Chapter 1

Introduction

1.1 The Background

Energy in different forms is used in our day-to-day, industrial and commercial activities. Out of all the forms of energy used by us, electric energy is the most utilized one as it can be converted from other forms of energy efficiently, transmitted easily, and consumed at a very reasonable cost. Thomas Edition was the person who established the first DC power network in the United states of America in 1882 to supply the lower Manhattan area of New York city. The invention of transformers in 1885 by William Stanley and the induction motor in 1888 by Nikola Tesla facilitate the power system engineers to raise the ac voltage level and replacement of DC motors, respectively. These inventions made ac system prevalent. In India more than a hundred years back in 1890, the hydro power plant was commissioned in Darjeeling.

The modern power system structure comprises generation, transmission, distribution, and load. Today's power system is highly non-linear and complex. In the previous decades, large a portion of the generation was centralized in nature and was dependent on the fossil fuels. Fossil fuels are non-replenished in nature or require very much time to refill. With the advent of renewable energy sources, nowadays power is generated by the non-conventional sources of energy are fed locally in distribution networks to supply local demands, thus forming a micro-grid. The micro-grid may also inject power into the main grid based on availability. Generally, distribution systems are redial in nature and distribute power to the various load centers through feeders. The major drawback of a distribution system is the high R/X ratio. This high R/X ratio and power distribution at low voltage produce a large amount of active power loss in the system. The power loss in the distribution line may be reduced by reducing the line resistance but it may not be economical. Remote end buses of a feeder in radial distribution networks may have low voltage magnitude in radial distribution network. The poor voltage profile at remote buses may also deteriorate the voltage stability margin. The placement of Distribution Generations (DGs) at optimal locations seems to be an effective remedy in reducing power loss and improving the voltage profile as well as voltage stability margin in the radial distribution network.

1.2 Distributed Generation

Lately, the problem of energy crux has become more and more exasperating, ensuing in amplified exploitation and search for fresh energy resources around the globe. As a result, countries are forced to review their energy policies, for example, the European Union has committed to lessen the emission of greenhouse gases to at least 20% below 1990 levels and to produce no less than 20% of its energy consumption from renewable sources.

Renewable Energy is generated from natural processes and is endlessly stocked. This includes Renewable Energy Sources (RES) like sunlight, geothermal heat, wind, tides, water, and various forms of biomass. This energy is inexhaustible, reliable, and plentiful.

In recent pasts, DG penetration, especially, through Renewable Energy Sources (RES) has been increasing vastly due to minimal carbon footprints. In addition, they make the system more reliable by minimizing the system power loss and voltage deviation of the distribution network. Distributed generation, Decentralized Generation, Small Scale Generation, Embedded Generation, or Dispersed generation are very low power rating generators (typically from a few kW to tens of MW), installed commonly in the vicinity of the consumer's load to strengthen the traditional power system [1], [2]. DGs are not

Table 1.1 Distributed Generation definitions

S. No.	DG Definition	Perspective
01	Electric power generation source connected directly to the distribution network or on the customer side of the meter	Location
02	Small generating units installed close to load centers	Location
03	Generation from a few kilowatts up to 50 MW	Capacity
04	All generation units with a maximum capacity of 50 MW to 100 MW, which are usually connected to the distribution network and which are neither centrally planned nor dispatched	Capacity
05	Generating plant serving a customer on-site or providing support to a distribution network, connected to the grid at distribution-level voltages	Location
06	Generation of electricity by facilities that are sufficiently smaller than central generating plants to allow interconnection at nearly any point in the power system	Capacity
07	Electric power generation or storage (typically ranging from less than a kW to tens of MW) that is not a part of a large central power system and is located close to the load	Capacity & Location
08	Small generation units of 30 MW or less located near consumer centers	Capacity & Location

new to the scientific world but have become popular in the last decade because of their numerous advantages over centralized power generation systems.

The definition of DG is inconsistent in literature and varies with factors like location, rating, purpose, environmental impact, penetration, etc. IEEE states that sources that are low-rated compared to central generation and provide flexibility enough to be connected at almost any node in the network are termed distributed generation [3], [4]. Other definitions are based on various perspectives as described in Table 1.1.

