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Optimal sizing and siting techniques for distributed generation in distribution systems: A review

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ABSTRACT

To extract the maximum potential advantages in light of environmental, economical and technical aspects, the optimum installation and sizing of Distributed Generation (DG) in distribution network has always been challenging for utilities as well as customers. The installation of DG would be of maximum benefit where setting up of central power generating units are not practical, or in remote and small areas where the installation of transmission lines or availability of unused land is out of question. The objective of optimal installation of DG in distribution system is to achieve proper operation of distribution networks with minimization of the system losses, improvement of the voltage profile, enhanced system reliability, stability and loadability etc. In this respect analytical (classical) methods, although well-matched for small systems, perform adversely for large and complex objective functions. Unlike the analytical (classical) methods, the intelligent techniques for optimal sizing and siting of DGs are speedy, possess good convergence characteristics, and are well suited for large and complex systems. However, to find a global optimal solution of complex multi-objective problems, a hybrid of two or more meta-heuristic optimization techniques give more effective and reliable solution. This paper presents the fundamentals of DG and DG technologies review the classical and heuristic approaches for optimal sizing and placement of DG units in distribution networks and study their impacts on utilities and customers.

An attempt has also been made to compare the analytical (classical) and meta-heuristic techniques for optimal sizing and siting of DG in distribution networks.

The present study can contribute meaningful knowledge and assist as a reference for investigators and utility engineers on issues to be considered for optimal sizing and siting of DG units in distribution systems.

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1. Introduction

The exponentially increasing electricity demand has resulted in the continuous depletion of the traditional power generation sources. The traditional power generation sources are operated centrally and are not suited for environmental and cost issues in today's liberalized electricity market. The major objective of the utilities is to provide electricity to their customers in a reliable, decent and cost effective manner. In this perspective, DGs offer the solution of these issues up to some extent. Since DGs require less area for installation, possess smaller unit size and can be powered by renewable and non-renewable source, they are gradually becoming integral parts of the electric distribution system [1–4].

The DGs are of relatively small sizes ranging from a few kW to around 100 MW [2,4,5]. Moreover, DGs are the sources of electricity generation that are directly connected to the customers' end [2–5].

Optimally placed DG units reduce system losses and leads to improvement in the voltage profile, system reliability, loadability, voltage stability, voltage security, power quality. Furthermore, DGs are also competent to mitigate harmonics, voltage sags and swells significantly [1,19,27–35,80] along with deferred investment in transmission and distribution. Therefore, DG placement in distribution systems is not only beneficial for customers but also for utilities. Moreover, the evolution of modular DGs calls for smaller space, less construction time and lower investment. As a consequence, DG has become an area of active interest for many researchers [7–11]. This motivates the authors to present a comprehensive review on this topic.

Besides these advantages, DG technology is also associated with some disadvantages if not installed at the optimal locations [2,5,13,14]. DG may lead to stability problems. Bidirectional power flow may lead to problems of protection. Furthermore, problems of frequency may occur along with islanding difficulties. Therefore, the following important issues and facts need to be considered vis-à-vis installation and sizing of DGs [2–5,13].

i. The types of DGs are a crucial factor to achieve optimal performance of the distribution system. The nature of injected power from DG units is exclusively depends upon type of DG is to be installed as requirement of load [10,24].

ii. The sizing and location parameters of DG have to be carefully determined to improve the overall performance and efficiency of the system technically.
iii. Evaluate the number and rating (size) of DGs to be placed in the power system for economic operation of the system. Since over size DG cause bidirectional power flow.

Table 1
Generation of DG at different level [2,4,13,14].

S.No.	Class	Size
1.	Micro distributed generation	1 W– < 5 kW
2.	Small distributed generation	5 kW < 5 MW
3.	Medium distributed generation	5 MW < 50 MW
4.	Large distributed generation	50 MW– < 300 MW

iv. Analyze the system security elements for carrying out continuous duty and maintain the appropriate indices (voltage profile index, power loss index, penetration level index and short-circuit level index) within acceptable limits [13,90].

Therefore, the installation of the DG becomes very crucial for reliable operation and to meet the demand of the consumers. Subsequently, these aspects need to be considered in detail for optimum sizing and siting of DG.

On the basis of literature survey the limitations and extensions of present study can be summarize as follows.

- The research work may further be extended in future by considering standalone and islanding difficulties associated with operation of DG and its impact on electric distribution networks.

Table 2
Major DG technologies and their merits and demerits [5,14].

S. No.	DG Technology(ies)	Electric Power Generation Range(s)	Merit(s)	Demerit(s)
1.	Solar Technology Solar Photo-Voltaic (SPV) Solar Thermal Power Plant Solar Thermal (Lutz System)	200 W–3000 kW 1 MW–80 MW 10–10 MW	• Easiest and cleanest • Maintenance cost is very less • Fuel free • Over all environmental friendly	• Require large solar collector • Solar thermal systems are health hazard • Need battery bank for storage • SPV module pose disposal problem • Initial cost is very high
2.	Integrated Gasification Combined Gas Turbine	30 kW–3000+kW	• System efficiency improved • Less emission • Reliability is more	• Unused heat dissipated in atmosphere • More maintenance • Initial cost is very high
3.	Micro Turbine	30 kW–1 MW	System efficiency improvedLess emissionReliability is more	• Emission is less • Initial cost is more
4.	Internal Combustion (IC) Engine	5 kW–10 MW	• Fast response • Investment is less	• Emission is more • Require more maintenance
5.	Small Hydro	5 kW–100 MW	• Free and renewable energy source • Less installation cost • Eco-friendly	• Generation depend on water • Affected in flood time • Load demand cannot be meet out • Initial cost is more
	Micro Hydro	1 kW–1 MW	• Small size, light weight • Emission free • Less noise	• Cost is more • Low working temperature • Less efficiency • Initial cost is more
6.	Wind Turbine	200 W–3 MW	• Generation cost is very less • No adverse effect on global environment • Fuel free • Saving of land use	• Wind generators are hazards • Noise pollution • Wind speed affect the output • Variable power production highly dependent on wind speed
7.	Bio-Mass Energy	100 kW–20 MW	• Renewable energy source • Reduce Green House Gas (GHG) emission • Lessen dependency on upon conventional fuel • Stops desertification	• Combustion of bio-mass produces air pollution • Source limitation • Maintenances are expensive • Soil erosion
8.	Geothermal Energy	5 MW–100 MW	• Economical as stations need small space • No fuel is needed • Renewable source • Its cost not rise with time	• Discharge of waste water polluted rivers • Noise pollution • Gases escape into atmosphere • Large-scale withdrawal of underground fluid may cause damage to surface structure
9.	Tidal Energy	0.1–1 MW	• It restrict emission of GHG • Fuel not required • Energy use is forecast able	• Problem faced in placement of machinery • Supply may available for limited time • Machines and supporting equipments are expensive
10.	Fuel Cell (FC) Technology Alkaline FCs Phosphoric- Acid FCs Molten Carbonate FCs Solid Oxide FCs Proton Exchange FCs Battery Storage	1 kW–300 kW 100 W–50 kW 200 kW–2 MW 250 kW–2 MW 250 kW–5 MW 1–250 kW 0.5–5 MW	• Noise less, eco-friendly • Efficiency is more • Wide choice of fuel • They can operate with waste water treatment plant	• Expensive • Requirement of fuel processing • Less durability • Initial cost is more
11.	Hydrogen Energy System	40–400 MW	• Carbon free • It is a non-conventional energy source • It is a energy carrier	• Difficulty in storage, packaging and public distribution • Pressurization is difficult • Initial cost is more
12.	Ocean Energy	100 kW–1000 kW	• Carbon free • It is a renewable based energy source	• Difficult to harness • Very less efficiency • Initial cost is high

- The uncertainties constrained in (DG output, load model and electricity prices) may also be included for long term and expansion planning of existing distribution system.
- Moreover, by combined utilization of two or more hybrid meta-heuristic techniques.

The remaining part of limitations and extension of present research work are appeared in Section 6 under recommendations of this paper.

This paper is organized in the following manner. Section 2, represents the details of DG, DG technologies, possible benefits and impacts of DG (technical, economical and environmental), importance and a generalized algorithm for the optimum sizing and siting of DG in distribution networks. Section 3 presents a comprehensive review on the various methods adopted for optimum DG sizing and siting based on various aspects such as system losses, voltage profile and reliability and their relative merits and demerits. Section 4 highlighted the various sizing and siting technique of DG, comparison and drawbacks of analytical and intelligent techniques along with integration issues of hybrid intelligent techniques. Conclusions and major recommendations for future work are presented in Sections 5 and 6 respectively.

2. Distributed generation

Although the concept of DG is not a new one but it has become more attractive nowadays because of its innumerable advantages over the central power generating units. The nomenclature adopted for DG varies throughout the world [1–5]. As far as its definition and size is concern there is no uniformity, in different countries its names are different such as, dispersed generation, embedded generation and decentralized generation etc [4,5]. Various researchers defined it in their own way some of them are given as, as per [4] DG is be defined as, “DG is an electric power source connected directly to the distribution network or on the customer site of the meter”. International Council on Large Electricity Systems (CIGRE) defined DG as, all generation units with a maximum capacity of few kW to 100 MW, that are usually connected to the distribution network and that are neither centrally designed nor dispatched [2]. Electricity generation units which are connected directly in the local distribution network, as opposed to connecting to the transmission network [13].

