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REVIEW PAPER

Distributed Energy Resources and Supportive Methodologies for their Optimal Planning under Modern Distribution Network: a Review

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Abstract

Rapid growth in electrical load demand with lack in generation of electrical power and transmission line congestion has set the trend for smart electrical system. In smart electrical system, need arises to deploy more non-conventional energy sources, which include Renewable Energy Sources (RES) as well as non-RES. Though, the RES are getting more encouragement due to several advantages over non-RES. In recent past, there is significant increase in the penetration of small units of local generation in existing distribution system. These small units (RES and non-RES), usually known as Distributed Generation (DG), may offer several technical, economic and environmental benefits like reduction in power loss, improvement in power quality, reliability, system security, reduction in capital cost investment at large level, reduction in emission of green-house gases and many more. However, these advantages are difficult to achieve due to some technical and non-technical barriers. To extract maximum potential benefits from the DG, the optimal planning of such sources in distribution network has always been a topic of great interest. Though, fresh researchers face many problems in carrying out research in this area due to lack of knowledge about suitable research software, standard test networks, types of renewable/non-renewable sources, appropriate literature, etc. This paper uses a systematic approach to discuss the DG and its technologies with advantages, disadvantages and effects on end users as well as on the utility. A comparative study of all optimization techniques for planning of DG in existing power system considering optimal size and location is also included. This paper also involves the details about some standard test systems along with details of useful software's (licensed & open source) for DG planning. The present study can add worthful information and serve as a base for the fellow working in this area.

Keywords Distributed generation · Distributed generation planning · Modern distribution system · Optimization approach · Power system · Renewable energy sources

Introduction

According to an estimation of United States (US) energy information administration, it is expected that electricity generation may increase by a very high percentage during the period 2016 to 2040. The growth may be significantly higher than global energy consumption. The RES will contribute greatly to the power generation mix with non-RES and other conventional sources to achieve the target as shown in Fig. 1 [1].

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In the last few years, penetration of the RES has been increased by tremendous rate. There are several factors such as government motivation in term of several incentives, environmental consciousness of society and advancement in technologies. Further, the key factors are changing the pace of power generation as the system is moving towards local generation near to their locality such as generation at home by solar, bio-mass and wind energy sources.

The local generation is affecting power flow direction as compared to the network with traditional centralized power generation sources, which has unidirectional power flow. In modern distribution systems, real power flow with the DG can be bi-directional. Since, the DG (renewable/non-renewable type) includes a broad range starting from 1 kW to 100 MW [2, 3], which can reverse the direction of real power at light

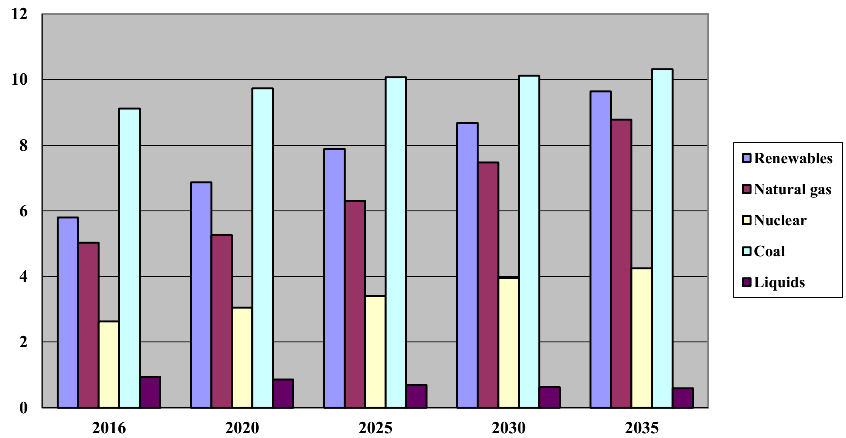


Fig. 1 Evolution of global electricity generation by various sources of energy (Trillion kWh) [1]

load or no load condition. In [4], Khatod suggested a broad classification as following:

(a) Micro DG (1 W < 5 kW),
(b) Small DG (5 kW < 5 MW),
(c) Medium DG (5 MW < 50 MW)
(d) Large DG (50 MW < 300 MW).

The above classification was also discussed in [5–8]. The DG units provide technical, economical and environmental advantages subject to planning strategy and technologies used for the DG. The technical advantage is an important concern as it reflects system health in terms of power loss, voltage profile, reliability and power quality. The DG can improve system performance. Further, it can also mitigate harmonics, voltage sag and swell significantly along with reduced investment in transmission and distribution [9–13].

There are certain challenges with DG technologies such as stability issues of power system due to intermittent source of energy, protection problem due to bi-directional flow of real power, frequency stability, islanding difficulties [1–105]. Therefore, some factors need to be considered for planning of sources in distribution networks [5, 6], [8], [14, 15].

- Power injection pattern from the DG is very important as it depends upon type of generation source, whether renewable or non-renewable. Hence, researchers must take care while choosing any renewable/non-renewable source for their study [16, 17].
- The optimal planning has its importance in improving overall performance of the system for getting the best possible potential from the DG.
- There is a great issue with the DG as it can cause bi-directional flow of real power. Therefore, suitable protection schemes need to be considered with load growth.

This work is prepared considering the importance and the necessity of the DG in existing power system. It includes a vast overview of the work carried out in the DG planning. Further, there are some important distribution systems, which required in planning of distribution system with the DG, are discussed with schematic figures. Moreover, a detailed section is given to discuss various open source and licensed software, which can be great help to the researchers.

This paper is organized as: Section II represents the details of the DG such as DG techniques, potential benefits and impacts of the DG. Section III introduces a brief overview of techniques used for planning of the DG in power system to extract maximum potential advantages. Section IV, chronologically, represents the involvement of the reviewed work. Section V includes the key issues for the DG integration in existing power system. In Section VI includes important test systems that are considered in several well established literatures. Some key supportive tools both open source and licensed (planning of the DG) are discussed in Section VII. Finally, Section VIII covers discussion and conclusion.

Distributed Generation

In [8], the DG is represented as a source of electrical energy that is connected to the radial structure of distribution system near the customer end.

According to International Council on Large Electric System, any generation units, connected to distribution network and having capacity from 50 MW to 100 MW, without facility of central planning and dispatchability is termed as DG [18].

Institute of Electrical and Electronics Engineer (IEEE) considers the DG as facility, comparatively smaller than central power plant and can be allocate at anywhere in power system [19].

The Electric Power Research Institute (EPRI) defines the DG as generation unit having maximum capacity up to

50 MW along with energy storage devices connected at consumers end or at distribution or sub-transmission substations [20]. Considering all the above views about the DGs, it can be concluded that the DG is a small source of electric power, connected near the load point or in the distribution network. The size of the DG is sufficiently smaller than the central power generation source.

A significant development in technology is making loads more sensitive. In addition, present polluted environment is attracting people towards the use of renewable energy. These are some factors providing momentum to go for renewable energy based DG. The DG has become a matter of interest for researchers, academicians and environmentalists due to its numerous advantages over conventional generating sources [5], [8, 9], [14, 15].