The DGs include various technologies like gas internal combustion engines, microturbines, fuel cells, wind and solar energy, tidal energy, biomass, hydrogen energy systems, small hydro-power, etc. under small-scale generation [5]. DGs may be categorised into four types. Distributed generators having unity power factor and injecting only active power to the power system (like PV cell and fuel cell) fall into category of Type-1 DG. Zero power factor DGs (like KVAr compensator, synchronous condensers and capacitors) inject only reactive power to the power system and fall in Type-2 category of DGs. Distributed generators with leading power factor such as diesel genset that injects both active and reactive power to the power system network fall into the category of Type-3 DG. Type-4

DG injects active power to the power system and absorbs reactive power. Such type of DGs operate at lagging power factor. Wind turbines/wind energy generators or induction generators operating at fixed speed fall under the category of Type-4 DG. However, Doubly Fed Induction Generator (DFIG) can either absorb or deliver reactive power to the grid. Wind turbine driven DFIG operating at leading power factor and injecting reactive power to the grid can be considered as Type-3 DG instead of Type-4. Fig. 1.1 illustrates major existing DG technologies with their generation capacities, benefits, and shortcomings.

The type of DG is an essential selection criterion if one wants optimal performance. Further, the real and reactive power penetrated from such sources is exclusively dependent upon the load requirements. There are several benefits of optimally placed DGs like load power factor improvement, voltage profile enhancement, grid strengthening, postponing or disregarding system upgrades, reduction in power losses and on-peak operating costs, harmonic mitigation, elimination of voltage sags/swells, improving system integrity, enhancement of loadability, voltage stability and security, reliability, power quality, efficiency, and a cut in Aggregate Technical & Commercial (AT&C) losses [6–8]. Furthermore, DG units can cater to the increased load demand over time regardless of necessarily expanding the distribution network.

However, the above-mentioned benefits of the DGs are exploited only when they are properly sited and sized in a network. A misplaced and missized DG may convert the above-mentioned merits into adverse impacts. Also, improper placement of DG can increase active power loss and an oversized DG can cause excess bidirectional power flow thereby hampering the control and protection operations. To add further, islanding of micro-grid may cause unacceptable frequency deviations from its nominal value.

1.3 Literature Review

A significant number of approaches have been suggested in the literature for optimal integration of DGs to enhance distribution network performance such as power loss reduction and voltage profile as well as voltage stability enhancement. Power loss reduction