The electric power generation of DG at different levels on the basis of the generation capacity is illustrated in Table 1 [2,4,13,14]

Currently, quite a small number of DG technologies are still in research and development phase. The major DGs technologies with their electric power generation capacities, merits and demerits are shown in Table 2, [5,14].

2.1. Importance of optimum sizing and siting of DG

The placement and sizing of the DG units in distribution network is very crucial and challenging because optimally and strategically placed DG reduced the system losses, improve system voltage profile, loadability, reliability, stability, power security, voltage regulation, voltage stability margin, power quality and voltage sag and swell, system power factor etc. In addition that bidirectional power flow also observed [1–3,5,19,20,44,52]. Furthermore, DG units are capable of deferment of network expansion to meet load growth. While random or unstrategical placement of DG creates many problems, that all the above mentioned merits will be in adverse mode besides these the protection system of the system get disturbed due to bidirectional power flow, since the systems are designed for unidirectional power flow, this may lead to increase the system losses [1–3,13,14,31,48–50]. Therefore, it is most essential that the placement and sizing of the DG units in distribution system should be at optimal and appropriate place for maximize their benefits to the utilities as well as consumers [4,14].

2.2. Impacts of DG

The impingements of DG can be broadly classified in three categories as listed below

i. Environmental Impacts of DG Units
ii. Economic Impacts of DG Units
iii. Technical Impacts of DG Units

2.2.1. Environmental impacts of DG

Rapid depletion of conventional resources in light of pollution and climate change effects has necessitated the generation of green energy. In this perspective, DGs are attracting the attention of researchers, academicians and environmentalists. DGs provide a feasible option since most of the DG technologies are powered by renewable resources. According to published literature, 80% of the total pollution around the world was produced by fuel burning [1–5,48–50,60,105].

Many researchers have claimed that the DG technologies are capable of reducing the emission of carbon, which is responsible for global warming [16,17,46]. According to a report published in 1999 in United Kingdom, the CHP based DG technology is able to cut the emission of carbon by about 41% [14].

DG technology is able to provide ancillary service benefits to the society with respect to the environment. The central power generation units emit large amount of green house gases (GHG) such as carbon mono-oxide, sulfur oxides, particulate matter, hydrocarbons and nitrogen oxides. These pollutants are the major contributors to the global warming [16,17,46]. Many researchers have confirmed that large-scale use of DG technologies substantially cuts emissions [16,17]. As a result, DG installation may have an effect on reduced health care cost.

Finally, DGs can support a country to increase its diversification of energy sources [3]. Many DG technologies like wind turbines, solar photovoltaic cells and hydro-electric turbines do not consume fossil fuels. On the other hand fuel cells, microturbines and some internal combustion engines burn natural gas. This increasing diversity helps to insulate the economy expenses, disruptions and fuel scarcity [2–5,14,15].

DG provide approximately 30% contraction in detrimental carbon dioxide (CO_2) ejection as compared with traditional heating apparatus and grid supplied electricity. The micro turbine has operating efficiency more than 40% and emits very less amount of toxic gases $NO_X < 7$ ppm (Natural Gas) [14,16,17,46].

2.2.2. Economical impacts of DG

The major benefits received by utilities and customers causing the shift towards the DG utilization, may be listed as under.

The other factors which affects the economy of investors or utilities as follows.

i. Deferred investments for enrichment of facilities.
ii. Reduced operation and maintenance costs of some DG technologies.
iii. Upgraded productivity.
iv. Reduced health care investments because of enhanced environment.
v. Reduced fuel expenses due to increased efficiency.
vi. Reduced reserve requirements and the supplementary expenses.
vii. Lower operating expenditure due to peak shaving.
viii. Increased protection for critical loads [1,2,5,14,105].

2.2.3. Technical impacts of DG

The insertion of DG in distribution system is always challenging. The optimal sizing and siting of DG technically is essential. If optimal sizing and siting of DG is not addressed properly, distribution system may face technical problems as reported in [1–5,14,31,48–50,60,63,69,105].

(1) *Power losses*

a. *Active power losses*
b. *Reactive power losses*
c. *Active and reactive power losses*

(1) *Voltage profile*

a. *Excess voltage*
b. *Voltage fluctuation*

(1) *Reliability*

(1) *Power Losses*

The placement of DG units in distribution systems has significant impact on electric power losses because of proximity to the load centers. The DG units are placed in such way so as to maximize the reduction in system losses. Optimally sized and placed DGs can reduce electrical losses significantly. 10–20% reduction in the system losses are common [6,8,10,11,16–21,23–47,53]

(1) *Active Power Losses*
Some DG technologies are competent to delivering active power such as solar photo voltaic, micro turbines and fuel cells [10,11]. Optimally placed DG units are capable of reducing the system losses significantly [17,20,21,23,24,29,35–37,41,53,88].
(2) *Reactive Power Losses*
A number of DG technologies are also incapable to delivering reactive power such as kVAR compensator and synchronous compensator [10,11]. Optimally placed sized DG units are capable of reducing the system losses significantly. Further, the demand and supply of reactive power get disturbed if DG not placed and sized optimally [24,30,36,37,41].
(3) **Active and Reactive Power Losses**

Many DG technologies are capable of delivering active and reactive power such as synchronous generators [10,11]. Optimally placed and sized DG units are well suited for reducing the active and reactive power loss components significantly [22,24–26,28,32,33,37,40,41].

(1) *Voltage Profile*

The optimal installation and sizing of DGs in distribution systems may lead to improvement of system voltage profile significantly. Further voltage profile depends upon the nature of the connected load and type of DG to be installed. The improvement in voltage profile, as a result the system performance also get improved [17,27,47,54–56,66,67,70,72,78,82].

(1) *Excess Voltage*
Random installation of DG produces many technical problems such as voltage rise, voltage fluctuation, introduction of harmonics and transients, voltage regulation. The voltage violation depends on the installation of the DG units and system characteristics, strength of network, active and reactive power export from local bus bars and nature of load [14,29,47].
(2) *Voltage fluctuation*

The introduction of the DG units in distribution network causes the voltage fluctuation because there is a mismatch between reactive power requirement of load and reactive power supplied by the system [14,64,86].

(1) *Reliability*

The purpose of electric utilities is to supply the electric power to their consumers in a prudent, efficient and reliable (decent) manner. It is worth note that intention to preserve reliable power systems because, disruption cost and power outages have several economical impacts on both utility as well as its consumers. The one of the major reason of installation of the DG units in distribution system is to enhance the reliability of the system. The DG could be utilized as alternative supply system or also as main supply system. The DG could also be operated during the peak load periods in order to defer additional charges [14,25,27,34,51,63,66,79,87].

The assessment of the reliability could be performed in terms of reliability indices. The indices linked with reliability such as SAIFI (system average interruption frequency index), SAIDI (system average interruption duration index), CAIFI (customer average interruption frequency index), CAIDI (customer average interruption duration index), AENS (average energy not supplied), ENS (energy not supplied) and EENS (expected energy not supplied) etc. Furthermore, the improvement in SAIDI gives rise to improvement in system reliability [27,51,63].

2.3. Problem objectives

A general procedure and necessary steps need to be considered for optimum sizing and siting of DG units in distribution network is proposed in present study. Subsequently arrange the associated group of parameters in logical manner to form the objective function with suitable constraints [12,90].

Define problem objective, it may be of single objective or multi-objective (the single objective functions are such as to minimize system power losses, system voltage profile improvement, cost minimization, improvement of system reliability, etc. and multi-objective function would be the combination of two or more single objective function) by considering suitable parameters and constitute the objective function, the objective function may be as follows [12].

2.3.1. Objective function

At first, it is to be decided whether the objective function is to be minimized or maximized. Subsequently, after formulating the objective function by considering all the parameters associated with it, the objective function is optimized [12,90].

$$y = x_1 + x_2 + x_3 + \dots\dots\dots x_n = \sum_{k=1}^{n} x_k \tag{1}$$

where 'n' is the number of parameters on which objective function depends, here four parameters have to be considered

(1) *System Power Losses*: the system losses can be determined as

$$x_1 = x(P_L) = P_L \tag{2}$$

where P_L is the entire system losses, adjusting the P_L by taking weight factor therefore the finalx_1 will be

$$x_1 = \beta_j \frac{P_L^{afterDG}}{P_L^{beforeDG}} \tag{3}$$

where β is the weight factor and 'j' is the bus number, where DG is to be installed.
(2) *Voltage Profile Factor*: the voltage profile depends on the bus voltage, it can be written as voltage after DG placement and

voltage before DG placement as 1.0 p.u. hence

$$x_2 = \mu_j \left(V_{bus,j}^{afterDG}\right)^2 \quad (4)$$

(3) *Short-Circuit Current Factor*: this parameter related to security concern and can be defined as

$$SCL_j = \frac{i_{scl,j}^{afterDG} - i_{scl,j}^{beforeDG}}{i_{scl,j}^{afterDG}} \quad (5)$$

$$x_3 = \eta_j (SCL_j)^2 \quad (6)$$

(4) *Sizing (Capacity) Factor*: the DG resources may be extracted in their more efficient way, achieving this objective the sizing should be done perfectly or else over sized DG may cause reverse power flow. If DG is being placed at 'j^{th}' bus of capacity 'CP'

$$x_4 = \sum_{j=1}^{N} \lambda_j \frac{CP_j}{S_{base}} \quad (7)$$

Therefore the final objective function will be

$$y = x_1 + x_2 + x_3 + x_4 \quad (8)$$

Taking the sum of all values from Eqs. (3), (4), (6) and (7) respectively

$$y = \sum_{j=1}^{N} \left(\beta_j \frac{P_L^{afterDG}}{P_L^{beforeDG}}\right) + \sum_{j=1}^{N} \mu_j \left(V_{bus,j}^{afterDG}\right)^2 + \sum_{j=1}^{N} \eta_j (SCL_j)^2 + \sum_{j=1}^{N} \lambda_j \frac{CP_j}{S_{base}} \quad (9)$$

where β is the weight factor of system power losses, μ is the weight factor of voltage profile, η is the weight factor of short-circuit level and λ is the weight factor of sizing.

