bus and 118-bus RDS	RER based DG are considered	Self compared algorithm	[75]

Table 4. (Continued)

S. No.	**Approach**	**Algorithm**	**Objective**	**Test system**	**Advantages**	**Disadvantages**	**Ref**
60.	Meta-heuristic	Grey Wolf Optimization (GWO)	Minimize power loss	IEEE 33-bus, IEEE 69-bus and Indian 85-bus RDS	Considered various optimization techniques in comparison	Considered only constant load	[10]
61.	Hybrid	Genetic Algorithm based Tabu Search	Minimize power loss	13-node and 34-node network	Harmonic power loss also reduced	Thermal limits not considered	[78]
62.	Hybrid	Ant Colony Optimization and Artificial Bee Colony	Minimize power loss, total emissions and electrical cost	IEEE 33-bus and 69-bus test system	Stochastic nature of wind generation is enlightened	Complicated methodology	[83]
63.	Hybrid	Hybrid Particle Swarm Optimization	Minimize power losses	16-bus, 33-bus and 69-bus radial distribution test system	Improve KVA margin to maximum loadability (KMML) and voltage profile	DG penetration more than 30% will effects actual system performance	[14]

64.	Hybrid	Evolutionary Programming and Particle Swarm Optimization	Minimize power loss	33-bus RDS	Less number of iterations and low computation time	Unsuitable for meshed networks	[105]
65.	Hybrid	Imperialistic Competitive Algorithm and GA	Minimize power loss, improve system voltage profile, load balancing and minimize cost	IEEE 33-bus and 69-bus RDS	Transmission and distribution relief capacity for both utilities and customers	Applicable only for uniform and constant power systems	[107]
66.	Hybrid	Particle Swarm Optimization and Gravitational Search Algorithm	Minimize total real power losses, mega volt ampere intake by the grid, improve voltage profile, DG quantity and reduce the emission	IEEE 69-bus RDS	High computational efficiency	Self compared algorithm	[82]
67.	Assorted	Pareto Frontier Differential Evolution	Improve voltage stability, minimize power loss and network voltage variations	IEEE 33-bus, 69-bus test systems	Non-dominated ranking methodology for finding optimal solution	Effect of reactive power is ignored	[84]
68.	Assorted	Symbiotic Organisms Search Algorithm	Minimize loss	33-bus and 69-bus distribution systems	Less convergence time	High computational time required	[85]
69.	Assorted	Quasi-Oppositional Swine Influenza Model based optimization with Quarantine	Minimize network power losses, improve voltage stability and voltage regulation	33-bus and 66-bus RDS	Computationally efficient	Premature convergence	[86]

Table 4. (Continued)

S. No.	**Approach**	**Algorithm**	**Objective**	**Test system**	**Advantages**	**Disadvantages**	**Ref**
70.	Assorted	Quasi-Oppositional Teaching Learning based Optimization	Minimize power loss, voltage deviation and improve voltage stability index	33-bus, 69-bus and 118-bus RDS	Overcomes slow convergence problem in TLBO	Self compared algorithm	[87]
71.	Assorted	Supervised Big Bang Big Crunch Method	Minimize power and energy losses	IEEE 37-node feeder	Applicable for balanced and unbalanced systems	Self compared algorithm	[88]
72.	Assorted	Modified Honey Bee Mating Optimization	Minimize costs, emission and losses	Typical 70-bus test system	Performs better in case of single and multi objective problem	Problem with comparison	[89]
73.	Assorted	Modified Bacterial Foraging Optimization	Minimize total power loss and improve voltage profile	12-bus, 34-bus and 69-bus RDS	Overcomes the delay caused in BFO	Self compared algorithm	[90]

74.	Assorted	Modified Teaching Learning based Optimization	Minimize total electrical power losses	69-bus and 119-bus test distribution system	Applicable for large networks	Compared with only brute force algorithm	[91]
75.	Assorted	Chaotic Artificial Bee Colony (CABC)	Minimize power loss, line flow limit, improve voltage profile and voltage stability index	38-node and 69-node RDS	Improves system overall performance	Economic benefits not addressed	[68]

According to No Free Lunch (NFL) theorem, computational complexity and optimization process for different problems have same computational cost for finding a solution. Therefore, no solution has "short-cut" method. For solving a particular type of problem all output solutions are statistically identical. Choosing appropriate optimization technique for a particular problem will depend on the choice of individual [110].

4. Conclusion

The present paper clearly illustrates the significance of ODG allocation and sizing in a distribution system. Simultaneously the study elucidates DG integration benefits like power loss minimization, voltage profile improvement, reduced investment with low operation and maintenance cost and reduced greenhouse gases emission by integrating RER based DG units. This study also focuses on parameters which depend on ODG allocation and sizing. Various researchers have already acknowledged ODG allocation and sizing benefits like technical, economic and environmental. In addition to this several analytical, heuristic, meta-heuristic and hybrid optimization techniques are adapted for ODG allocation and sizing. Analytical approaches are not computationally difficult for simple systems but not suitable for a system with large and complex networks. Incorporation of uncertainties associated with DG output, load demand, electricity pricing and emission will make system more complex. Meta-heuristic and hybrid techniques are well suitable for extensively large systems. They process with high accuracy and splendid convergence features. This technique provides global optimum solutions for simple single or complex multi-objective problems. It is found that for ODG allocation and sizing several meta-heuristic optimization techniques are performing extremely well. Various techniques such as CSO, WOA, IWD, IWO, ABC, SFLA and SSA may seem to be promising in future.

5. Scope

The significance of research scope and recommendations based on above literature survey are pointed out below.

- The research work can be extended by the planning of distribution networks with intermittent nature of DG units like wind and solar. Such type of planning involves stochastic studies.
- RERs based DG units with battery energy storage systems and their significance not considered in the present study.
- ODG allocation and sizing through hybrid techniques are recommended which may give effective and better results.
- Introduction of new algorithms in future for ODG allocation and sizing problem may improve the performance and reduction in computational time.
- Distribution network expansion and protection schemes via DG installation by considering static, seasonal and practical load models for future work.
- Operating DG as standalone mode may extend the future scope of research.

Acknowledgements

Author gratefully acknowledges the encouragement and support of VIT University in the publication of this paper.

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