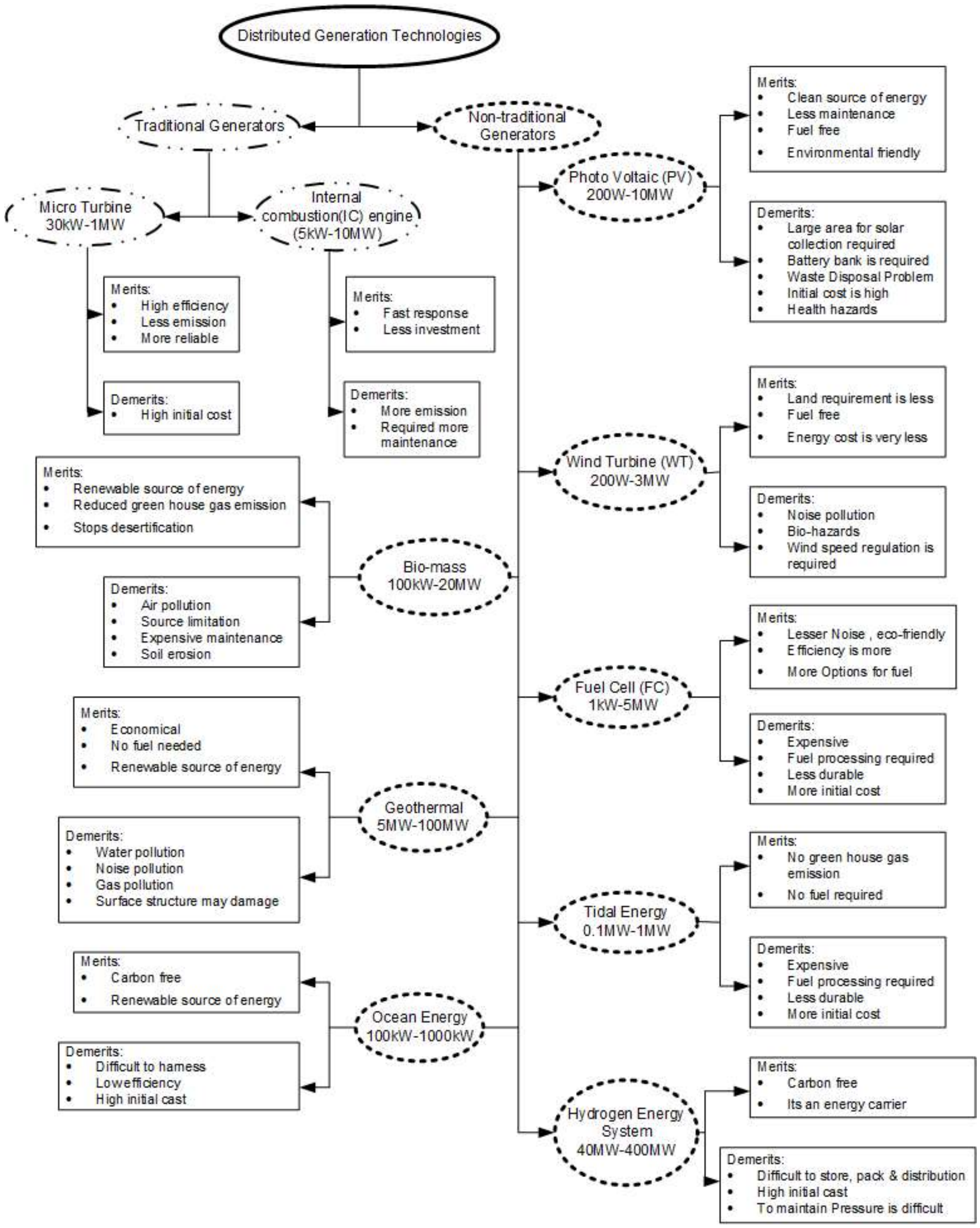

Fig. 1.1 DG Technologies

and voltage profile as well as voltage stability enhancement through reconfiguration of the network is also suggested by various researchers. Some of the analytical and numerical methods of DGs placement suggested in the literature are presented below in Subsections

1.3.1 and 1.3.2, respectively. The heuristic and metaheuristic methods have been used to be very efficient in solving many practical optimization problems. A brief survey report on the optimal placement of DGs and network reconfiguration for loss minimization and voltage profile as well as voltage stability enhancement through heuristic and metaheuristic approaches are presented in subsection 1.3.3.

1.3.1 Analytical Methods of DGs Placement

Active power support by integration of DGs or FACTS devices, reactive power support by integration of static condenser or FACTS devices, and an anti-Z element-based analytical approach proposed in [9] to improve the voltage at receiving end and reduce the line loss in the Radial Distribution System (RDS). Active and reactive power-support-reduces current in the line as a result of voltage profile improvement resulting in loss minimization. A derivative-based analytical approach has been proposed in [10]. The proposed analytical approach is used to determine the optimal size of DG. The size of Type-1 DG at each node has been computed by the derivative of power loss with respect to real power injection at each bus. Similarly, the size of Type-2 DG may be computed by the derivative of power loss with respect to reactive power injection at each bus. The optimal location of each type of DG has been computed through Particle Swarm Optimization (PSO) in [10]. In [10], firstly optimal location of DG is computed through PSO and then the optimal size is computed by the proposed analytical approach. Optimal single DG integration in RDS has been proposed in [11] using an analytical method based on the exact active power loss formula. Bus impedance matrix calculation is required for finding an efficient solution to optimal DG integration problem in large RDS. An improvement in the analytical expression previously presented in [11] has been done by the authors in [12]. The investigation over optimal placement and sizing of three other types of DGs (i.e. DG injecting reactive power, DG injecting active and reactive power, and DG injecting active power and consuming reactive power) apart from Type-1 DG has been proposed in [12]. Further, the authors in [13] improved the analytical method proposed in [12]. the study discussed the importance of DG operation in terms of active and reactive power dispatch and evaluated the optimal

DG power factor for minimizing power losses. A multiobjective index-based analytical method has been proposed in [14] to determine the optimal size of the unity power factor DG unit. With the consideration of uncertainties of demand and DG output, optimal planning of dispatchable and non-dispatchable DG units has been proposed in [15].

1.3.2 Numerical Methods of DGs Placement

Various numerical methods have been used in the literature to solve optimal DG integration problem. A few methods are given below:

Gradient search method

The gradient search method is a linear approximation-based general optimization method to minimize or maximize the objective function by iteratively updating the optimization parameters. With and without fault constraints based solution of optimal DG integration problem using gradient search method has been proposed in [16] and [17], respectively.