2.3.2. Constraints

The constraints are extremely important parameters. The objective function should satisfy all the given constraints. If all the constraints not satisfied and any mismatch, the sizing and placement consequently, obtained could not serve the purpose and may lead malfunction performance of the system. The following are the main constraints used [12,19,43].

(1) *Bus Voltage Constraint*: the voltage of the bus should be varies within prescribed limit

$$V_{MIN} < V_{bus,j}^{afterDG} < V_{MAX} \quad (10)$$

In this $\pm 5\%$ tolerance of bus voltage is allowable, that is V_{MIN} goes up to (0.95 pu) and V_{MAX} goes up to (1.05 p.u)

(2) *Short-Circuit Current Constraint*: the short circuit current level must be in allowable limit, if increase beyond the range it would be dangerous, this factor work as safe guard to the system.

$i_{scl,j}^{afterDG} <$ *Short circuit current level installed protective devices*

(3) *DG Sizing (Capacity)*: the summation of the generated active power by the installed DG units should not more than the total load demand of the system

$$\sum_{j=1}^{No.of DG} CP_j \le P_{LOAD} \quad (11)$$

This constraint impedes the bidirectional power flow.

(4) *Power Factor Constraints*: the power factor of DG which is to be installed must be varies within specified range, the utilities also interested in operating in upper power factors, this factor mainly considered at the time of sizing

$$0.8 \le pf_{DG,j} \le 1 \qquad j = 1, 2, \ldots No.of DG$$

(5) *Weight Factor*: the weight factors have to be selected in such a way that the sum of the all weighted factors must be equal to 1 such as

$$\beta + \mu + \eta + \lambda = 1 \quad (12)$$

The weight factors can be calculated as follows

(6) *Weight Factor β*: it can be calculated as

$$\beta = \frac{P_L^{beforeDG}}{P_L^{afterDG}} \quad (13)$$

(7) *Weight Factor μ*: this can be evaluated as

$$\mu_j = \frac{1}{\left(V_{bus,j}^{afterDG} - 1\right)^2} \quad (14)$$

(8) *Weight Factor η*: this can be evaluated as

$$\eta = \left(\frac{I_{scl,j}^{afterDG}}{I_{scl,j}^{afterDG} - I_{scl,j}^{beforeDG}}\right)^2 \quad (15)$$

(9) *Weight Factor λ*: it can be evaluated as

$$\lambda = \frac{S_{base}}{CP_j} \quad (16)$$

Evaluating all these weight factors, subsequently normalizing them by multiplying suitable common factor so that their sum must be equal to 1

2.3.3. Required indices

The indices have significant position in estimating the efficiency of the system. The indices introduced here offer information of deviation of the parameters. Additionally, they can spot whether the parameters are in tolerable range or not [90].

(1) *Power Loss Index*: with the help of this index, the magnitude of difference of active and reactive power losses due to placement of DG units, can be calculated as

$$PL_I = \left(1 - \frac{\mathrm{Re}\{LossesafterDG\}}{\mathrm{Re}\{LossesbeforeDG\}}\right) \times 100\% \quad (17)$$

$$QL_I = \left(1 - \frac{\mathrm{Im}\{LossesafterDG\}}{\mathrm{Im}\{LossesbeforeDG\}}\right) \times 100\% \quad (18)$$

Here PL_I and QL_I are the %age fluctuation of active and reactive power losses respectively

(2) *Voltage Profile Improvement Index*: this estimates the deviation in voltage after the placement of the DG units in distribution network, can be illustrated as

$$VP_{II} = \gamma \cdot \left(\frac{VP_{afterDG}}{VP_{beforeDG}} - 1\right) \times 100\% \quad (19)$$

where $VP_{before\ DG}$would be as

$$VP_{beforeDG} = \sum_{k=1}^{N} V_k \quad (20)$$

and

$$\gamma = \begin{cases} 1 & (0.95 < V_k < 1.05) \\ 0 & (V_k < 0.95 or V_k > 1.05) \end{cases} \quad k = 1, 2, ...N \tag{21}$$

The higher value of VP_{II}, results more improvement in voltage profile

(3) *Short Circuit Current Level Index*: this index can be evaluated as

$$I_{scl} = \rho.\left(\frac{I_{scl}^{afterDG}}{I_{scl}^{beforeDG}} - 1\right) \times 100\% \tag{22}$$

where I_{scl} short-circuit current level index and

$$I_{scl} = \sum_{k=1}^{N} I_{scl}^{k} \tag{23}$$

To diagnose, whether short-circuit current level more than that of allowable magnitude of the circuit breakers (CBs) or not, therefore, it is to be decided by ρ, and ρ can be defined as

$$\rho = \begin{cases} 1 & (I^k < I_{switch}^k) \\ 0 & (I^k > I_{switch}^k) \end{cases} \quad k = 1, 2, ...N \tag{24}$$

Assuming that short-circuit current level of each buses in allowable range of the circuit breakers, then ρ would be 1 otherwise 0

(4) *Penetration Level*: the penetration level of DG units in the system can be estimated on the average penetration of the DG units [59].

$$\sum_{j=1}^{N} \sum_{t=1}^{m} x_4.P_{DG_{t,j}} \le r. \sum_{j=1}^{N} P_{D_j} \tag{25}$$

where N is the total number of buses, m is the total number of DG units to be placed, x_4 is the capacity factor $P_{DG_{t,j}}$ rated power of the tth DG unit and 'r' is the maximum penetration level as the fraction of the peak load and P_{D_j} peak active load at bus 'j'.

The advantages of this process may be stated as the deviation from above explained modus operandi may lead to unwanted system losses, reduced voltage profile, poor system reliability, efficiency and overall performance of the system will get reduced etc.

2.4. Generalized algorithm for DG sizing and siting

The backward and forward sweep method is to be applied for balanced, single phase and radial distribution system for load flow. The generalized algorithm for optimum sizing and siting of DG is illustrated as following [90].

Step 1: read the system data. System configuration such as, line resistance, line impedance, bus number from sending end to receiving end, active and reactive load on particular bus.
Step 2: run the load flow.
Step 2(a): determine the bus voltage.
Step 2(b): determine the system losses.
Step 2(c): determine the bus short circuit current
Step 3: constraints present or not.
Step 4: if constraints present – estimate the initial weight factor and followed by objective function.
Step 5: if constraints not present – go to step 2.
Step 6: apply suitable optimization technique to estimate the objective function.
Step 7: is the calculated objective function is the best fit objective function?
Step 8: calculate the required indices.
Step 9:analyze the weight factor-if weight factors are appropriate then display result and -end, if weight factors are not appropriate then go to step 6.
Step 10: calculated objective function is not best fit then go to step (2) for new optimum placement and sizing. The flow chart of the applied generalized algorithm for DG sizing and siting is illustrated in Fig. 1.

3. Comprehensive reviews for DG sizing and siting based on various aspects

The objective of this paper is to present a comprehensive review of challenges, difficulties, issues and opportunities being faced in optimum installation and sizing of DG in distribution systems. This review is carried out on the basis of both classical (analytical) and intelligent (meta-heuristic) methods / techniques. Furthermore, the present work analyzes the associated techniques

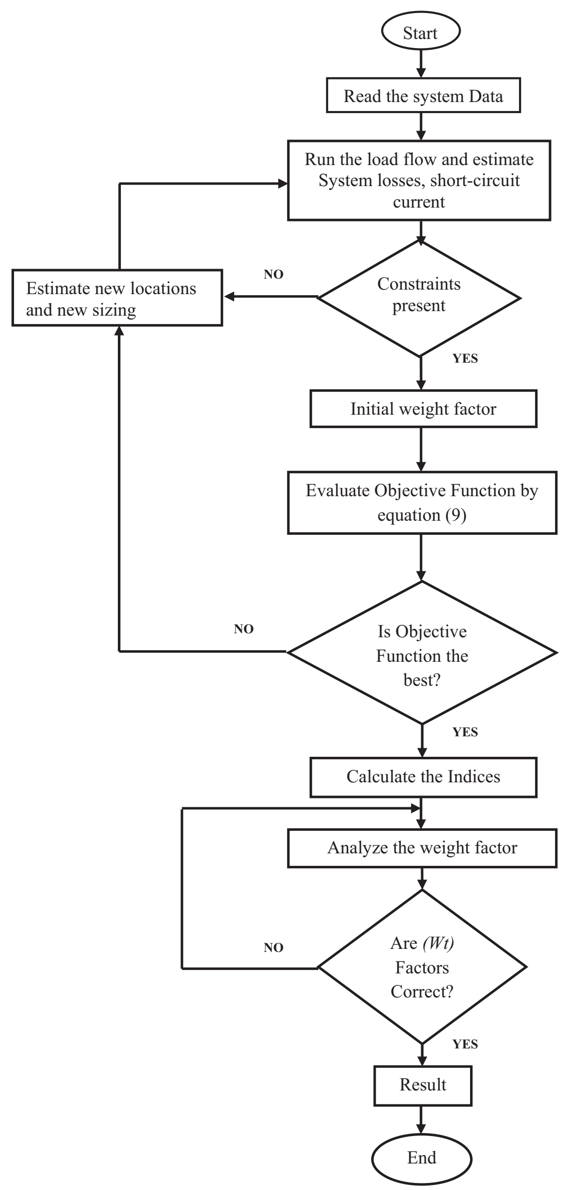

Fig. 1. Flow Chart for Generalized Algorithm for DG sizing and siting.