Key DG Technologies

Renewable energy sources as DG are beneficial in contrast of reduction in green-house gases, but uncertainties in power supply is also an issue. Some of the Renewable technologies require large space but most can be concise at small place like bio-gas plant for installation and initial cost is high, however, still less than centralized power generating source. Currently, to a certain extent, some of the DG technologies are still in research and under development phase. The major DG technologies with their range of electric power generation, primary source of energy, cost of installation is shown in Tables 1 and 2 [4, 7, 14, 21].

After-Effects of DG

The impacts of the DG can be generally classified into three categories as technical, financial and environmental impacts.

***Technical issues*:** Insertion of the DG in existing distribution network is beneficial in many technical aspects. The DG is installed near load centre, therefore, reduces power loss and at the same time improves voltage profile by keeping the voltage in limits. The DG improves reliability, system security and energy efficiency of the supply. All these benefits appears only if the DG is planned optimal, otherwise, the DG may produce several technical problems as presented in [2, 5], [14, 15], [7–9], [22–27].

***Financial issues*:** Installation of the DG is beneficial for the utility as well as the customer. Since, the DG reduces the capital cost by delaying the need for investment in new transmission and distribution infrastructure. It also reduces depreciation costs of the fixed assets in the network, loss in the system

Table 1 A summary of major renewable DG technologies

S. No.	DG Technologies	Power Generation Range	Energy Conversion	Dispatchability (Avoiding Grid Expansion)	Primary Source of Energy	Capital Cost/kW	Merits & Demerits
1	Solar photo-voltaic (SPV)	1 kW–80,000 kW	Solar radiation to electrical	Difficult	Sun	70,000	These are represented in [4].
2	Small hydro	5 kW–100,000 kW	Gravitational potential energy to electrical	Difficult	Water	650,000-845,000	
3	Micro hydro	1 kW–1000 kW	Gravitational potential energy to electrical	Difficult		650,000-845,000	
4	Wind turbine	200 W- 3000 kW	Wind energy to electrical	Difficult	Wind	45,000–68,500	
5	Bio-mass energy	100 kW–20,000 kW	Chemical to electrical, thermal and in bio-fuels	Difficult	Biomass	45,000–50,000	
6	Geothermal energy	5000 kW- 100,000 kW	Heat to electrical	Difficult	Hot water	170,000–350,000	
7	Tidal energy	0.1–1 MW	Kinetic energy to electrical	Difficult	Ocean water	–	
8	Hydrogen energy scheme	40–400 MW	Chemical to electrical	Difficult	Water, organic compounds, biomass, and hydrocarbons	–	
9	marine energy	100 kW–1000 kW	Kinetic to electrical	Difficult	Ocean wave	–	

Table 2 A brief overview of major non-renewable DG technologies

S. No.	DG Technologies	Power Generation Range	Energy Conversion	Fuel Type	Capital Cost/kW	Merits & Demerits
1	Integrated gasification combined gas turbine	30 kW-3000+ kW	Fuel to gas then to electricity	Gas, diesel or coal	55,000–116,200	These are represented in [4].
2	Micro turbine	30 kW–1000 kW	Chemical to mechanical then electrical	Biogas, propane or natural gas	78,000–110,500	
3	Internal combustion (IC) engine	5 kW–10,000 kW		Diesel, gas or natural gas	17,000–37,000	
4.	Fuel cell (FC) technologies		Chemical to electrical	–	–	
	Alkaline FCs	100 W- 50000 W		Alkaline electrolyte like KOH	>12,965	
	Phosphoric-acid FCs	200 kW–2000 kW		Acidic solution like H_3PO_4	194,479	
	Molten carbonate FCs	250 kW–2000 kW		Molten carbonate salt electrolyte	>12,965	
	Solid oxide FCs	250 kW–5000 kW		Ceramic ion conducting electrolyte in solid oxide form	64,826	
	Proton exchange FCs	1–250,000 W		Proton exchange membrane	97,240	
	Battery storage	500–5000 kW			6500–13,000	

Non-renewable DG technologies, mentioned in Table 2 can avoid expansion of grid if these are dispatchable

network, operation & maintenance costs. The DG reduces electricity tariffs by creating favourable market environment for new agents [3, 5, 14, 28].

Environmental issues**:** Major DG technologies are associated with renewable sources; therefore, it is possible to generate green energy. As per the published literature, fuel burning is the main cause of around 80% pollution all over the world [23–25]. Many researchers have proved that the DG technologies, mainly renewable energy based, are capable of reducing the emission of carbon, technology and capable to cut the emission of carbon by approximately 40% [7]. As per the above mentioned definitions, it is clear that the DG can be installed near the load centres. Hence, there is no need of large space and it reduces deforestation. Though, there are some adverse impacts of renewable technologies on environment. Wind turbines are particularly not favorable to the bird species. Moreover, wind turbine required to be dug deep into the earth, which off-course has negative effect on underground habitats. In addition, it creates noise pollution. Similarly, ocean wave energy can be harmful to local water species during energy production.

Popular Techniques for Optimal Sizing and Sitting of the DG

The DG planning depends upon the requirement of the system such as: (a) Technical Issues (b) Economic Issues (c) Environmental Issues. In technical issues, key issues of the DG planning are voltage profile improvement, energy loss minimization, harmonics reduction, mitigating the issues of intermittent nature of the DG and maximization of reliability. There are several economic issues related to distribution system where the DG can help in mitigating such issues. Therefore, economic issues can be as key objective of the planning, whereas sometimes it can be merely a constraint. In several developed country, environmental issues are so important that the DG planning primarily considers it. Thus, the RES are mainly considered in such countries even they are costlier option.

The DG can be planned to address single or multiple issues, which may be combination of above said issues. This makes planning as single objective or multi-objective planning with or without constraint. In continuation, selection of the optimizing tool is based on nature of the planning and system constraints.

To maximize the requirement of the system, it is necessary to place the DG with proper sizing and siting considering the key constraints in distribution system. Such planning can result as desirable output. Hence, there are a lot of techniques available in the literature as per the objectives of the planning [125–135].

The following techniques have been adopted by the researchers to serve the objectives of sizing and siting of the DG in appropriate manner. The major acting techniques can be categorized as follows [12, 29].

- Analytical Techniques
- Classical Optimization Techniques
- Artificial Intelligent (Meta-heuristic) Techniques
- Miscellaneous Techniques
- Other Techniques for Future Use

Analytical Techniques

In Analytical techniques, mathematical replica is used to represent the system and numerical solution of the system, which can be computed reliably. Beauty of this technique is less computation time, high efficiency and simplicity of system with less state variables. Accomplishment of the technique has been reported in [2, 3], [10–12], [15, 16], [29–32]. However, Analytical techniques may have some restrictions for bulky and difficult systems. These optimization techniques broadly include many key techniques and some of them are shown in Fig. 2.

Classical Optimization Technique

These optimization techniques are utilized to expand the advantage of the system according to the created formulation as per the necessity under given circumstances with system limitations. In this way, it needs to apply an appropriate optimization technique to get the required aimed function. These optimization techniques mainly cover important methods as shown in Fig. 3.

Artificial Intelligent Techniques

The beauty of Artificial Intelligence (AI) technique lies in getting well-organized, precise and best possible solutions wisely. The supposition extracted from the AI technique is the most up to date and adorable meta-heuristic explore technique. There are some other family optimization algorithms that have been adopted in meta-heuristic as shown in Fig. 4 [4–6], [13, 22], [25–28], [2, 33–45].