Linear programming

Linear programming is an optimization method to solve the objective function with constraints when both are correlated with the decision variable linearly. In literature [18] and [19], the authors model the optimal DG integration problem for computing maximum DG penetration and maximum DG power harnessing, respectively.

Sequential quadratic programming

Sequential Quadratic Programming (SQP) is one of the best programming iterative methods for solving the non-linear optimization problem. Non-linear optimization problems for which the objective functions and constraints are continuously differentiable are solved by SQP. Optimal planing of constant power DG sources has been proposed in [20] using the SQP approach for improving the voltage profile and energy efficiency of the DC grid.

Authors in [17] and, [21] solved the optimal DG integration problem with and without fault constraints using SQP.

Nonlinear programming

In [22], authors proposed a reduced probabilistic generation-load model for the optimal placement of various types of DGs using Mixed Integer Non-Linear Programming (MINLP). Also, the electricity market price fluctuation-based optimal DG integration problem has been solved in [23] for various types of DGs using MINLP. Alternatively, the optimal DG planning problem has been solved in [24] by MINLP in an integrated distribution network. Voltage stability margin improvement in RDS by optimal placement and sizing of DGs using MINLP has been proposed in [25].

Dynamic programming

Dynamic programming is a sequentially solving technique. It is used to solve problems that have several sub-problems. Profit maximization of the distribution network owner by the optimal deployment of DGs at the light, medium, and peak load conditions has been proposed in [26] and solved by the dynamic programming approach.

Exhaustive Search

Exhaustive search is also known as Brute-force search in computer science engineering. It thoroughly and completely searches for the optimal solution to optimization problems. Reliability maximization and loss minimization by optimal location search of DG (at fixed size) using an exhaustive search approach proposed in [27]. In [28], a multiobjective optimal DG integration problem has been solved for the time varying behavior of the demand side and generation side.

1.3.3 Heuristic/Metaheuristic Optimization Methods for DG Placement and Network Reconfiguration

There are several heuristic/metaheuristic and hybrid optimization techniques found in the literature to solve the optimal DG integration problem.

- ➢ *Particle Swarm Optimization (PSO)*

  Optimal planning of multiple DGs in 13-bus RDS for the objective to improve voltage deviation, minimizing Power loss and total harmonic distortion, has been suggested in [29] with the help of PSO. A method based on PSO for optimal planning of individual unity and non-unity type DGs to minimize loss is suggested in [30]. A hybrid Genetic Algorithm (GA)-adaptive PSO is proposed in [31] for optimal planning of a only single type of DG. Genetic Algorithm-Particle Swarm Optimization (GA-PSO) is used to optimize the size of DG and also to determine the site of the same by taking active, reactive power loss & voltage deviation as a weighted fitness function in [32], and the results were compared with GA and PSO with DG and without DG. The authors in [33] proposed Mixed Particle Swarm Optimization (MPSO) for real power loss minimization and voltage profile enhancement in the distribution network. The proposed technique is made up of mixing Binary PSO (BPSO) and conventional PSO. The BPSO was used for optimal distribution network reconfiguration, whereas, conventional PSO was considered to optimally integrate the DG in the distribution network. The proposed approach was tested on IEEE 33-bus and 69-bus RDS. Two well-established meta-heuristic algorithms, PSO, and Elephant Heard Algorithm are amalgamated in [34] to solve the optimal DG integration problem in RDS. The voltage profile of 33-bus IEEE network has been improved by the authors in [35]. The Multi-Objective Particle Swarm Optimization (MPSO) approach is utilized to optimally integrate the DGs before and after the reconfiguration of the radial distribution network. In [36], voltage stability is enhanced and network power loss is reduced by optimally reconfiguring IEEE 33-bus and 69-bus test systems using heuristic approaches. The heuristic approaches like integrated PSO, Teaching Learning Based Optimization (TLBO), and Jaya optimization are utilized for the first time to solve simultaneous optimal reconfiguration and optimal DG integration problem. The reconfiguration framework has been presented in [37] by considering uncertainties over DG power generation and load demand. Also, the proposed framework reduces power loss and improves voltage stability of the test system. The modified PSO has been utilized to solve the problem on IEEE 33-bus, 69-bus, and 109-bus systems using the proposed framework. In [38], a hybrid of binary PSO and Shuffled Frog Leap (SFL) algorithm is suggested for optimal planning of individual single-type and multiple single-type DGs. Minimization of loss improves voltage at each bus in 33-bus and 68-bus IEEE networks. Also, the result section presented various cases like single DG alone, single DG with network reconfiguration, and Multiple DG of the same type with network reconfiguration. An improved parameter PSO and Sequential Quadratic Programming (SQP) has been proposed in [39] for optimal planning of individual and multiple Type-1 DGs to minimize active power loss. The results are tested over 33-bus & 69-bus IEEE networks.