/ methods to extract the maximum potential benefits of optimum sizing and siting of DG units for the utilities as well as their consumers. The detailed literature survey is presented in Table 3.

3.1. DGs optimal sizing and siting technique and their merits and demerits

Based on published literature various sizing and siting techniques for DGs units in distribution networks are applied. The Table 4 represents the merits and demerits of those techniques with different objectives.

4. Methods for optimal sizing and siting of DG in distribution system

To maximize the benefits of DG, it is necessary to address proper sizing and siting of DG in distribution system. It results in reduction of system losses, cost, investment of distribution companies, improvement in system voltage profile, system reliability and voltage stability etc. The following methods have been adopted by earlier researchers to serve the objectives in appropriate manner [69].

The major techniques and methods that being used for sizing and siting of DG can be categorized as follows [13,14].

(1) *Analytical Techniques*
(2) *Classical Optimization Techniques*
(3) *Artificial Intelligent (Meta-heuristic) Techniques*
(4) *Miscellaneous Techniques*
(5) *Other Techniques for Future Use*

The Fig. 2 illustrated the detailed classification of techniques / methods used for sizing and siting of DGs.

4.1. Analytical techniques

Analytical techniques represent the system by a mathematical model and compute its direct numerical solution. The results obtained by these techniques are very accurate and offer less computation time. Such techniques are suitable for small and simplistic system where the numbers of state variables involved are small in number. Implementation of these techniques have been reported in [1–3,5,12–14,20,23,52,60,69]. However, for large and complex systems, analytical techniques perform adversely in respect of computational efficiency.

4.1.1. Eigen-Value based Analysis (EVA)

EVA has extra ordinary characteristics to investigate the stability of the power system. The stability becomes crucial factor for successful operation of power system components at the time, when load not remain static as suggested by [13].

4.1.2. Index method (IMA)

The index method based on the concept that deviation of any parameter from its actual value. Moreover, indices are measured in terms of relative deviation or change. The index based analysis has been majorly employed for reliability evaluation as proposed by [26,84].

4.1.3. Sensitivity Based Method (SBM)

The technique based on the concept that the variation in one variable(s) will influence the target variable. The basic objective of the method is to reduce the search space. The various loss sensitivity factors based methods commonly used for sizing and siting of capacitors and DG units in distribution system highlighted by [13,26,28,67,82]

4.1.4. Point Estimation Method (PEM)

The method is very efficient for the optimal sizing and siting of nondispatchable DG for the uncertain power output. This method is most decisive for uncertainty managing and provides the acceptable results. Moreover, the PEM required appropriate probability density functions for input variables those are usually uncertain in nature suggested by [16,43].

4.2. Classical optimization technique

These optimization techniques are applied to maximize or minimize the developed formulation according to requirement under given conditions and within the limits of constraints. Subsequently, apply suitable optimization technique which would provide the optimized value of the objective functions. These techniques broadly classified as.

4.2.1. Linear Programming (LP)

The technique is pertinent to optimize the functions whose objective functions are linear along with their constraints. The converging property of the approach is excellent. The drawback of the LP is that it can handle linear objective functions and constraints only proposed by [13].

4.2.2. Mixed non-linear programming (MINLP)

The method is combination of LP, nonlinear programming (NLP) and mixed integer programming (MIP). The technique is applicable for discrete as well as continuous variables and nonlinear functions. Since power flow formulations are nonlinear in nature. Furthermore, MINLP based method able to provide accurate, efficient and reliable solutions for multi-objective formulations implemented by [8,22,45].

4.2.3. Dynamic Programming (DP)

DP is a multi-stages type sequential optimization technique, competent to handle the real time and complex problems with an efficient and reliable manner. In this sequential applications the method shall be proceed in different time domain for solving a problem by breaking it into several sub problems. The method takes very less time to produce the optimum result proposed by [27].

4.2.4. Sequential Quadratic Programming (SQP)

The method is an iterative type and most capable to handle those formulation which are highly non- linear with inequality constraints. Since many non-linear formulation and inequality constraints involved in load flow equations, therefore, the method is able to handle optimum sizing of DG units efficiently. Furthermore, SQP algorithm based on zone investigation in reactive power optimization [8,18].

4.2.5. Ordinal Optimization (OO)

The OO is a tool which utilizes to lessen the computational task in simulation based optimization problems. Since computation ground of this method is powerful as equipped with efficient linear programming model. Therefore, the method is well suited for find an optimal sizing and siting of DG in a distribution system to fit the objectives such as system losses, cost or adjustment between loss minimization and DGs capacity suggested by [10,30,85]

4.2.6. Optimal Power Flow (OPF)

The optimal power flow solver tool is a very crucial for the forthcoming extension strategy of the power systems, so as to find out the optimal performance of current power systems. Also assist to achieve the information in response to magnitude of bus voltage and reactive power flowing along with phase angle of every line proposed by [48,58,65,66,82].

Table 3
Comprehensive reviews for sizing and siting of DG.

S.No.	Method(s)/Technique(s)	Parameter(s) to be optimize	Parameter(s) to be improve/enhance	Reference(s)
1.	Published review literature	Addressed issues, challenges, opportunities and impacts of DG units placement and sizing in context of technical, environmental and economical on system as well on society and important issues affecting distribution system	Voltage profile, reliability, voltage stability, voltage stability margin, power quality, fault level and voltage regulation	[1–5,12,13,22,48,51,56,60,64,65,69,94,96,105,107]
2.		Described role of DG in development of low-carbon power grid		[109]
3.		Highlighted the role and contribution of polygeneration in development of DG		[110]
4.		Focus on current energy scenario in Spain with different renewable energy options mainly solar		[111]
5.		Addressed the impacts of installation of large scale photo voltaic on various electrical parameters such as active power, reactive power and grid stability		[112]
DG type, uncertainties and power quality				
6.	Location of wind operated DG by least lost method and optimization by particle swarm optimization (PSO)	Minimize Real power loss	Voltage profile	[10,74]
7.	Mixed integer non-linear programming (MINLP) based approach	System losses, generation cost and search space	Improve voltage profile and voltage stability margin	[21,73]
8.	Novel technique	System losses, and congestion in branches		[31]
9.	Location of SPV, wind and biomass operated DG by Capacity Factor (CF) method and for optimization MINLP based technique	Energy loss and harmonic distortion		[42,45,53]
10.	Chance constrained programming (CCP) and combined genetic algorithm (GA) and point estimation method (PEM) for wind operated DG placement by considering uncertainties in output, load growth and electricity prices	The combination of (GA-PEM) exhibited excellent result than the other combination like (GA-Monte Carlo Simulation (MCS))		[61]
11.	CCP based technique to consider uncertainties of load growth and stochastic generation from wind and solar	Cost of operation, maintenance and adequacy		[75]
12.	Bellman–Zadeh algorithm		Reliability and power quality	[63]
13.	GA based technique for DG placement and sizing and for uncertainties in load model the LR fuzzy number based method	Cost minimization	The method is efficient, accurate and faster	[71]
14.	GA optimization technique and probabilistic approach for dispatchable and non- dispatchable DG	Minimize the annual energy losses and harmonic distortions		[80]
15.	Loss sensitivity factors to identify nodes for DG placement and clustering based approach for uncertainties handling of DG output	Minimize system energy losses	Improve voltage profile	[83]
16.	Probabilistic nature of DG outputs by mixed integer programming	Minimize operation and maintenance cost and, fuel and emission costs	Maximize profits	[62]
17.	Generalized approach	Minimize cost	Maximize DG power output	[66]
Analytical and sensitivity based methods				
18.	Analytical approach for biomass, wind and solar operated DG sizing and placement	Minimize system energy loss, the impact of dispatchable DG more as compare to non-dispatchable DG on system energy reduction		[11,24,36,41]
19.	Analytical approach for sizing and loss sensitivity factor for location identification	Minimize total system power losses	Method is faster	[20]
20.	Analytical approach for DG placement in radial and mesh distribution system for different types of load	Minimize total system power losses		[23]
21.	Analytical method based on loss saving	Minimize total system power losses		[88]
22.	Kalman filter algorithm and power loss sensitivities	Minimize system power losses		[89]
23.	Sensitivity analysis for optimum size of DG and operating point for different load	Minimize system active and reactive power losses	Improve voltage profile	[26,28]
24.	Sensitivity analysis and heuristic based technique to identify most sensitive bus for DG and capacitor placement	Reduce search space and system losses	Improve voltage profile	[67]

Table 3 (*continued*)