Miscellaneous Techniques

There are many more verities of methods observed in the work of literature, which are kept under miscellaneous techniques as shown in Fig. 5.

Future Promising Optimizing Techniques

There might be several new optimization techniques, with capabilities to have room for the multifaceted questions of the DG planning with multi-objective function, which can be classified as shown in Fig. 6.

Significant Contribution in the Reviewed Planning of the DG

Table 3 describes the main contribution of the published DG works reviewed in this paper in a chronological order.

Challenges with Distributed Generation

Integration of the DG in distribution network has lots of benefits including technical, economic and environmental. Still, integration of the DG unit with existing power system is facing some challenges [4, 8, 28, 36], [90–92]. These are divided into three categories as:

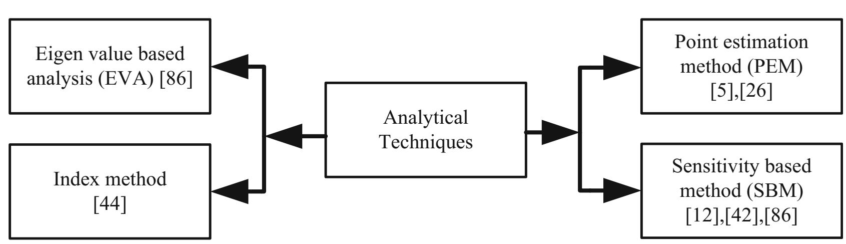
- Technical issues
- Economical issues
- Operational & connection issues

These all issues are discussed in detail under this section.

Technical Issues

The prime objective of the DG integration with existing distribution network is to overcome technical troubles

Fig. 2 Analytical techniques



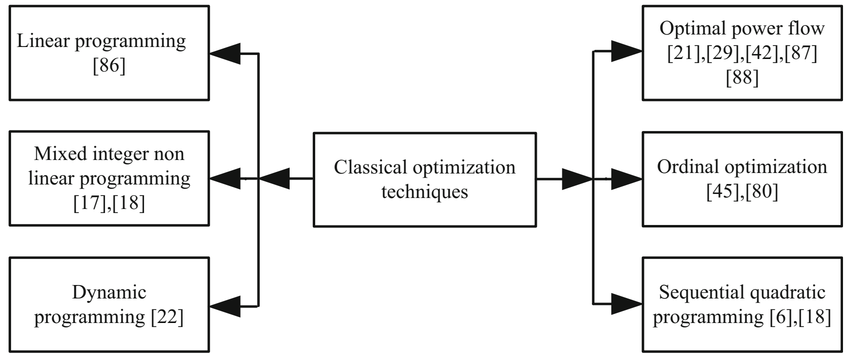


Fig. 3 Classical optimization techniques

like reliability, power loss, harmonics, voltage fluctuation, stability and power quality [4]. The DG can successfully mitigate these problems; still the DG integration has some technical issues. These issues are discussed as follows.

Power Handling Issue

Addition of the DG at the distribution level can significantly affect the amount of the power to be handled by types of equipments such as cables, lines, transformer and many other [93]. In [93], it is discussed that the transformer is the mainly affected during power generation increases with power utilization. The system's peak hours are more critical as both base and peak distributed generators will operate to cash in the price premium.

Power Quality Issue

This issue depends on the technique, which are used for the DG and their modes of the operation. The key cause of harmonics is frequent on/off or frequent change in voltage and current, which adds non-linearity. In addition, too much use of power electronics devices and modern automatically controlled devices produce power quality issues. Though, these devices are very sensitive to voltage-frequency fluctuations [90].

Short Circuit Capacity

Integration of the DG in existing distribution network increases the short circuit capacity of the system by increasing the steady state current at fault. This depends on size, type and remoteness of the DG from the

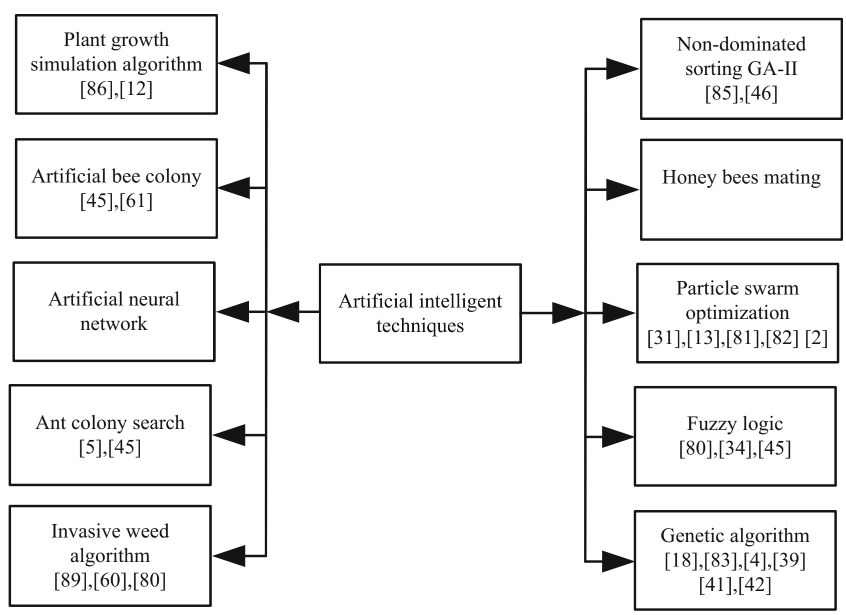


Fig. 4 Artificial intelligent techniques

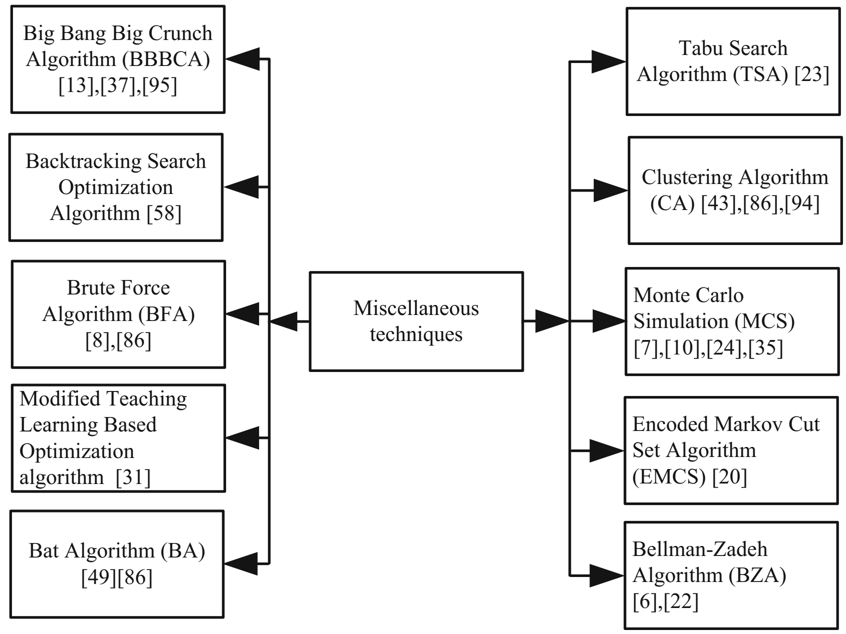


Fig. 5 Miscellaneous techniques

location where fault occurs. This adversely affects the system reliability as well as its safety. Although, sometimes it is desirable to have high short circuit capacity in case of inverter of a line commutated HVDC station, but in general increase in short circuit capacity dominantly indicated problems [90].