➢ *Gravitational Search Algorithm (GSA)*

In [40], optimal DG Allocation and network reconfiguration problem for time-varying load has been discussed. The optimal DG allocation problem has been solved by GSA. Authors in [41] propose a methodology for the optimal operation of the smart distribution system considering optimal DG integration, optimal capacitor placement for reactive power compensation, and optimal network reconfiguration. The system power loss has been minimized using GSA. In [42], an optimized model of the distribution system in integration with an energy storage device is proposed. An Improved GSA (IGSA) has been used to solve the proposed model. Also, IGSA in iteration with Dual-Stage Optimization (DSO) was used further to speed the inertia coefficient that ensures global and local searchability.

➢ *Grey Wolf Optimization (GWO)*

Grey Wolf Optimization (GWO) is a competent optimization approach. It is used in [43] for optimal integration of multiple DGs with appropriate sizes and sites in RDS. A modified GWO approach has been utilized in [44] for optimal reconfiguration of the distribution network for maximizing loss reduction in RDS.

➢ *Genetic Algorithm (GA)*

In [45], the authors proposed a cycle-break algorithm in combination with GA for optimal distribution network configuration to minimize system power loss. In [46], authors developed a GA-based optimization model. This model is utilised to minimize the total cost of power production by optimal DG allocation in coordination with network reconfiguration of RDS. A multi-objective optimization-based approach has been proposed in [40] for optimal DG integration and optimal network reconfiguration in RDS to minimize power loss and maximize annual saving. Optimal network reconfiguration has been done using GA. Optimal DG location and size have been determined using GSA and GA, respectively.

➢ *Taboo Search Algorithm (TSA)*

In [47], TSA has been used to solve optimal site and size of multiple DGs and results show its superiority in respect of processing time. In addition, the results are compared with GA. The study in [48] proposes a simultaneous solution for optimal DG integration and network reconfiguration problem with the help of TSA. Further, the results are validated with PSO. Energy saving maximization of balanced and unbalanced distribution system through optimal network reconfiguration and capacitor bank placement is estimated in [49] by using a new Modified Tabu Search and Harper Sphere Search Algorithm (MTS-HSSA).

➢ *Ant Colony Optimization (ACO)*

In [50], Ant Colony Optimizer (ACO) determines the optimal site and size of DGs for the minimum investment cost of DG and operation cost of the system. An optimal recloser and DG placement scheme have been solved in [51] using ACO for enhancing system reliability. A composite reliability index is used to access the reliability of the system using ACO. Authors in [52] present an efficient method for the reconfiguration of radial distribution systems for the minimization of real power loss using adapted ACO.

- *Simulated Annealing (SA)*

  Higher quality solutions obtained from multi-objective function as compared to single objective for optimal siting and sizing of DG with the help of Simulated Annealing (SA) are shown in [53]. Impact of DG on distribution network reconfiguration is analyzed by authors in [54] in both normal operation and post-fault scenarios at different load levels. A Simulated Annealing (SA) method is used for optimization purpose. An enhanced SA method is proposed in [55] for power loss minimization and voltage profile enhancement by distribution network reconfiguration.

- *Water Cycle Algorithm (WCA)*

  In [56], a novel optimization algorithm (i.e., Water Cycle Algorithm (WCA)) for determining the optimal configuration of DGs over multi-objective function is proposed. Water Cycle Algorithm (WCA) gives more flexibility in terms of the power factor (pf) of DGs which shows its advantage over DGs with fixed pf. Distribution network planning is enhanced in [57] by optimal DG integration as well as distribution network reconfiguration for minimum system power loss using WCA. Also, the power factor of DG is optimized for the same objective. In [58], enhanced WCA is presented to optimize simultaneous DG integration and distribution network reconfiguration problem for minimum system power loss and maximum Voltage Stability Index (VSI).