S.No.	Method(s)/Technique(s)	Parameter(s) to be optimize	Parameter(s) to be improve/enhance	Reference(s)
25.	Sensitivity analysis to identify best buses for DG placement with GA, OPF, bacterial foraging optimization algorithm (BFOA), invasive weed optimization (IWO), chaotic artificial bee colony (CABC) and intelligent water drop (IWD) optimization	Reduce search space and system losses and cost	Improve voltage profile and voltage stability	[30,82,95,100,101]
26.	Conventional iterative search technique	Minimize system losses and cost		[76]
27.	Novel power stability index (PSI), determine the most sensitive bus for DG placement particle swarm optimization (PSO)	Minimize system losses		[6,97]
28.	Monte carlo simulation (MCS) based novel index method for different type DG	Reduce system energy loss and energy cost		[9,50]
29.	Generation worth index (GWI)	Reduce system energy loss and energy cost		[84]
30.	Novel sensitivity based method	Reduce system losses	Improve voltage profile	[106]
Miscellaneous Techniques				
31.	GA for various types of DG and enhanced GA based technique	Minimization of cumulative average daily active power losses, minimize system losses		[52,57]
32.	Rank evolutionary PSO based approach Integrated with evolutionary programming (EP)	Maximize profit, improve voltage profile and reduce the system losses		[39]
33.	PSO based technique	Minimize the system losses	Maximize system voltage stability	[19,58,70]
34.	Multi-objective index for optimization PSO based approach applied	Reduce the active and reactive power losses		[77]
35.	Analytical and PSO based approach	Minimize system losses		[33]
36.	Modified teaching learning based optimization (MTLBO) and EP	Reduce the system losses		[38]
37.	Artificial bee colony (ABC)	Minimize the system real power losses		[37]
38.	Sequential quadratic programming (SQP) and branch and bound (BAB)	Minimization of system losses		[8]
39.	Modified big bang –big crunch (BB-BC)	Reduction of energy losses for balanced and unbalance distribution network		[15]
40.	GA and fuzzy-c clustering	Minimize energy losses		[44]
41.	BAT algorithm	Minimize system losses	Improve system voltage profile	[72]
42.	Ordinal optimization (OO)	Minimization of system loss	Maximization of DG capacity	[85]
43.	Quasi-Oppositional Swine Influenza Model Based Optimization with Quarantine	Minimization of system loss	Improve voltage stability and voltage regulation	[104]
44.	Backtracking search optimization algorithm (BSOA)	Reduce the system real power losses	Improve voltage profile	[68]
45.	New Harmony search algorithm (HSA) based algorithm	Reduce the system losses	Improve voltage profile	[54]
46.	New methodology	Reduce the system losses and voltage rise issues	Improve voltage profile	[47]
47.	Visual optimization based approach	Reduce the system losses	Improve voltage profile	[78]
48.	Continuous power flow (CPF)		Maximize loadability and voltage limit	[55]
49.	GA and PSO based multi-objective mixed approach	Minimize the system losses	Improve the voltage regulation and voltage stability margin	[7]
50.	Ant colony optimization (ACO) and artificial bee colony (ABC) algorithm for uncertainties efficient PEM approach	Minimize system losses, emission produced by source, energy cost	Improve system voltage stability	[16]
51.	Improved honey bee mating optimization (HBMO) based multi-objective optimization algorithm	Minimize the cost, emission, system losses	Improve voltage	[17]
52.	Improved PSO and MCS based multi-objective algorithm	Reduce the investment of active and reactive losses	Improve system voltage profile and reliability	[25,51]
53.	Fuzzy logic based optimization technique	Minimize number of DGs to be installed and system power losses	Maximize voltage stability margin	[32]
54.	GA based approach		Improve system reliability	[34,81,87]
55.	GA based approach	Reduce system losses, voltage sag and cost (installation and maintenance),		[29,81]
56.	ε-constrained and GA mixed multi-objective technique	Reduce investment of network upgrading, cost of system losses and cost of energy not supplied		[18]
57.	Non-dominated sorting genetic algorithm-II (NSGA-II) and PEM	Minimize line losses, investment and voltage fluctuation	Improve mutation and cross over procedure	[43,86,98]

58.	Novel successive elimination (SE) integrated based methodology	Investment deferral		[49]
59.	Dynamic programming (DP) based multi-objective technique	Reduce system losses	Improve system reliability and voltage profile	[27]
60.	Shuffled frog leaping algorithm (SFLA) technique	Minimize real power system losses and system cost and pollutant emission		[35,40,46]
61.	Pareto frontier differential evolution (PFDE) based technique	Minimization of system power losses and network voltage variations	Maximization of voltage stability	[64]
62.	Generalized approach for optimal capacity of CHP-based DG units for coupling generalized urban energy distribution network	Minimize of the cost and congestion in branch	Maximize DG output	[66]
63.	Bat algorithm (BA) based optimization technique	Minimize system losses	Improve system voltage profile	[72]
64.	Immune algorithm (IA) based dynamic model of DG	Minimize various cost environmental, DG capacity, O&M and loss cost		[98]
65.	Improved Non-sorting dominated genetic algorithm-II (NSGA-II)	Minimize investment, operational and voltage deviation		[99]

4.2.7. Continuous Power Flow (CPF)

The CPF is a mathematical based methodology for the solving the systems of nonlinear equations. The method is based on to identify the condition of voltage collapse by Jacobian matrix of load flow equations. The matrix value becomes zero means the singular matrix give the voltage collapse conditions. Subsequently, identify the most sensitive bus and reduce the search space as suggested by [55].

4.3. Artificial intelligent (meta-heuristic) techniques

These techniques are capable enough to get efficient, accurate and optimal solutions in smart way called intelligent methods. The hypothesis evolves from artificial intelligent technique is the most recent and adorable meta-heuristic search techniques. These methods are most auspicious for solving troublesome problems in diversified areas. Some of the family algorithms that have been adopted in meta-heuristic such as genetic algorithm (GA), particle swarm optimization (PSO), fuzzy logic (FL), honey bees mating optimization (HBMO), simulated annealing (SA), non dominated sorting GA-II(NSGA-II), artificial neural network (ANN), body immune optimization (BIA), ant colony optimization (ACO),artificial bee colony (ABC) and invasive weed optimization (IWO) algorithm etc. implemented and suggested by [7,9,10,16,18,24,25,29,30,34,35,38–40,43,44,47,51,61,64, 70–72,74,77,79,81,101].

4.3.1. Fuzzy Logic (FL)

This method was introduced by Lotfi A. Zadeh in 1965 having approximate linguistic variables rather than exact valued function. In addition to the linguistic variables have the degree of membership function highlighted by [13,14,44].

4.3.2. Genetic Algorithm (GA)

GA is an adaptive kind of heuristic search algorithm based on concept of natural selection and genetics. The algorithm is inspired by natural evolution such as inheritance, mutation, selection and crossover. The genetic algorithm is very simple and easy to understand and it does not require the knowledge of complex mathematics. The algorithm suffers from more computational time since it associates many parameters. GA starts with its search from a randomly generated population proposed by [7,34,44,79,81,82].

4.3.3. Particle Swarm Optimization (PSO)

The PSO was first came into existence in mid at 1995 by Kennedy and Eberhart, inspired by flocking ability of birds, school of fish in search of food. In PSO a set of arbitrarily provoked solutions moves in the design arena favoring the best solution over number of repetitions highlighted by [25,29,32,33,39,70,74].

4.3.4. Non-dominated Sorting GA-II (NSGA-II)

The method is competent to find out global optimal solutions of any multi-objective optimization formulations. Moreover, it has greater accuracy in comparison to other optimizing approaches proposed by [43,86].

4.3.5. Plant Growth Simulation Algorithm (PGSA)

The algorithm is simple and fast optimization technique that does not required the tuning of the parameters. This technique can be applied to solve several optimal problems of different systems such as optimum sizing and siting DG and capacitor in radial distribution system. Furthermore, the method is capable to addresses the modeling challenges required by radial distribution system suggested by [13,14].

4.3.6. Ant Colony Search Algorithm (ACS)

The technique based on the foraging behavior of real ants in search of food to established shortest paths from their nest to food

Table 4
Optimal sizing and siting technique for DG, and their merits and demerits based on review.