Power Conditioning Issues

The power output pattern of the DG, either AC or DC depends upon the DG technology. The DG source with DC output needs converter to convert DC into AC. In some cases, Cyclo-converters are required to have variable frequency AC supply. The converters may generate harmonics in the system.

Economical Issues

Cost of the DG is the key factor in its growth and adoption as a new technology [94]. The DG has many advantages; still cost of the DG unit is barrier in its growth. Further, the DG is lagging behind due to regulatory plus policy issues. These issues are point wise discussed here.

Electricity Pricing Issues

In the present scenario, as price of the electricity is increasing continuously due to increasing demand by all types of the consumers. There is a possibility that distribution companies and industrial load may install their own generation units to partially fulfil their energy demand. This will reduce purchasing of electricity from grid.

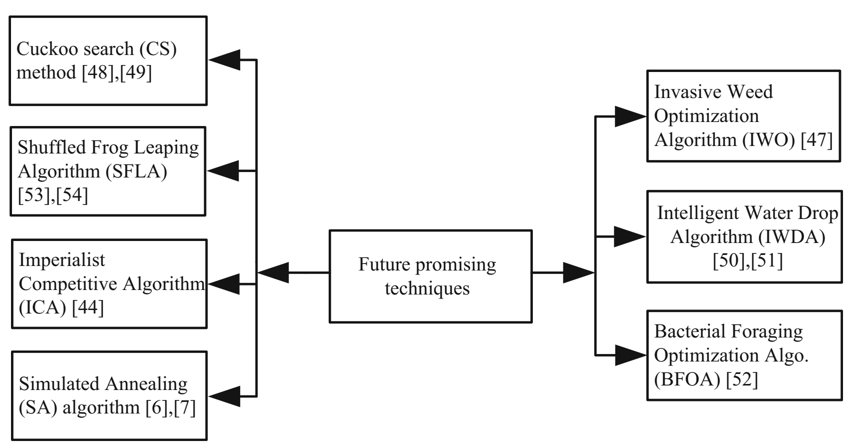


Fig. 6 Future promising techniques

Table 3 Main contribution of the published Optimal DG Planning works in chronological order

S. No.	Goal of the Planning	Planning Variables	SO/MO	Algorithm	Ref.
1	Minimization of total electrical power losses (PL)	Optimal placement of multiple DG units	SO	Stud Krill herd Algorithm	[46]
2	Minimization of total electrical PL	Optimal placement of different types of DG units	SO	Bat Algorithm	[47]
3	Minimization of total electrical PL	Optimal location and sizing of DG unit	SO	Intelligent Water Drop algorithm along with loss sensitivity factor	[48]
4	Minimization of total electrical PL	Optimal siting and sizing of DG units	SO	Analytical method	[49]
5	Minimization of total electrical PL	Optimal site and size	SO	Sequential Quadratic Programming and Branch and Bound algorithm	[50]
6	Minimization of total electrical PL	Optimal allocation and sizing of different types of DG units	SO	PSO-based algorithm and also analytical method	[32]
7	Minimization of total electrical PL	ODGP and sizing of multiple DG	SO	Kalman Filter Algorithm, optimal locator index	[51]
8	Minimization of total electrical PL	Optimal allocation (sizing and siting) of DG and capacitor	SO	Method based on analytical approach with heuristic curve fitting technique	[52]
9	Minimization of total electrical PL	Optimal placement of DGs and size of the DG's	SO	PSO technique	[43]
10	Minimization of total electrical PL	Optimal allocation of three types of DG (Solar parks, wind farms and power stations)	SO	GA	[53]
11	Minimization of total electrical PL	Optimal placement and size of DG units	SO	Modified Teaching Learning Based Optimization Algorithm	[40]
12	Minimization of total electrical PL	Size and Location of DG	SO	Immune Algorithm with active model of DG in the smart network including all kind of cast factors.	[54]
13	Minimization of total electrical PL	Optimum sizes and operating strategy of DG units	SO	Three alternative analytical expressions (Elgerd's loss formula, branch current loss formula, branch power flow loss formula)	[39]
14	Minimization of total electrical PL	Optimal DG-unit's size, power factor, and location	SO	Meta-heuristic, population-based optimization methodology with an Artificial Bee Colony (ABC) algorithm	[55]
15	Reduction in power loss along with voltage stability enhancement	Optimum DG placement	MO		[56]
16	Addition of cost of real power and energy loss cost with power loss optimization	Optimal location and size of multi DG	MO	Adaptive Differential Search Algorithm	[57]
17	Comparison of three optimization techniques for reduction of the real power loss and voltage profile improvement	Optimal placement of DG	MO	PSO, GA and PSO + ABC	[58]
18	Real power loss minimization and voltage improvement and improvement of voltage stability index	Optimal location and size of DG	MO	Teaching learning based optimization algorithm	[59]
19	Network power losses, achieve better voltage regulation and improve the voltage stability	Optimal location and sizing of DG unit	MO	Quasi-Oppositional Swine Influenza Model Based Optimization with Quarantine	[60]
20	Diminishing real power disaster, working expense and improving voltage steadiness	Optimal location and sizing of DG unit	MO	IWO along with the loss sensitivity factor	[61]
21	Reducing power losses and improving voltage profile	Optimal location	MO	Loss reduction sensitivity method Voltage improvement sensitivity method	[62]
22	Minimizing power losses and generation costs	Optimal location and sizing of DG unit	MO	Relaxed MINLP	[63]
23	Minimum annual investment and operation (I&O) cost of DG, purchasing electricity cost & voltage deviation	Optimal sitting and sizing	MO	Improved Non-dominated Sorting GA-II	[64]
24	Energy loss minimization considering the random nature of some distributed resources and the time varying loads	Optimum allocation of DG	SO	Refined parallel Monte Carlo method	[65]
25	Optimal multiple DG	Location	SO	Rank Evolutionary PSO By hybridizing the Evolutionary Programming in PSO algorithm.	[66]
26	Power loss, line flow maximum value, and voltage summary and voltage steadiness directory combined using weighting coefficients.	Optimal siting and sizing of DG units	MO	Chaotic Artificial Bee Colony Algorithm	[34]

Table 3 (continued)

