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A REVIEW ON DG IN DISTRIBUTION SYSTEMS - OPTIMAL ALLOCATION AND SIZING TECHNIQUES

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Abstract- Appropriated Generation (DG) offers the solid and financial wellspring of power to customers. These are associated straightforwardly to the dispersion framework at purchaser load focuses. Reconciliation of DG units into a current framework has essentially high significance because of its countless benefits. In any case, Optimal DG (ODG) designation and estimating is dependably a difficult errand for utilities just as shoppers. The significant target of ODG distribution and measuring is to further develop framework in general effectiveness with least power misfortune, greatest framework security, voltage dependability, and unwavering quality. Logical methods are performing admirably for little and straightforward frameworks, not appropriate for a framework with enormous and complex organizations. Be that as it may, different meta-heuristic strategies are performing better as far as exactness and intermingling for widely enormous and complex organizations. Mixture advancement is a blend of at least two enhancement strategies. This method offers productive and dependable worldwide ideal answers for complex multi-objective issues. In this specific situation, a thorough writing audit of DG essentials and the diverse specialized methodologies for DG coordination into the appropriation framework are broke down here. Besides, an endeavor has been made for correlation of scientific, old style (non-heuristic), meta-heuristic and half breed advancement methods regarding objective capacity, test framework, benefits, and impediments. This current review will give inside and out information and goes about as a straightforward reference for fast approaching examiners and financial backers for ODG designation and estimating in a circulation framework.

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

1. INTRODUCTION

A long-term situation witness that conventional power age strategies have predominance over years. In these creating units, traditional sort energy assets (petroleum products) are utilized for power age. Because of a huge ascent in power interest, use of customary sort energy assets causes ecological issues. These power age units discharge a tremendous measure of ozone harming substances. Worldwide worry towards lessening adjustment on non-renewable energy source and decrease environment changes, a substitute method of force age worldview has taken on. It is to disperse age along dissemination framework. 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 NOx emissions over diesel generators. Although micro- turbines have low NOx 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 CO2, NOx 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].

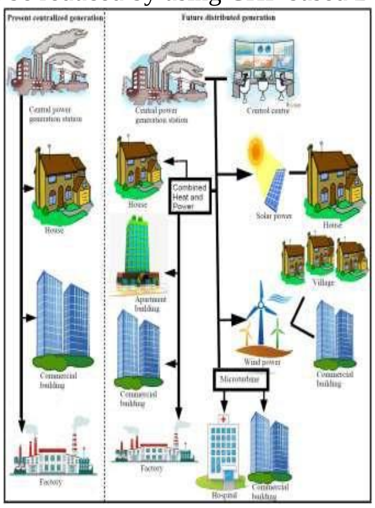

Fig. 1. Present centralized and future distributed generation scenario

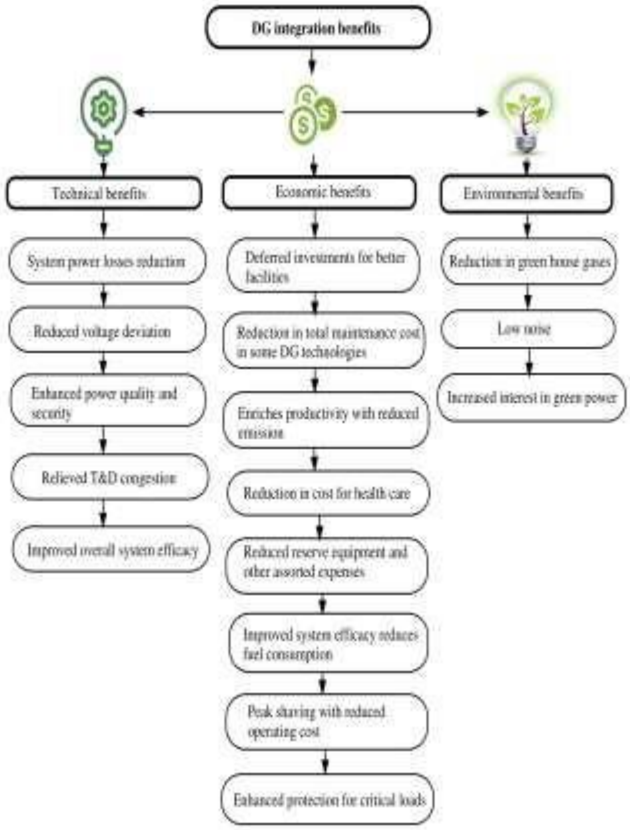

Fig. 2. DG integration benefits

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.

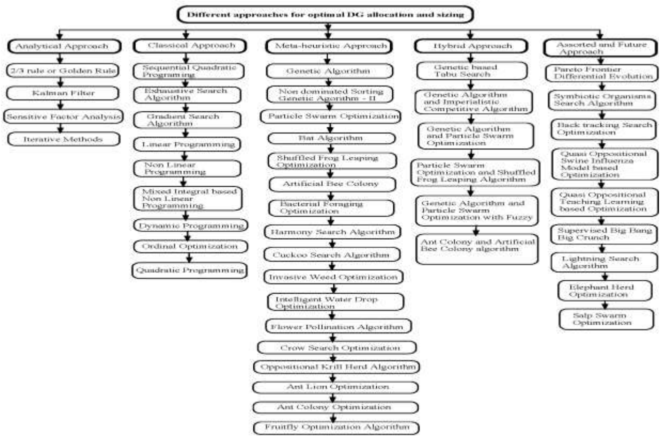

Fig. 3. Different approaches for ODG allocation and sizing

- 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 produceuperior 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.
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.

4. CONCLUSION

The current paper plainly shows the meaning of ODG assignment and estimating in a circulation framework. At the same time the review clarifies DG reconciliation benefits like power misfortune minimization, voltage profile improvement, decreased venture with low activity and support cost and diminished ozone harming substances discharge by coordinating RER based DG units. This concentrate likewise centers around boundaries which rely upon ODG assignment and measuring. Different specialists have as of now recognized ODG portion and estimating benefits like specialized, monetary and natural. Notwithstanding this few scientific, heuristic, meta-heuristic and half breed improvement methods are adjusted for ODG assignment and estimating. Scientific methodologies are not computationally hard for basic frameworks yet not appropriate for a framework with enormous and complex organizations. Fuse of vulnerabilities related with DG yield, load interest, power evaluating and discharge will make framework more intricate. Meta-heuristic and half breed methods are well appropriate for widely huge frameworks. They process with high exactness and stunning union highlights. This procedure gives worldwide ideal answers for basic single or complex multi-objective issues. It is found that for ODG distribution and measuring a few meta-heuristic enhancement strategies are performing very well. Different strategies, for example, CSO, WOA, IWD, IWO, ABC, SFLA and SSA might appear to be encouraging 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. 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].
- 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.

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