S.No.	Objective(s)	Technique(s)	Merit(s)	Demerit(s)	Reference(s)
1.	Reduction of the system losses as single objective	Genetic algorithm (GA) with fuzzy c-clustering	Improve the accuracy of clustering under noise condition	The convergence time is more and lack of accuracy when high quality results are required	[44,52,57]
		An analytical based technique	More accurate and efficient, Losses are significantly reduced	Required more time for complex system	[11,20,21,23,24,36,41]
		A Novel Power Stability Index (PSI) based analytical technique adopted	Accuracy and efficiency improved significantly	Problem formulation is difficult and computation time increases for large and complex system	[6]
		Rank Evolutionary Particle Swarm Optimization (REPSO) based approach and hybridizing with EP in PSO algorithm	Capable to find most optimal and next to optimal candidate on ranking basis in faster way	For large number of functions method has poor efficiency	[39,51,77]
		Modified Teaching Learning Based Optimization (MTLBO) algorithm	Reliable, accurate and robust and outstanding performance for global optimization	Expensive, suffers from premature convergence, slow convergence rate for multi-objective problems	[38]
		Artificial bee colony (ABC) based optimization algorithm	For global optimization an multi modal and multi variable results are excellent	Low efficiency, very much dependent on the control parameters associated to the algorithm	[37]
		Loss sensitivity factor and exhaustive load flow based an improved analytical method for multiple DG placements.	Very simple technique, handle uncertainty efficiently and reduce the search space, capable to directly calculate the change in all network variables	Time consuming process, does not provide results at critical point of transfer limit due to singularity of power flow Jacobian	[28,36]
		An analytical analysis method and for objectives new PSO-based algorithm employed	Accurate and excellent computational efficiency for less number of function evaluation	The method suffer from poor efficiency for large number of function evaluation	[33]
		An algorithm to assess the effects of DG on distribution network.	Reduction of system losses and congestion in branch	The voltage profiles not improved	[31]
		Probabilistic model based on Beta and Rayleigh probability density functions	The best utilization of renewable DG resources	Unable to take all the data associated to wind and solar uncertainty	[42,45,53]
		Sensitivity analysis based technique	Reduces search space and losses reduces significantly	Enough information not available for probability distribution as input	[28]
		Improved Analytical (IA) based technique adopted	Capable to accommodate for optimal sizing and siting of all types of DG and require less computation time	The total system losses calculated by IA are slightly higher than exact they are	[24]
		Mixed Integer Non-linear Programming (MINLP) based technique	Reduce search space, excellent convergence property, capable to place any number and any type of DG.	Two phase modeling were required first as Siting Planning Model (SPM) and second as Capacity Planning Model (CPM)	[8,45]
		Refined Parallel Monte Carlo method	Very simple and simulation time not depend on numbers of generation units	Required high number of runs as a result require more time for computing	[9]
		Kalman Filter algorithm (KFA)	Low complexity	Gives accurate result for Gaussian linear models only	[89]
		Supervised Big Bang-Big Crunch based method	Applicable to balanced an unbalanced distribution network, capable to handle all size of distribution network and convergence time is less	For large system the computational time is more	[15]
		Distribution System Planning (DSP) model for DG sizing and siting, for optimization binary decision variables	More accurate	Adjustment between DG generation and purchasing power from grid.	[22]
		Successive linear programming (SLP), generalized reduced gradient (GRG) and LINGO software packages	Efficient for linear model formulation	Provide approximate solution	[51]
		A chance constrained programming (CCP), based approach and Monte Carlo Simulation (MCS) with GA	The less convergence time and capable to handle uncertainty of generation and load excellent	Not capable to solve complicated, nonlinear, multiple uncertainties inputs and multiple probabilities constrained outputs	[75]
3.	Losses minimization and voltage profile improvement	GA and Particle Swarm Optimization (PSO)	Higher capable to find optimum solutions, more competent for searching best solutions	Time consuming process	[7,52,58]
		Comparison of Fuzzy reasoning, PSO and Plant Growth Simulation Algorithm (PGSA), a muti-objective MINLP based approach	External barrier and control factor as crossover and mutation rate, not required	Inferior for qualities solutions	[32]
		An efficient methodology based on continuous power flow (CPF) technique	Very efficient, robust, effective and capable to handle different number and penetration level of DG	Limited by the high dimensionality of power systems and information regarding voltage stability limit not available	[55]

		Pareto Frontier Differential Evolution (PFDE) based algorithm	Capable to optimized multi-objective problems	Several iterations are required for convergence	[64]
		Sensitivity analysis based heuristic method	Reduce the search space, improved voltage profile and reduce the system losses significantly	Not provide any information multiple DG and capacitor placement	[67]
		Backtracking Search Optimization Algorithm (BSOA) for DG placement	Excellent property for global optimization solution	Followed non-uniform crossover strategy, a random mutation strategy that is only one direction for each individual target	[68]
		Particle Swarm Optimization algorithm (PSO) based technique	High degree of accuracy and less converging time	Suffers from the partial optimism, due to that its velocity and direction not maintained and inefficient for large and complex systems	[51,70,74]
		Bat Algorithm (BA) based optimization technique	Accuracy and efficiency much superior to other algorithms	The convergence rate is very much affected by adjustment parameters	[72]
		A visual optimization based approach	Very simple, efficient, flexible and highly view of practical applications	The accuracy and efficiency depend upon proper selection of weight factor	[78]
		Sensitivity analysis based technique and for optimization GA along with OPF algorithms	Easier dispatch for active and reactive power, extreme reduction of transmission losses, efficient for large and complex problems required less computational time	Complex mathematics is required to solve the formulation and cannot handle problems with discontinuities and non-convexity and have multiple minima suffer optimality	[47,82]
		BFOA and modified BFOA	Convergence, robustness and precision are better than GA and PSO	Difficulty face in global convergence	[95,100]
4.	Improvement of voltage profile as single objective	Harmony search algorithm	Able to handle continuous and discontinuous function, free from disparity, able to conquered of GA and good global search	Local convergence speed is lethargic	[54]
		New algorithm	Suitable to find best candidate node for installing DG for bigger systems without further modifications.	The method applied for type-IV DG only	[56]
		Beta and Weibull probability distribution functions and MINLP	Capable to optimize the linear and nonlinear type of problems	Successfulness depend upon its speed and its reliability to locate and provide round off results only	[73]
5.	Reduction of cost and system losses	Comparison between the proposed algorithm brute force (BF) algorithm and MINLP based formation	Reduce the search space, less optimal solution time	Effectiveness suffered and not practical for optimization	[21]
		Successive Elimination algorithm	The computation time reduced considerably	Multi-stage planning was needed in order to determine required investment	[49]
		Meta heuristic approach Shuffled frog leaping (SFLA) algorithm	Highly efficient and good computing performance and global search capability	Suffer from uneven initial population, lethargic searching speed and catching local maxima easily	[35]
		Non-dominated Sorting Genetic Algorithm II (NSGA-II), Point Estimation Method (PEM), and Multi-objective (MO) optimization based formulation	Less convergence time and have capability to maintained better solutions for many types data and to handle uncertainties in load, electricity prices and generation efficiently	PEM technique have to compromise with accuracy and it require sophisticated computation	[43,61,86]
		Conventional iterative search technique and Newton Raphson method for load flow study	Excellent convergence and reliability characteristics	Fails when some ill-conditions encountered	[76]
6.	Reduction of system losses, cost, improvement of voltage profile and system loadability	Improved Particle Swarm Optimization (IPSO) and MCS based algorithm	High degree of accuracy and net saving was more as compare to other techniques and capable to handle all types of loads as DG penetration level increases	Difficulty faced to select the inertia weight	[19,25]
		The PSO and weibull probability function was adopted to address the uncertainties	Computational effort is less and take real number as particle rather than binary number	Becomes inefficient for large and complex systems and provide multiple-optimal solutions	[10]
7.	Minimization of the (losses, cost), load growth and improvement of voltage profile, system reliability	Multi-objective evolutionary programming GA based approach	Ability to quick and precise for all possible combinations in real size cases	Compromise between different noninferior solutions	[18]
		Loss sensitivity, index vector, and voltage sensitivity index method combination	Reducing search space, deferring higher kVA requirement for same size	Better performance	[26]
		Dynamic programming (DP) for time-varying load	The DP enables to found sub solutions for a large problem	Provide the partial solutions	[27]
		GA based technique employed	Capable to solve multi-faceted non differential, imbalance, complex and discrete and continuous problems. Further, a set of variables are provided rather than a single solution	Time consuming technique and accuracy suffer when high quality solution is required and due to limited population size GA may be bad representatives of good search regions	[34]
		An integrated methodology based technique and for optimization MPSO based technique adopted	Better performance of convergence than PSO	Integer based technique to be adopted for siting	[51]

Table 4 (*continued*)

S.No.	Objective(s)	Technique(s)	Merit(s)	Demerit(s)	Reference(s)
		Multi-objective Tabu Search (MTS) based approached proposed	Capability to have an adaptive memory that produce most flexible behavior	The method is efficient for local optimization only and time consuming	[60]
8.	Minimization of costs, emission and system losses and improvement of voltage profile	Improved honey bee mating optimization (HBMO) algorithm	Provides better and accurate result in shorter time and have excellent computational capacity	Become slower and inefficient when number of iteration increases	[17]
		Combined Ant Colony Optimization (ACO) and Artificial Bee Colony (ABC) based algorithm and handle uncertainty associated to DG, generation and load demand PEM was adopted	More effective as compare to other methods, easy to implemented and facility of extendable to multi-objective problem	Multi-objective, ABC used to produce a set non-dominated solutions	[16]
		Mixed Integer Programming (MIP) based probabilistic method for DG	Applicable to random variables associated with load and generation		[62]
		An interactive fuzzy satisfying method based on HMSFLA	Performance improved over the other algorithm such as GA	Used a new search acceleration factor, C, to select the value is very crucial	[40,46]
9.	Improvement in the power quality and reliability	Multi-objective formulation based on Bellman-Zadeh algorithm for optimal placement of DG into distribution system	Provide information about best utilization of renewable DG resources	Unable to take all the data associated to wind and solar uncertainty	[63]
10.	Investigation on fault location in distribution system	A general method to locate faults in presence of DG in distribution system	Provide information about future arbitrary penetration of DG level in distribution system	Provides only satisfactory result for higher penetration level of DG	[59]
		Pseudo dynamic based algorithm, for uncertainty handling L R fuzzy load points concept employed	The method is transparent, applicable for highly complex systems	Expensive, inaccurate and not give satisfactory result when expert rule based system not set properly	[71]
		AC optimal power flow (ACOPF)-based technique	Capable to solve nonlinear, multi-objective formulation and able to provide global optimization solution	At the time of network congestion the method become inaccurate	[65,66]
12.	To identify the vulnerable node and impact them on distribution network and voltage stability	GA based optimization technique	Capable to solve multi-faced non differential, imbalance, and complex problems.	Require more convergence time	[81]
		Chaotic Artificial Bee Colony (CABC) based algorithm			[30,102]
		Continuous Power Flow (CPF) based technique	Robust and effective	Limited by the high dimensionality of power system	[52]
13.	To determined sensitivity of the power flow equations	GA based technique for optimization	Capable to solve multi-faceted non differential, imbalance, and complex problems.	Require more convergence time	[79]
		Novel index method and for optimization Monte Carlo (MC) algorithm	Accuracy is directly proportional to dimension	Complex and computationally expensive for large and complex system, poor efficiency	[50]
		A clustering-based approach applied	To reduce calculations burdens, and converging time is very less	and delayed converge	[83]
14.	Extensive review of methods of DG optimal placement	Analytical method, optimal power flow and various artificial optimization techniques and hybrid intelligent approaches.	Systematic and accurate optimization technique	Time consuming and complex method	[1,2,5,13,14,60,69]
15.	Investigated the comparison by DG integrated cost	Heuristic approach based on long run incremental cost (LRIC) and sensitivity to identify the best site for DG placement	Capable to evaluate economic potential of DG	Require more number of iterations and global optimal solution not guaranteed	[9]