S. No.	Goal of the Planning	Planning Variables	SO/MO	Algorithm	Ref.
27	Mitigation of losses, improving the voltage profile and equalizing the feeder load balancing in distribution systems	Optimal siting and sizing of multiple DG units	MO	Hybrid Fuzzy-IWD Approach	[67]
28	Network real loss and enhance the voltage profile combined power factor and reduction in network reactive power loss	Optimal allocation of DG	MO	Backtracking Search Optimization Algorithm	[68]
29	Costs are minimized and profits are maximized	Optimal locations, sizes and mix of dispatchable & discontinuous DGs	MO	Column and Constraint Generation framework	[69]
30	Improving voltage profile and stability, power-loss reduction, and reliability enhancement, economic analysis	Optimal DGs places, sizes, and their generated power contract price	MO	PSO	[70]
31	Enhancement of power quality includes improvement of voltage and reduction of line losses	Optimal placement and sizing of Distribution Static Synchronous Series Compensator	MO	PSO	[71]
32	Removal of susceptible nodes to maintain the voltage level of system	Optimal location and capacity of DG units	SO	GA	[72]
33	Voltage stability and loss minimization	Optimal location and size of DGs	MO	Maximum Power Stability Index and PSO Algorithm	[73]
34	Promoting energy competence	Optimal network capacity and distribution of the CHP-based DG	SO	Integrated System Dispatch model	[74]
35	System loss minimization and voltage profile improvement	Optimal siting and sizing of DG units	MO	BA	[75]
36	Reduce the total power loss and to improve the voltage profile	Optimal siting and sizing of DG units	MO	Bacterial Foraging Optimization Algorithm Modified Bacterial Foraging Optimization Algorithm	[76]
37	Reduction in power system losses, maximization of system load ability and voltage quality improvement.	Multi-DG placement and sizing	MO	Hybrid PSO	[10]
38	Voltage constancy, power losses and network voltage fluctuations	ODGP and sizing	MO	Pareto Frontier Differential Evolution algorithm	[77]
39	Voltage regulation problem considering random nature of lower heat value of biomass and load.	Optimal location of biomass- fuelled gas engines	SO	Frog-Leaping Algorithm and three phase probabilistic load flow combined with the Monte Carlo method	[78]
40	Uncertainties considered: (i) the future load growth in the power distribution system, (ii) the wind generation, (iii) the output power of photovoltaic's, (iv) the fuel costs and (v) the electricity prices	Optimal siting and sizing	MO	Point estimate method embedded GA	[79]
41	Minimizing annual energy losses	Optimal location, size and power factor of dispatchable and non-dispatchable DG units	SO	Analytical Approach	[80]
42	To make mini hydro scheme a cost-effective renewable energy option	New designs of turbines, electrical equipment's and governor controllers	SO		[45]
43	Improvement in power system parameters	Optimal sitting and sizing of DG	MO	ICA and GA	[44]
44	Minimize real power losses by maintaining the fault level and the voltage variation within the acceptable limit.	Optimal sizing and siting of DG	SO	CS technique	[81]
45	Minimize energy loss considering time- varying characteristics of both load and wind-generation profile	Optimal size of wind turbine	SO	Weighting factor based methodology incorporating genetic algorithm with power flow analysis with fuzzy–c means clustering to reduce execution time.	[82]
46	Minimize the annual energy losses and reduce the harmonic distortions	Optimally allocating different types of DG (i.e. wind-based DG, solar DG and non-renewable DG)	MO	Probabilistic planning approach	[13]
47	Reduced number of DG, less power loss and maximizing voltage stability	Optimal sizing and siting of DG	MO	Non-Linear Programming with fuzzification to avoid problem of selection of weighting factors.	[83]
48	High loss reduction in large-scale primary distribution networks	Optimal size and location of 4 types of DG	SO	Improved analytical method including loss sensitivity factor and exhaustive load flow method.	[42]

Table 3 (continued)

S. No.	Goal of the Planning	Planning Variables	SO/MO	Algorithm	Ref.
49	Power losses and voltage profile	DG placement and sizing	MO	Improved Multi-Objective Harmony search	[41]
50	Total imposed costs, total network losses, customer outage costs, private investments	Optimal location of DG	MO	Non-dominated Sorting GA-II	[31]
51	Minimizing total electrical energy losses, total electrical energy cost and total pollutant emissions produced	Optimal placement and sizing of DG units	MO	Interactive fuzzy satisfying method, which is based on Hybrid Modified Shuffled Frog Leaping Algorithm,	[84]
52	Reduce the real power losses and cost of the DG. The paper also focuses on optimization of weighting factor, which balances the cost and the loss factors	Placement of DG	MO	Population based meta heuristic approach namely Shuffled Frog Leaping Algorithm	[12]
53	Network losses reduction & voltage profile and stability enhancement.	DG placement and sizing	MO	Line voltage stability index	[10]
54	Improve voltage profile and reduce power loss	Optimal DG allocation	MO	CS	[85]
55	Improving the stability margin considering system voltage limits, feeders' capacity, and the DG penetration level	DG placement and sizing	MO	Modified voltage index method using mixed-integer nonlinear programming	[86]
56	Minimize the costs of losses with voltage profile and reliability enhancement	Optimal DG allocation and sizing	MO	Hybrid method based on improved PSO algorithm and Monte Carlo simulation	[38]
57		Optimal DG allocation and sizing		GA with the inclusion of weighting factors.	[30]
58	Power losses and voltage levels	Optimal DG allocation	MO	Bellman-Zadeh algorithm with DiGSILENT software	[26]
59	Reduce the network energy loss, energy cost, and energy not supplied	Optimal size and location DG & of remote controllable switches	MO	GA generation worth index and annual DG operation strategy	[87]
60.	Minimize network power losses, better voltage regulation and improve the voltage stability.	Optimal location and sizing of DG	MO	Combination of GA and PSO	[88]
61.	Reduction in line loss, voltage sag problem and economical factors like installation and maintenance cost of the DGs	Optimal location and sizing of DG	MO	GA supported weighting method	[89]
62.	Optimal number of DGs, along with sizes and bus locations	Optimal location and sizing of DG	MO	GA	[17]
63	Minimizing power loss of the system with enhanced reliability and voltage profile.	Optimal location and sizing of DG	MO	Dynamic Programming	[11]
64	Losses, voltage profile and short circuit level	Optimal location and sizing of DG	MO	Appropriate weight factors based algorithm	[37]

Table 4 Important test systems in literature

S. No.	Test System	Base power (MVA)	Base voltage (kV)	Figure	Data reference
1	12-Bus network	0.01	11		[96–98]
2	16-Bus network	100	23	See Appendix	[16, 42]
3	30-Bus network		11		[99]
4	33-Bus network		12.66		[16, 42, 100]
5	41-Bus network		33		[101]
6	69-Bus network		12.66		[16, 42, 97, 102, 103]
7	85-Bus network		11		[104]
8	141-Bus network		12.47		[105]
9	IEEE Test System	[106]			

Table 5 Important software tools and their brief description (Open source)

