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Review

Optimal Multi-Objective Placement and Sizing of Distributed Generation in Distribution System: A Comprehensive Review

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Abstract: For over a decade, distributed generations (DGs) have sufficiently convinced the researchers that they are the economic and environment-friendly solution that can be integrated with the centralized generations. The optimal planning of distributed generations requires the appropriate location and sizing and their corresponding control with various power network types to obtain the best of the technical, economical, commercial, and regulatory objectives. Most of these objectives are conflicting in nature and require multi-objective solutions. Therefore, this paper brings a comprehensive literature review and a critical analysis of the state of the art of the optimal multi-objective planning of DG installation in the power network with different objective functions and their constraints. The paper considers the adoption of optimization techniques for distributed generation planning in radial distribution systems from different power system performance viewpoints; it considers the use of different DG types, distribution models, DG variables, and mathematical formulations; and it considers the participation of different countries in the stated DG placement and sizing problem. Moreover, the summary of the literature review and critical analysis of this article helps the researchers and engineers to explore the research gap and to find the future recommendations for the robust optimal planning of the DGs working with various objectives and algorithms. The paper considers the adoption of uncertainties on the load and generation side, the introduction of DGs with energy storage backups, and the testing of DG placement and sizing on large and complex distribution networks.

Keywords: distributed generation; electrical power network; artificial intelligence; grid network; grid-tied generation; distribution system

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Citation: Kumar, M.; Soomro, A.M.; Uddin, W.; Kumar, L. Optimal Multi-Objective Placement and Sizing of Distributed Generation in Distribution System: A Comprehensive Review. *Energies* **2022**, *15*, 7850. https://doi.org/10.3390/en15217850

Academic Editor: Junfeng Liu

Received: 26 September 2022
Accepted: 20 October 2022
Published: 23 October 2022

1. Introduction

The electricity market competitiveness and increased load demand are the core challenges for distribution companies. In addition, enhancing the transmission and distribution system capacity may not be an economical solution. These challenges have motivated distribution companies to cope with power demand with the proper planning and designing of the network [1,2]. Distributed generation offers the solution to the problem of meeting this demand and is also a feasible and attractive choice even for densely populated and far-flung rural areas. DGs can be connected locally for an isolated consumer or by integration with the distribution network. DG provides benefits for the consumers and utilities where central generation is impossible, and there are deficiencies in the transmission network. Various research has confirmed that the DG penetration of 10–15% of the maximum load can be installed easily in the existing system without major structural changes [3]. It also offers benefits over the traditional sources of electric power for domestic, commercial, and industrial consumers that utilities explore for the best choice by which to meet the electric power supply challenges [4,5]. Moreover, DG investments can potentially establish a competitive market.

Distributed generation is referred to as on-site generation, embedded generation, dispersed generation, and decentralized generation. It is generally defined as the electric power source (renewable and non-renewable) connected to either the distribution network or the consumer site. This technology offers various benefits to electric utility companies with regard to the economical, technical, and environmental factors. However, traditionally, the distribution systems have been designed to operate with a unidirectional power flow [6–8], whereas integrating DG allows a bidirectional power flow with various challenging operating conditions, such as increased terminal voltage level, fault current, harmonic distortion and stability, and reverse power flow [9,10]. Therefore, the planning of DG installation for delivering real and reactive power to the system is still an open-ended challenge for the research community. The DG planning requires appropriate location, sizing, and the corresponding control with various types in the power networks. Choosing a proper strategy for DG prompted the urge to seek for mathematical optimization techniques that can assist in the decision-making process of designing and planning [11,12].

Despite the many advantages offered by DGs, the random placement and sizing of DGs cause many operational complexities in the distribution system. The distribution system was designed to carry a unidirectional current [13], whereas the installation of DG creates a bidirectional power flow. This leads to technical problems, such as variations in power losses, issues of voltage fluctuations (in both sending and receiving power), and disturbances in power stability and reliability. The bidirectional power flow may also overstep the protection measures, and the introduction of power invertor-based DGs produces more harmonics and transients in the system. Furthermore, renewable generation, such as wind turbines and solar PVs, depends on their inputs. They are stochastic in nature and depend on wind velocity and solar irradiance; it is expected this may overrule the reliability and stability of the system. It must be noted that the installation of DG in distribution systems is not a simple plug-and-play move. It requires a robust model which helps the distribution network operator to decide the location of installation, the type, and size of the DGs. Therefore, interest has developed in employing optimization methods that are applied to minimize the challenges and maximize the benefits while dealing with multiple contradictory objectives.