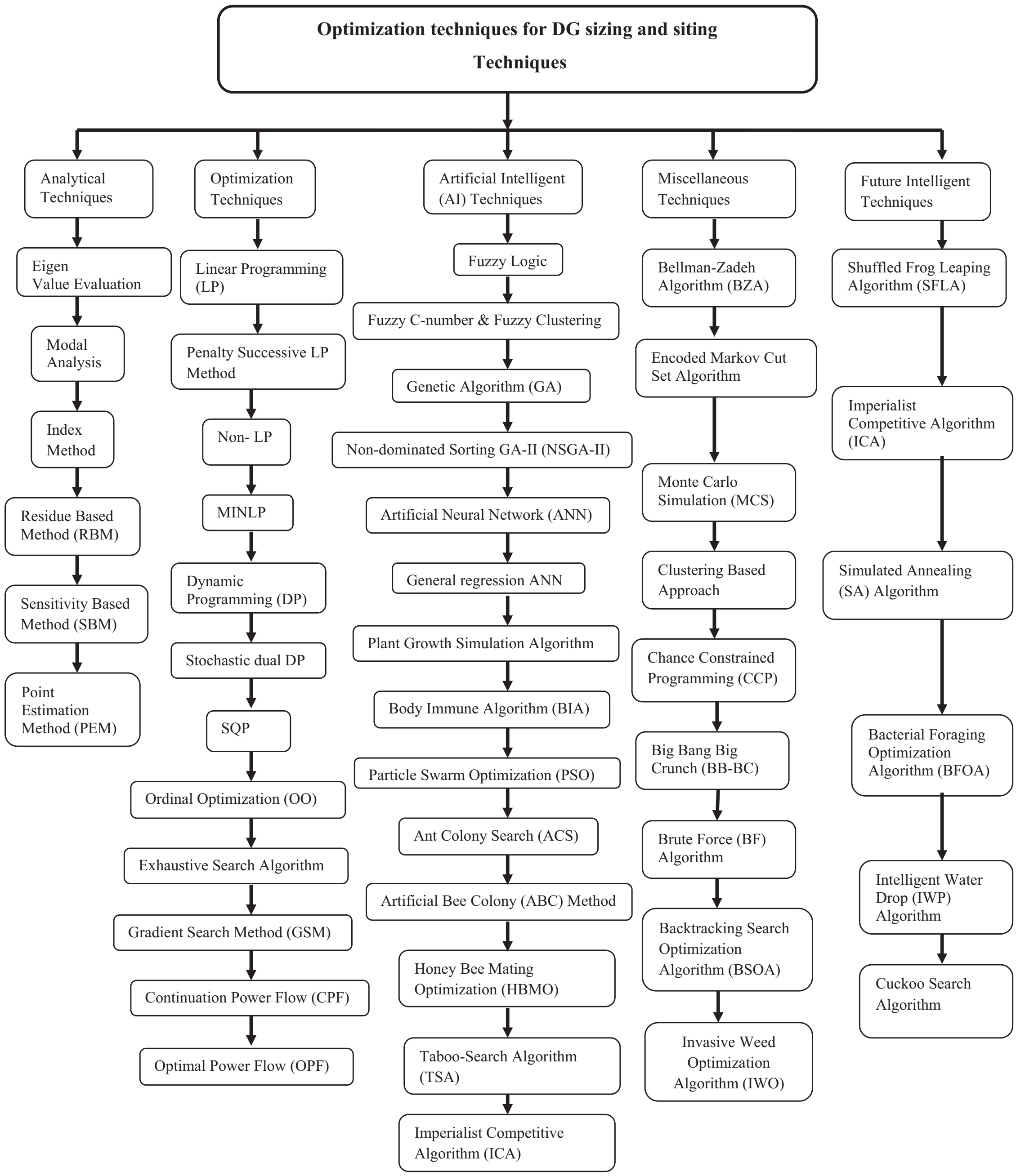

Fig. 2. Optimal sizing and siting methods of distributed generation in distribution network.

source. Each ant makes decision by using pheromone trails as a communication mechanism. Strength of pheromone trail deposited on the ground depends on the quality of the solution (food source) found incorporated by [16,37].

4.3.7. *Artificial Bee Colony Algorithm (ABC)*

In the ABC algorithm, have three groups of bees, employee bees, onlookers and scouts. This optimization algorithm based on the fact that, the food source exhibits the feasible explication of the elaboration problem and the ambrosia amount of a food source resemble to the aspect of the solution implemented by [30,37,102].

4.4. *Miscellaneous techniques*

There are numerous other classes of methods observed from the literatures which are put forward under miscellaneous techniques these are given below

4.4.1. *Bellman-Zadeh Algorithm (BZA)*

BZA is inspired by fuzzy functions and a multi-objective type methodology capable for optimal placement of DG in distribution system at appropriate feeder suggested by [13,63].

4.4.2. *Encoded Markov Cut Set Algorithm (EMCS)*

A Markov cut set is a least numbers of elements where, the fail situation for each element in the set, results system outage. The method is specially applied to evaluate system reliability [57].

4.4.3. *Monte Carlo Simulation (MCS)*

MCS based on random numbers utilization, it is an iterative method that gives better result as the numbers of iteration increases in lesser processing time. The MCS is of two types as probabilistic and deterministic depending upon behavior and outcome of random processes highlighted by [9,19,25,75].

Table 5
Comparison of analytical and intelligent techniques of sizing and siting of DG in distribution system [108].

S.No.	Analytical method(s)	Intelligent optimization technique(s)
1.	Such techniques are useful in finding the optimum solution or unconstrained maxima or minima of continuous and differentiable functions.	Such techniques are useful in finding the optimum or near optimum solution of constrained, discontinuous and non differential functions
2.	Since these methods are based on mathematical model developing theory therefore, these methods are make use of differential calculus in finding optimum solution	Such techniques are inspired by artificial intelligence and natural or biological evolutionary theory
3.	The techniques are well suited for finding out local maxima or minima	Such types of techniques are capable in finding out local as well as global optimum solution
4.	The methods are capable to handle single variable functions, multi variable functions and multivariable functions with both equality and inequality constraints	The methods are capable to handle constrained and unconstrained single variable functions, multi variable functions and multivariable functions with both equality and inequality constraints
5.	These methods lead to a set of nonlinear simultaneous equations that may be difficult to solve.	Such types of difficulty not involved in these techniques
6.	These techniques offer accurate optimum solution	These techniques offer optimum or near optimum solution
7.	These techniques offer short computing time	The simulation time may or may not be short
8.	Not easy to implement	Easy to implement
9.	These techniques might not be suitable for large and complex problems	Such type of restrictions not applied to these methods
10.	Not iterative in nature and suitable for local search	Iterative in nature and suitable for global search
11.	Convergence problem not exist	Premature convergence problem exist
12.	The optimization function should be differentiable	Optimization function need not to be differentiable
Drawbacks of analytical and intelligent techniques		
1.	Cannot be applied straight forward for size complication and peculiar characteristics of distribution system	Does not yield correct result further these results are not assured to be optimal
2.	May cause inaccurate solution for real time problems	Some assumptions cannot be satisfied in most real life problems
3.	Do not meet robustness requirements	Computationally cheap in terms of memory and speed
Benefits of hybrid heuristic optimization techniques over mono heuristic optimization techniques		
	Hybrid meta-heuristic technique(s)	**Simple meta-heuristic technique(s)**
1.	Robust and powerful global optimization techniques	They require more computational time
2.	For similar quality of results it require less number functions evaluation	More number of functions need to be evaluated to produce similar kind of results
3.	They can handle various constrained and unconstrained multi-objective optimization problems successfully	Their performance is poor for similar kind of problems
4.	Ability enhanced to deal the problems	Poor performance with respect to multiple results

4.4.4. Clustering-based approach

The approach based on grouping of patterns exhibiting consistent behavior. In this technique it is assumed that each node work as separate cluster. Subsequently, couple of nodes represents the minimum distance from particular cluster. The heap process goes on incorporate the two clusters having least distance till number of clusters reaches the value set by user. The approach reduces calculations burden and converging time suggested by [13,83].