S. No.	Tool	Description
1.	The Engineering, Economic, and Environmental Electricity Simulation Tool (E4ST)	The Engineering, Economic & Environmental Electricity Simulation Tool (E4ST) was presented in [107].
2.	Panda Power (Load Flow Programme)	Radial distribution system has been used to implement this power flow programme, which is based on backward/forward sweep approach. In [108], tutorials to use this software are given. Also, the panda power flow programme may be suitable software for power system analysis [109].
3.	Electric Grid Test Cases	This webpage is intended to provide a repository of publicly available, non-confidential power system test cases [110].
4.	iPST	The iPST is open-source software which was designed to provide a stage for examination of security and safety of expanded power system. It is an active power system simulator for simulating the dynamics of the system. It additionally encourages the power grid data-mining utilizing huge-data databases that permit storing time-series of power system related information's [111].
5.	MATPOWER	MATPOWER is a software package for solving load flow and system optimization related problems. It was primarily developed as part of the Power Web project [112].
6.	PSAT (Power System Analysis Toolbox)	The PSAT is an obliging software for power system examination and modeling. It can assist in power system stability problems with real time analysis, wind turbine models, change of information records from a few configurations. It provides interfaces to GAMS and UWPFLOW programs [113].
7.	Open DSS	The Open DSS is a comprehensive electrical power system simulation tool. It supports nearly all frequency domain (sinusoidal steady-state) analyses, which are commonly performed on electric utility power distribution systems. In addition, it supports many new types of analyses that are designed to meet future needs related to smart grid, grid modernization and renewable energy research. Other features support analysis of such things as energy efficiency in power delivery and harmonic current flow. The Open DSS has room for changes to meet future needs [114].
8.	Smart Residential Load Simulator (SRLS)	The SRLS facilitates the study of energy management systems in smart grids. This provides a complete set of user-friendly graphical interfaces to properly model thermostats, air conditioners, furnaces, water heaters, refrigerators, stoves, dish washers, cloth washers, dryers, lights and pool pumps as well as wind, solar, and battery sources of power generation in residential houses. The simulator allows modeling, the way appliances consume power and helps to understand how these contribute to peak demand providing individual and total energy consumption and costs and allowing assessment of generated power by residential power sources. This platform can be a useful tool for researchers and educators to validate and demonstrate models for residential energy management and optimization. It can also be used by residential customers to model and understand energy consumption profiles in households [115].
9.	Grid LAB-D	Grid LAB-D is a power distribution system simulation and analysis tool that provides valuable information to users to design and operate distribution systems. It incorporates the most advanced modelling techniques to deliver the best in end-use modelling. The Grid LAB-D can be integrated with three-phase unbalanced power flow and retail market systems [116].
10.	Miscellaneous Data Set	Several public data sets available from IEEE-PES ISS at [117]. Data related to energy and water [118]. The data related to house hold electric consumption having resolution of 1-min [119]. The data related to house hold electric consumption having resolution of 15-min [120].

Table 6 Key features of some popular licensed software

S. No.	Tool	Description
1.	DIgSILENT	The Power Factory Monitor (PFM) is multi-functional Dynamic System Monitor, which can be fully integrated with DIgSILENT Power Factory software. The beauty of PFM is grid and plant monitoring, fault data record, grid characteristics analysis by offering easy access to recorded information, analysis trends, verification of system upset responses and test results [121].
2.	GAMS	The GAMS is an advanced-level mathematical optimization modeling tool for linear, nonlinear, and mixed-integer optimization problems. They can be efficiently modeled and solved using GAMS. The system is tailored for and allows the user to build large maintainable models that can be adapted to new situations and complex, large-scale modeling applications. The GAMS develop models in concise pattern and human-understandable algebraic statements [122].
3.	PSCAD	PSCAD/EMTDC provides the facility to researchers to build, simulate and model power system networks with ease and limitless possibilities for simulation. The PSCAD/EMTDC also incorporates a comprehensive library of system models ranging from simple passive elements and control functions to electric machines and other complex devices [123].
4.	ETAP	ETAP is the wide-ranging electrical engineering software platform for the design, simulation, operation, and computerization of generation, transmission, distribution, and industrialized systems. As a fully integrated model-driven enterprise solution, The ETAP extends its scope from modeling to operation in real-time power management system [124].

Therefore price will get affected as consumers having option to choose power supply either from grid or from own generation unit. This will reduce the market price of electricity and create good competition between different electricity generation companies [8].

Demand Response Effect

Several countries are having electricity market and for its better financial status, demand response is a major tool. The demand response is less effective in case of the RES due to its intermittent nature [90].

Regulatory Issues

The DG is more beneficial, if integrated at proper location in distribution system. Still due to lack of transparent policies and regulatory instruments which are associated with DG treatment, this technology is at brimming stage. In order to promote green energy it is necessary to develop new schemes that support integration and implementation of the DG. An appropriate regulatory policy of Government must be developed for future growth of the DGs.

Operation & Connection Issues

The DG integration in an existing system may introduce protection and power flow related issues. Further, non-optimal location as well as size also creates many problems, therefore, the optimal location with size should be globally optimized. These issues are point wise discussed below.

Protection system Co-Ordination Issue

Earlier distribution systems were radial distribution network where power flow was unidirectional, however, after the DG integration, power can flow in both directions and this may cause some critical challenges in existing network.

The DG units can modify fault current level and disturb the settings of protection devices, making it harder to detect fault. Further, it is complicating co-ordination among the protection devices. Presence of the DGs affects speed of reclosing of switch and it may lead to other serious problems. Since, higher reclosing speed may lead to failure of some DG.

The overall protection schemes and their modification depend upon size, type and location of the DG. In order to avoid major modification, the total capacity of the DG should be 5% [95]. Therefore, a balance is required to manage successful operation of distribution system with RES/non-RES DGs.

Islanding Issues

Islanding issue comes when power is required to continuously deliver to a part of the system by the DG during grid supply is off. It may be challenging for the utility as workers may work on a charged line and it prevents automatic operation of the switching devices. Islanding can be great challenge for synchronization of renewable sources, which results in false tripping at the moment of re-closer operation [8].

Stability

Traditionally, the distribution systems were passive with radial topology. Moreover, it needs not to be analysed on the basis of stability as system remains stable during most of the circumstances. However, increased penetration of the DG makes necessary to consider system stability including short duration transient and long term steady state stability [90].

Distribution Test Systems and Load Representation

In present era, looking at the power crisis problem and several other technical and non-technical issues, RES and non-RES DGs are placed near to electrical load centers considering types of loads as: Uniformly distributed, increasingly distributed, centrally distributed, and randomly distributed loads. It is observed in the literature that the majority of the planning of distribution system was carried out for following test systems shown in Table 4.

In [96–98], 12-bus (Indian) System was popularly used in testing of several research works. The 12-bus system data is given in [96–98]. For load flow study, a power base of 0.01 MVA and voltage base of 11 kV can be taken. The one line diagram of 12-bus system is given in Appendix Fig. 7. The 16-bus system was mainly considered in [16, 42]. For study, 100 MVA and voltage base of 23 kV can be suitable base values for power and voltage, respectively. The one line diagram of 16-bus system is presented in Appendix Fig. 8. This system has six capacitors to maintain the system voltage profile at rated value. The 33-bus system data can be obtained from [16, 42, 100]. For load flow study, a power base of 100 MVA and voltage base of 12.66 kV can be considered. The one line diagram of 33-bus system is comprises in Appendix Fig. 9. The 41-bus system data is given in reference [101]. For study, a power base of 100 MVA and voltage base of 33 kV were taken in the literature. The one line diagram of 41-bus system is represented in Appendix Fig. 10. The 69-bus system data is taken from references [16, 42, 97, 102, 103]. For study, a power base of 100 MVA and voltage base of 12.66 kV can be taken. The one line diagram of 69-bus system is presented in Appendix Fig. 11. The 85-bus system data is given in [104]. For study, a power base of 100 MVA and voltage base of 11 kV can be taken. The one line diagram of 85-bus system is presented in Appendix Fig. 12. The 141-bus system data is given in [105]. For study, a power base of 100 MVA and voltage base of 12.47 kV can be considered. The one line diagram of 141-bus system is shown in Appendix Fig. 13.

Supportive Tools for Distributed Generation Planning

Researchers working in the power system have used various research tools to analyse the planning problem for the DG. Therefore, some useful supportive tools, which help greatly in research related to the planning of the DG, have been presented in this section. Tables 5 and 6 can help researchers in working with distribution system including distributed energy sources.