- *Harmony Search Algorithm (HSA)*

  A metaheuristic Harmony Search Algorithm (HSA) is used in [59] to simultaneously reconfigure and identify the optimal locations for the installation of DG units in a distribution network to minimize the system power loss and improve the voltage profile. An improved HSA has been proposed in [60] for optimal planning of individual diesel, wind, and Photo-Voltaic (PV) type DGs for loss and voltage digressions. The optimal planning attributes were optimized on IEEE 33-bus, 69-bus, and 85-bus RDS. The proposed method was validated on IEEE 16-bus, 33-bus, and 69-bus RDS. In [61], an improved HSA and a new simple and effective system impedance matrix-based process to detect islanding of nodes as a strategy to meet radiality constraint to solve the distribution network reconfiguration problem is proposed.

➢ *Grasshopper Optimization Algorithm (GOA)*

Optimal network reconfiguration of RDS for power loss minimization is proposed in [62] using GOA. A two-stage Grasshopper Optimization Algorithm (GOA) based fuzzy multiobjective approach is proposed in [63] for optimum sizing and placement of DGs, shunt capacitors, and EV charging stations for improving the substation power factor, real power loss reduction, and voltage profile improvement of the distribution system. A new GOA is used in [64] to determine the optimal allocation of DGs and battery swapping stations for power loss minimization and voltage stability improvement in the distribution network. A hybrid of Cuckoo Search (CS) with Grasshopper Optimization Algorithm (GOA) has been proposed in [65] for optimal planning of single-type DG. The approach was executed on IEEE 33-bus and 69-bus RDS.

➢ *Harris Hawks Optimization (HHO)*

Microgrid structure consisting of renewable energy-powered DGs (Photo-Voltaic (PV), Wind Turbine (WT), Battery Energy Storage System (BESS)), and diesel generator set (gen-set) is proposed in [66]. Optimal sizing of the ac microgrid components is done by HHO for cost minimization and reliability maximization. After the sizing problem is solved using the HHO algorithm, the results are used in the design of the proposed microgrid. Optimal siting and sizing of PV and WT using HHO are proposed in [67] for active power loss minimization and voltage profile and voltage stability index enhancement in RDS. Harris Hawks Optimization (HHO) in integration with Sequential Quadratic Programming (SQP) algorithm is used in [68] for optimal coordination of directional overcurrent relays incorporating distributed generations. Single and multi-objective based improved Harris Hawks Optimization (HHO) algorithm has been presented in [69] for optimal integration of unity pf, 0.95 lead pf, and optimal pf DGs in 33-bus & 69-bus IEEE networks. Network reconfiguration problem to find optimal network topology using an improved Harris Hawks Optimization (HHO) algorithm has been presented in [70]. The proposed approach is applied to modern distribution networks to find the optimal network topology for which the overall system power loss is minimum and the voltage profile is improved. The methodology is validated on IEEE 33-bus and 69-bus distribution networks.

➢ *Moth Search Optimization (MSO)*

Authors in [71] have developed a novel Moth Search Optimization (MSO) algorithm to solve the complex DG integration problem in IEEE 33-bus and 118-bus RDS.

➢ *Coyote Optimization Algorithm (COA)*

In [72], COA, a two-stage optimization approach has been employed for optimal zero power factor DG integration in the 123-bus IEEE network. Voltage regulator tap and power loss minimization has been taken as the objective function. Results have been compared with that of classical mixed-integer nonlinear programming, GA, PSO, and GWO. The authors in [73] proposed a novel enhanced COA and applied the proposed approach to select the optimal location and size of the DGs in RDS. Optimal integration of DGs simultaneously reduces power loss, and operating cost as well as enhances the voltage stability of the network. An improved COA is utilized by the authors in [74] for optimal placement of DGs along with fault current limiters in different phases.

➢ *Cuckoo Search Algorithm (CSA)*

Power loss minimization and voltage stability improvement objective based on optimal allocation and sizing of DGs using CSA is presented in [75]. Authors in [65] came up with a new hybrid of the Cuckoo Search Algorithm (CSA) & Grasshopper Optimization Algorithm (GOA) for optimal planning of Type-1 DG. The objective function adopted is the weighted sum of the loss, voltage deviation, and cost of DG power generated. In [76], authors proposed a bio-inspired novel methodology CSA for simultaneous integration of DG and DSTATCOM in RDS. Voltage stability index and loss sensitivity factor-based approach has been used for finding the optimal location of DGs and DSTATCOM, respectively.