4.4.5. Tabu-Search Algorithm (TS)

Tabu Search is a meta-heuristic optimization technique was proposed by Fred Glover in 1986. The basic property of algorithm is its use of adaptive memory that produces the most flexible search behavior. It operates in a sequential manner, in this process search starts at a given point and algorithm selects a new point in the search space to next current point [60].

4.4.6. Bat Algorithm (BA)

The bat algorithm was introduced by Yang in 2010. This algorithm is based on echolocation properties of microbats with varying vibrations rates of discharge and loudness. This technique constitutes of objective function so as it can be mixed with the function which is to be optimized and reconstitute a new optimization function. The accuracy and efficiency of this method are much superior to other algorithm advised by [13,72].

4.4.7. Big Bang Big Crunch optimization algorithm (BB-BC)

BB-BC is a nature inspired optimization technique. It was first introduced in 2006. It possesses excellent convergence property with less computational time. In this whole process, candidate explications are arbitrarily dispensed over the entire investigating arena. The BB-BC generates random points in orderly fashion and shrinks these points into a single point. The Big Crunch phase has a concurrence operator that has several inputs but only one output known as center of mass proposed by [15,77].

4.4.8. Brute Force algorithm (BF)

The BF algorithm is a very simple problem solving technique. The technique consists of orderly calculating all feasible candidates for solution and investigates whether each candidate satisfies the problem statement. The BF enables us to solve small problems absolutely. Finally, it will help us to evaluate the performance of the other algorithm by observing how much they deviate from absolute solution calculated by BF algorithm recommended by [13,21].

4.4.9. Backtracking Search Optimization Algorithm (BSOA)

The BSOA is a new evolutionary algorithm. It is applied to find out solution of real valued, non-linear, non-differential and complex numerical optimization functions. It is a simpler, effective, fast and easily adaptable to different numerical optimization technique advised by [68].

4.4.10. Modified Teaching Learning Based Optimization algorithm (MTLBO)

The MTLBO is a new decent, authentic and sturdy global optimization technique. The algorithm is capable to solving the high dimensional complex problems. The algorithm enhanced the disturbance potential of search space. The algorithm has several advantages over other algorithm in terms of convergence speed, accuracy and stability implemented by [38].

4.5. Other promising techniques for future use

There might be numerous new optimization techniques which have capabilities to accommodate the complex problems of DGs sizing and siting, can be classified as follows.

4.5.1. Shuffled Frog Leaping Algorithm (SFLA)

The SFLA is a meta-heuristic based optimization technique, depends on the tendency of group of frogs try to seek the locations where more quantity of food is available. The evolutions of memes improve the qualities of the memes of an individual and enhance the frog's performance towards the goal. The algorithm is highly efficient and has good computing performance with global search capability implemented by [35,40,46].

4.5.2. Imperialist Competitive Algorithm (ICA)

The ICA is an evolutionary algorithm that starts with initial population known as country and divided into two colonies as imperialists along with empires. Each country is defined as vector with socio-political like culture, language and religion. The method is more capable and efficient then other methods for stage based calculation implemented by [91].

4.5.3. Simulated Annealing (SA) algorithm

SA was developed by Laarhoven and Aarts in 1987. The technique associated with heating and restrained cooling of a material to expand the dimension of its particles and reduce their defects. These both properties are of material based on free heat energy. The heating and cooling of material affect the free heat energy. As a result, the lethargic rate generating enormous shrinkage. Therefore, the moderate cooling incorporated in SA algorithm as a slow decrease in the probabilities of accepting worst solution as it search the solution space quickly recommended by [13,14].

4.5.4. Bacterial Foraging Optimization Algorithm (BFOA)

The algorithm is inspired by foraging properties of E. coli bacteria. According to this, bacteria search the food in such a manner to maximize the obtained energy per unit time. The isolated bacterium also convey to others by delivering a signals. In this process bacterium take decision for searching food after examine two preceding factors in this, the bacterium moves by taking small steps at the time of searching the nutrients known as chemotaxis. The basic concept of BFOA is mimicking chemotactic movement of virtual bacteria in the problem exploration arena advised by [13,90,95,100].

4.5.5. Intelligent Water Drop Algorithm (IWDA)

The algorithm was first introduced by H. Shah-Hosseini in 2007. It is a population based nature influenced optimization technique. The technique called water drop technique because of path finding procedure of rivers. The flow of river always tries to find an optimal path among lots of possible paths in its way from source to destination. Many artificial water drops contribute to change their climate in such a way that the optimal path is revealed. In brief, the authenticity of IWD algorithm based on two properties one is velocity and other is soil [93] and [103].

4.5.6. Cuckoo search (CS) method

Cuckoo search is a meta-heuristic technique which is motivated by replication scheme. The method based on the behavior of the cuckoo which is a special bird which laying their eggs in the nest of host bird (crow another species of bird) in this process some hosts birds can engage with direct conflict with the cuckoos. The cuckoos are usually very specialized in the pretense in colors and impression of the eggs of a few chosen hosts. The cuckoo search is an adaptive search technique used to optimization for engineering problems suggested by [92,104].

4.5.7. Invasive Weed Optimization Algorithm (IWO)

This algorithm was first introduced by Mehrabian and Lucas in 2006. It is based on mathematical stochastic optimization algorithm. The technique is motivated by phenomenon of inhabitancy of invasive weeds in nature is based on weed biology and ecology. Invading of weeds of cropping system is done by means of dispersal. Every invading weed takes the unused resources in the field and matures to the flowering weed and yields new weed independently [101].

4.6. Comparison and drawbacks of analytical and intelligence optimization techniques

On the basis of literature survey it can be concluded that analytical and intelligent methods of sizing and siting of DG in distribution system have some sort of properties and drawbacks which can be sum up in Table 5.

4.6.1. Integration of meta-heuristic optimization techniques

Integration of a meta-heuristic with other optimization approaches it may also be called hybrid metaheuristic optimization technique. Methods are capable to provide more efficient performance and reliable results with higher flexibility. This is because hybrid meta-heuristics combine their advantages with the complementary strengths. Furthermore, these techniques may be used to add learning capability of meta-heuristic approaches that is capable to adapt the value of some algorithm parameters automatically. These approaches emerge as fast methods for optimization of complex, nonlinear objective functions. The integration of meta-heuristic techniques not only accelerates the capability of exploitation and convergence but provide better results also. It provides best performance with reduced number of iterations.

However, these techniques are associated with some drawbacks. They get stuck in finding local optima, multiple results are obtained. These results are not optimal but near to optimum solutions. Moreover, it is not possible to accommodate all better qualities of one technique and rectify all poor qualities of other technique. Furthermore, different sets of hybridization deliver different results for same objective function [108].

5. Conclusions

The present study focuses on optimum sizing and siting techniques of DGs in distribution networks. Simultaneously the study also presents the impacts of insertion of DG on distribution system operation and performance, voltage profile, system losses, loadability, stability, reliability, power quality and voltage stability margin etc., consequently various parameters need to have an extra care for optimum placement and sizing of DG. This study also focuses on the advantages and disadvantages (economical, environmental and technical) of DG installation in distribution system.

Many researchers have already disclosed that the optimum sizing and siting of DG is beneficial in many folds such as technically, environmentally as well as economically. In addition to these advantages the installation of DG defers the expansion of existing power distribution systems, since DG serve as a standby option for onsite power supply for load growth. The extended application of DG may be as protection device (since DG units are automatically disconnect when voltage at the system connection point becomes very high) for existing distribution systems in future. The reverse power flow is observed due to installation of oversize DG. Additionally, the stand alone and islanding application of DG also may be the part of current / future research for that reasons the DGs technologies are universally accepted.

As a whole the study reveals that the techniques implicated for optimum sizing and siting of DG by the researchers, carryout the researches for finding the global optimum solution of a complex problem for their single objective or multi-objective problem specially those have many local optima. Once the uncertainties associated to the DG output, load, emissions and price of the electricity is incorporated the system become more complex. The uncertainties are successfully and competently handled by newly introduced techniques.

Various researchers have acknowledged numerous sizing and siting techniques for DGs in distribution network. The analytical methods are not computationally efficient for large and complex systems. In this respect, intelligent (meta-heuristic) techniques are well suited for large and complex systems. They are speedy and possess excellent convergence characteristics. It has been reported that to find a global optimal solution of a complex, multi-objective problem a hybrid of two or more meta- heuristic optimization techniques confer more effective and reliable optimum solution. For optimum sizing and siting of DGs, newer heuristic optimization techniques such as BFOA, SA, IWD, SFLA and IWO etc. may appear promising in future.

6. Recommendations

The following research scope can be pointed out on the basis of the above literature survey.

(1) The research work can be extended by considering uncertainties associated to generation of non-dispatchable DG units such as wind and solar for long term expansion planning of existing distribution systems.
(2) By the utilization of hybrid or combination form of two or more meta-heuristic techniques for optimum sizing and siting of DG in distribution network the better result can be obtained.
(3) The newly introduced meta-heuristic optimization techniques may be used in future for optimum installation and sizing of DG in distribution network.
(4) By considering the static load model, seasonal load models as well as realistic load models may be used for extended research work in future.
(5) The application of installation of DGs may further be extended for expansion and protection of existing distribution systems.
(6) The research may be extended in future by using DG units as a standalone and islanding mode of operation.

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