Conclusion

This paper focuses on optimal planning of DG considering various objective functions and constraints in distribution networks planning. In addition, it also covered the impacts of DG integration on distribution network's voltage, protection scheme, reliability and security. It is evident from literature that DG installation influences technical, environmental as well as economical benefits in distribution network. Thus, this article also discussed the key benefits and shortcomings (technical, environmental and economical) of addition of DGs. Moreover, renewable energy technology with their comparative study is also presented to make this paper more useful. Further, brief overview of several test systems and open source as well as licensed software presented in this article.

This paper also covered application of modern optimization techniques such as Bacterial Foraging Optimization Algorithm, Simulated Annealing Algorithm, Intelligent Water Drop Algorithm, Shuffled Frog Leaping Algorithm and Invasive Weed Optimization Algorithm in optimal siting and sizing of the DG.

Appendix

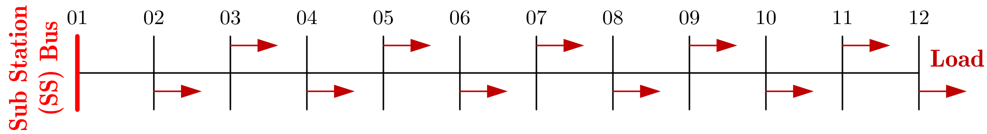


Fig. 7 12-bus system

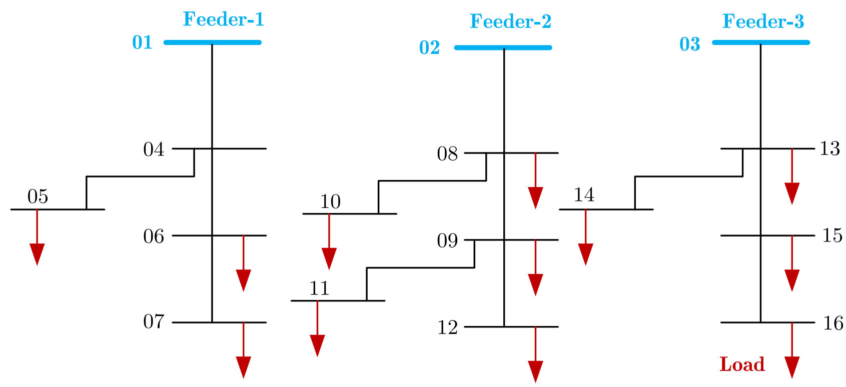


Fig. 8 16-bus RDS (Tie switches are not shown)