➢ *Practical Heuristic Algorithms*

Authors in [77] integrated three unity power factor DGs optimally for loss minimization. In [78], an optimization model based on Affine Arithmetic (AA) for individual DG (i.e. wind, PV, and microgrid turbine) planning is developed. Various other types of DGs and their combinations may be the scope left in the paper. In [79], a novel metaheuristic approach for optimal integration of capacitor bank, single and multiple DGs in IEEE 33-bus, 69-bus & 119-bus RDS is suggested. The capacitor and DG may be combined together to see the effect in the network. Chaos map theory in integration with Sine Cosine Algorithm (SCA) based optimization has been introduced in [69]. Further, enhanced power system reliability, reduced power loss, and improved voltage profile have been achieved through optimal location-allocation of individual and multiple single types of DGs in IEEE 33-bus and 69-bus RDS.

In [80], authors proposed a Mixed Integer Conic Programming (MICP) model to find the optimal type, size, and site of DG to minimize investment cost, production cost, CO_2 emission, and load shedding for various cases such as considering only gas turbine generation, wind turbine and Energy Storage Device (ESD), PV generation, intermittent of DG and ESD and considering all alternatives. A hybrid of empirical discrete metaheuristic & steepest descent method is proposed in [81] to solve the problem of optimal DG location-allocation by minimizing power loss. Qualitative and quantitative analysis in terms of efficiency, convergence & robustness has been carried out on a 34-bus IEEE network. Optimal planning of only Type-1 DG has been presented in the paper. The novel quasi-op-positional chaotic symbiotic organisms search algorithm has been proposed in [82]. The aim is to minimize system power loss and place the multiple Type-1 and Type-2 DGs with appropriate sizes at an optimal location in 33-bus & 69-bus IEEE networks. Every optimization algorithm may not be suitable for finding the optimal solution for each type of DG. Uniform Voltage Distribution Algorithm (UVDA) proposed in [83] is not suitable for optimal siting and sizing of Type-2 DG. An improved eco system-based optimization approach is implemented by the authors in [84] for optimal integration of unity pf, fixed pf & optimal pf DGs in 33-bus & 69-bus IEEE networks.

The authors in [85] propose an optimization approach for optimal network reconfiguration and optimal DG placement with the objective of loss reduction and voltage stability improvement. The proposed approach improves the objectives considered and is tested over 33-bus IEEE network for Constant Power (CP) load. Authors in [86] show the improvement in the Voltage Stability Index (VSI) and loss minimization after optimal reconfiguration of the 33-bus and 69-bus IEEE network at fixed load conditions. Optimal DG integration and network reconfiguration problems for loadability enhancement and loss minimization have been solved in [87] using an improved optimization approach. Considering voltage-dependent Constant Power (CP) load, Residential Load (RL), Commercial Load (CL), and Industrial Load (IL), the approach has been tested on 33-bus and 69-bus IEEE networks. A knee-point driven method-based distribution system reconfiguration problem formulation is posed in [88]. The margin towards voltage stability has been enhanced and overall system power loss has been reduced by utilizing the said approach. The feasibility and effectiveness of the proposed method have been tested on 33-bus, 69-bus, and 119-bus IEEE networks. System loss and voltage divergence are minimized in [89] by the authors using the Slap Swarm Algorithm (SSA). The problem is solved over 33-bus and 69-bus IEEE test beds by the proposed algorithm. In [90], the optimal reconfiguration problem has been solved in the integration of DG to enhance the voltage stability and reliability of the IEEE 33-bus test system. Results are also compared with the base case test system. Voltage stability of buses that are near voltage collapse has been improved in [91] using the Feasibility Preserving Evolutionary Optimization (FPEO) approach. The results are verified on 33-bus, 69-bus, and 119-bus IEEE networks, and the statistical analysis shows the excellent persistence of the results. The authors in the paper [92] solve simultaneously network reconfiguration and optimal DG integration problem by the newly proposed sine-cosine method in combination with levy flight to optimize the objective function comprising of power loss and Voltage Stability Index (VSI) over 33-bus and 69-bus IEEE networks. Optimal reconfiguration of IEEE 33-bus, 69-bus, and 118-bus test systems along with DG and distributed STATCOM to solve a multi-objective function made up of loss and VSI using the modified flower pollination algorithm has been proposed in [93]. A constraint-based graphical approach has been presented in [94] for network reconfiguration to enhance the loadability of the 33-bus and 69-bus IEEE test systems. DG integrated optimal reconfiguration of 33-bus, 69-bus, 84-bus, 119-bus, and 136-bus test systems to minimize loss and improve the voltage profile of the system has been suggested in [95]. The Stochastic Fractal Search Algorithm (SFSA) has been used to solve the problem.

1.4 Motivation

The radial distribution system has a large R/X ratio that results in high power loss. Nowadays, optimally placed Distributed Generators (DGs) are utilized to generate power in a decentralized manner to compensate for the power loss in the distribution system. Several methods have been reported in the literature on the optimal placement of distributed generators for loss minimization. These methodologies may broadly be classified as analytical approaches and metaheuristic approaches. Analytical approaches are found most accurate in solving optimal DG integration problem but the major drawback is that these are not suitable for large power system networks. The drawback of the analytical approaches has been overcome by classical non-linear optimization algorithms. But such optimization algorithms generally get stuck at local minima and fail to find the optimal solution. Metaheuristic optimization techniques have been employed by several researchers for a variety of optimization problems. The convergence and efficacy of the meta-heuristic approaches can further be improved by hybridizing two optimization techniques. This motivated me to propose a few new metaheuristic approaches for the optimal placement of DGs and distribution network reconfiguration.

Table 1.2 presents the application of different types of DGs considered by researchers in enhancing distribution network performance through heuristic/metaheuristic approaches. It is observed from Table 1.2 that research has mainly concentrated on the application of either single-type of DGs or a few combinations. This motivated me to consider all possible combinations of different types of DGs in examining their impact on distribution network performance enhancement as shown in Table 1.2.

Table 1.2 Application of DG types and their considerations in enhancing distribution network performance represented in literature and work proposed in this thesis

Literature	**DG Type**						
	I	II	III	I & II	II & III	III & I	I, II & III
[31, 38, 65, 69, 71, 96]	√	×	×	×	×	×	×
[60]	√	×	√	×	×	√	×
[30, 65, 78]	√	×	√	×	×	×	×
[79]	√	√	×	×	×	×	×
Proposed Work	√	√	√	√	√	√	√

Apart from DG placement, distribution network performance may also be enhanced through its reconfiguration. The power loss and system voltages may not be accurately assessed if loads are not modeled properly. This needs to consider voltage dependency and variations with respect to the time of loads present in the system. Very limited efforts seem to be made in literature in considering network reconfiguration under voltage-dependent and time-varying loads. This motivated me to investigate the impact of voltage-dependent and time-varying loads in loss minimization and voltage profile as well as voltage stability enhancement through network reconfiguration.

1.5 Research objectives

In view of the above motivation, the following research objectives have been formulated:

- To consider the optimal placement of DGs through Particle Swarm Optimization-Grey Wolf optimization (PSO-GWO) approach for power loss minimization, reducing voltage deviations at buses from reference value and voltage stability enhancement.
- To consider optimal integration of different types of DGs along with their all possible combinations in distribution networks through hybrid Particle Swarm Optimization-Gravitational Search Algorithm (PSO-GSA) for loss minimization.
- To propose a novel improved Coral-Reef Optimization (CRO) for optimal integration of Type-1, Type-2 and Type-3 DGs for loss minimization.
- To investigate the role of voltage-dependent loads in assessment of the real and reactive power losses, voltage profile and voltage stability of distribution networks, and loss reduction together with voltage profile and voltage stability enhancement of distribution network through their reconfiguration by hybrid metaheuristic approach.

1.6 Thesis outline

The thesis has been organised into the following six chapters.

- Chapter-1 presents a brief literature survey carried out on work related to this thesis, and sets motivations behind the work carried out in this thesis along with the research objectives framed.
- Chapter-2 proposed the optimal placement of the multiple numbers of Type-1 DGs, in distribution networks through a hybrid PSO-GWO algorithm for loss minimization, voltage profile improvement and voltage stability enhancement.

- In Chapter-3, a hybrid PSO-GSA algorithm is suggested for the optimal placement of classified distributed generations for loss minimization in distribution networks.
- Chapter-4 proposes a novel PSO-CRO algorithm for the optimal placement of Type-1, Type-2, and Type-3 DGs in the distribution network for loss minimization.
- Chapter-5 suggests network reconfiguration under voltage-dependent loads through the PSO-CRO algorithm for loss minimization and voltage profile as well as voltage stability enhancement.
- Chapter-6 concludes the thesis by highlighting the main contributions and sets future research directions related to the work carried out in this thesis.

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