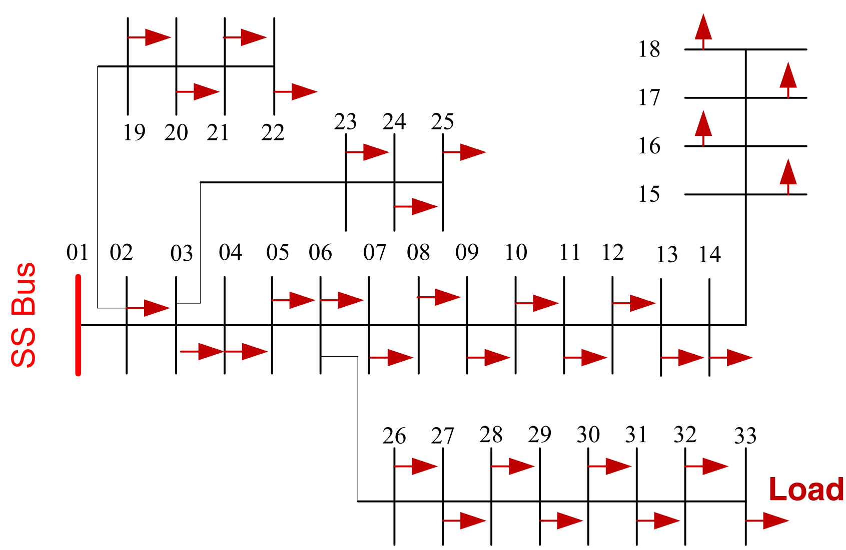


Fig. 9 33-bus RDS

Fig. 10 41-bus RDS

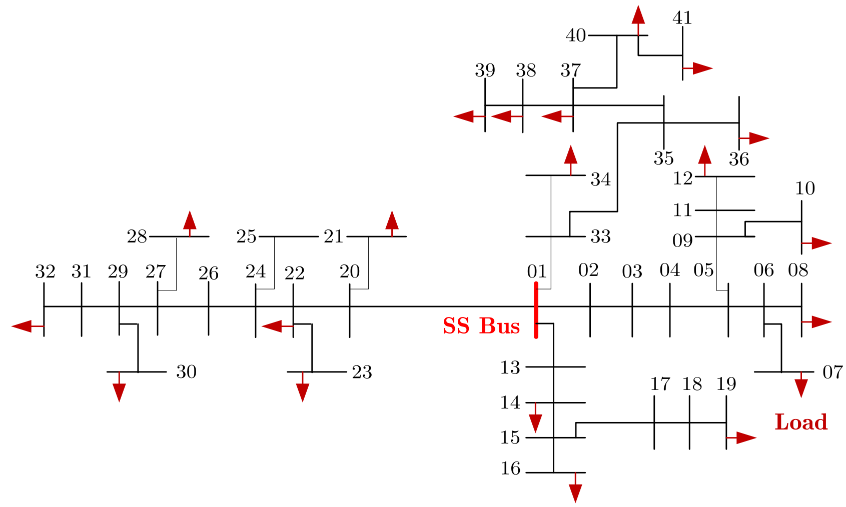


Fig. 11 69-bus RDS

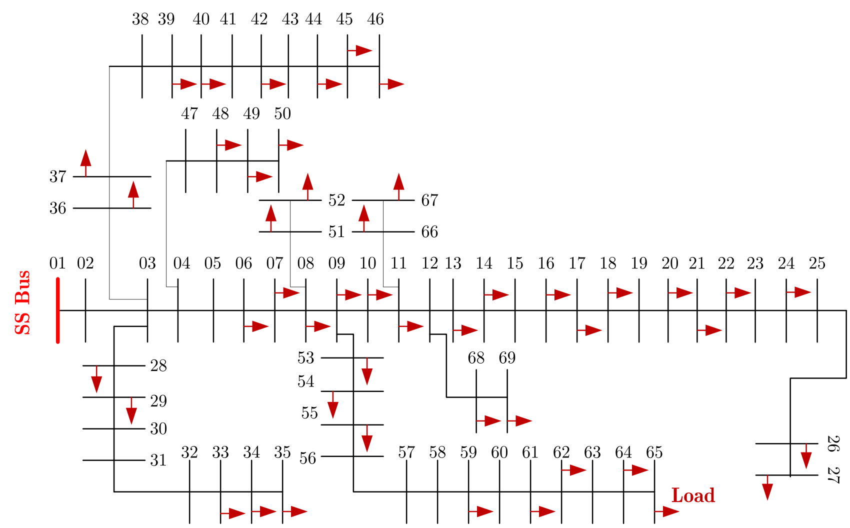


Fig. 12 85-bus RDS

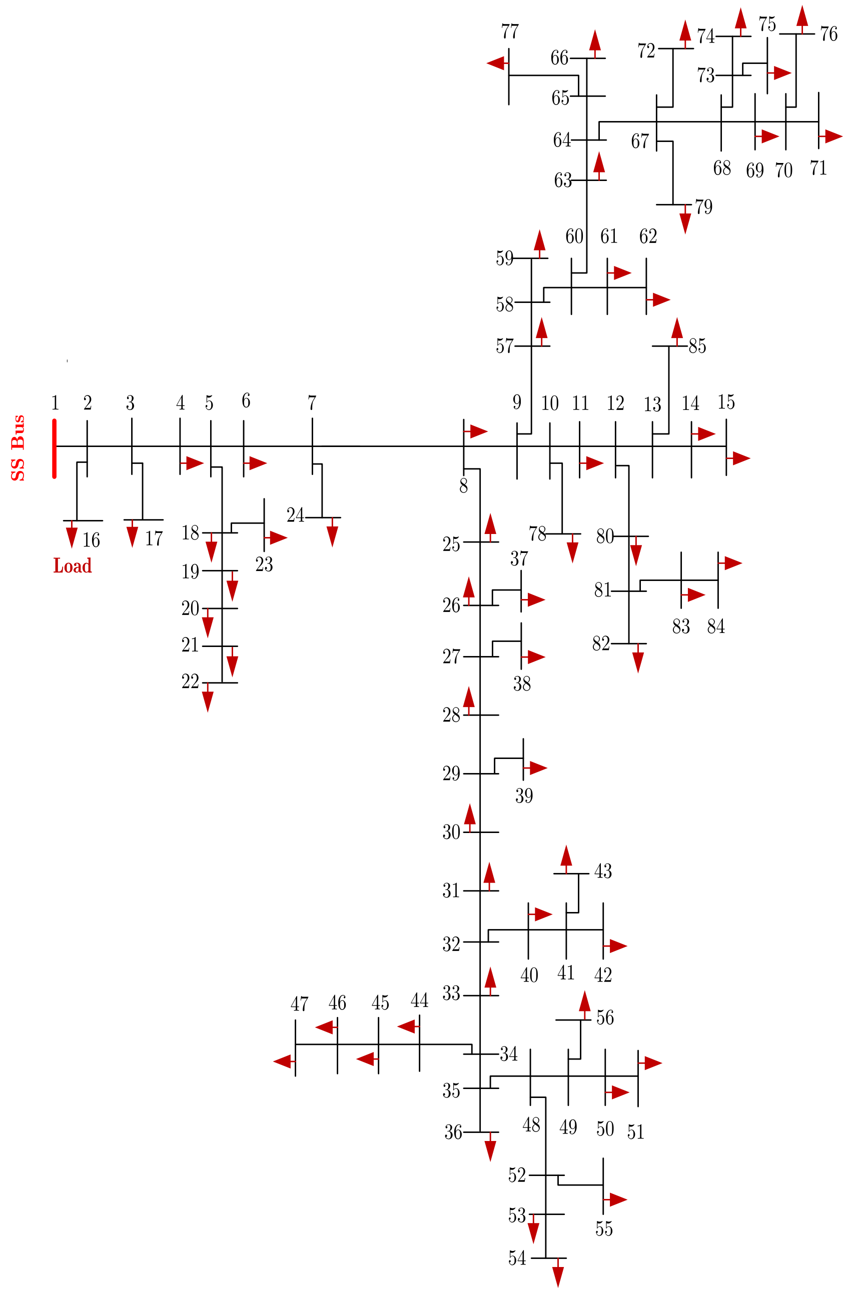
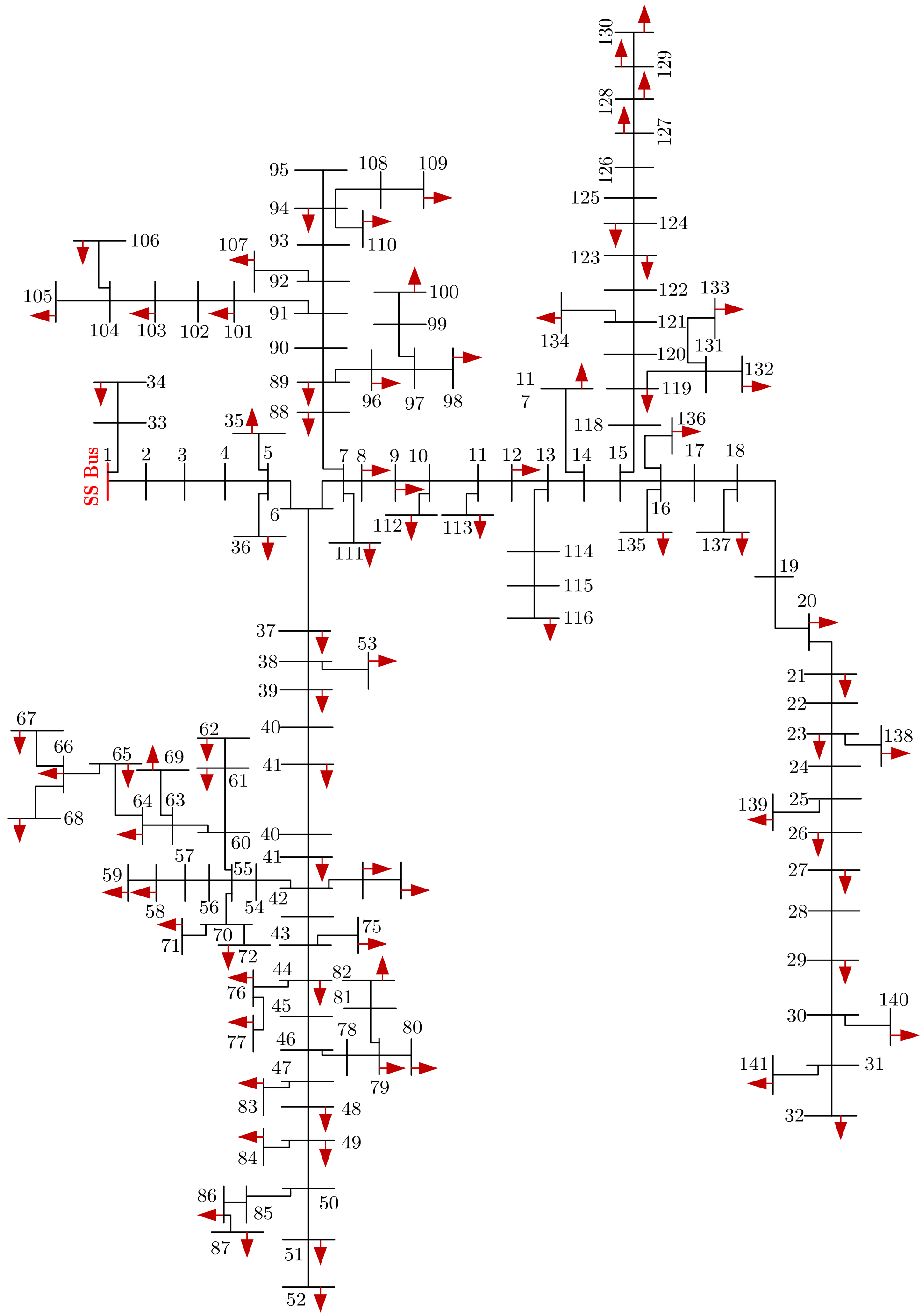


Fig. 13 141-bus RDS



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