During the last decade, many countries around the world have focused on the challenges of integrating DG in low-voltage networks. This could have changed the operational and control behavior of the power system. Various research reviews have been carried out and published on the optimal configuration of distributed generation. For instance, G. Pepermans et al. [14] have discussed the challenges and benefits of DGs. Tan et al. [15] carried out a review of the multi-objective planning of DG resources along with the advanced renewable energy technologies. The planning of DG technologies, objectives, and techniques with a grid connection has been studied by Paliwal et al. [16]. The techno-economic system reliability with a low investment in standalone photovoltaic/wind hybrid system optimal sizing has been reviewed in [17]. The optimum size of the PV, wind, and battery backup with power losses and energy cost considerations was the challenge. Khatod et al. [18] reviewed the DG placement and sizing problem from the perspective of the methods used for the optimal integration of distributed generation in the radial distribution system. Pesaran et al. [19] conducted a comprehensive study of different objective functions, constraints, and algorithms for optimal DG allocation. Singh et al. [20] studied DG planning performance in terms of real and reactive power loss, stability, load ability and oscillations, power transfer capacity, voltage profile, and short circuit capacity with environmental friendliness.

Despite the various review articles focusing on DG planning in terms of its sizing and placement, the multi-objective optimization techniques, and the technical challenges in both standalone and grid-integrated DG installation, the challenges remain for optimal power system performances and energy savings. It is observed that with regard to the DG placement and sizing in radial distribution networks with multi-objective optimization techniques, a review of the existing body of knowledge is needed. As the research trend for radial networks is in the replication of the real networks, multi-objective optimization problems are the dire requisites for dealing with the various unpredictable factors in DG planning. Hence, a wider review is required to fill this gap in the body of knowledge. Therefore, the objective of this paper is to comprehensively review the optimization approaches utilized for distributed generation planning in radial distribution power networks from different power system performance viewpoints. It covers the technical, commercial, and regulatory objectives, the associated methods, and the system constraints in order to give complete knowledge of the multi-objective optimal placement and sizing of DGs in the existing distribution systems.

This paper reviewed the state-of-the-art, optimal, multi-objective placement and sizing problems of DGs in distribution systems. The key terminologies relevant to optimization have been searched as 'distributed generation', 'optimal placement and sizing of DG', 'optimal capacity and location of DG', 'optimal multi-objective problem in DG', and 'multi-objective placement and sizing of DG in distribution system'. The scope of this paper limits the optimal multi-objective DG placement and sizing problems for the radial distribution network. The keywords for this literature review were searched in well-known search engines, which include IEEE Explore Digital Library, Web of Knowledge, Google Scholar, and MDPI. The timeline for the search was limited to almost ten years, and the journals and conference papers were encapsulated in the review. The comprehensive summaries of the selected articles are presented in Table 1. The literature review evaluates the mathematical model, simulated for techno-economic and environmental objectives, constraints, and validation purposes. The review also demonstrates the models and the research used in the study to integrate intermittent-based generation with its varying load demands. The entire literature review is presented in a chronologically descending order to encapsulate the recent advancements in the cited issue.

Table 1. Summary of literature reviewed for the optimal multi-objective placement and sizing of DG in the distribution system.

Ref.	Year	Country	Journal/ Conference	Problem		DG No.		DG Type	DG Mix/ Distribution Network Mix	Load Type	Objective Function(s)								Other Objective Functions	Distribution System Model	Optimization Algorithms/Methods
				Sizing	Placement	Single	Multiple				Active Power/Energy Losses	Reactive Power/Energy Losses	Voltage Profile/Fluctuation	Voltage Stability	Loadability	Reliability	Cost/Investment	Environment			
[21]	2019	Egypt	IEEE Conference	√	√		√	WT + PV		Constant	√		√	√						IEEE 118	NSGA-III
[22]	2020	India	*Neural Computing and Applications*	√	√		√	WT + PV + Biomass		Constant	√		√				√			IEEE 69	MOMSOS
[23]	2020	Denmark	*Energy*	√	√		√	PV		Linear and Non-Linear	√	√	√							IEEE 33 IEEE 69	GA + PSO
[24]	2020	India	*Int. Transactions on Electrical Energy Systems*	√	√		√	PV + Wind		Constant	√						√			38 bus system	ABC
[25]	2020	Iran	*Electrical Power System Research*	√	√		√	Dispatchable/PV		Constant	√	√								IEEE 33	Analytical method
[26]	2018	Egypt	*IEEE Systems Journal*	√	√		√	PV/Wind/GT		Constant	√	-	√	√	-		√	√		IEEE 33 IEEE 69	Water Cycle Algorithm
[27]	2018	India	*Energies*	√	√		√	DG		Constant	√		√							30 Node 141 Node	GA, PSO, GA-PSO
[28]	2018	Iran	*Int. J. of Elec. Power & Energy Systems*	√	√		√	DG		Linear and Non-Linear	√						√	√	Total Harmonic Distortion	31-Bus	PSO
[29]	2018	Colombia	*Energies*	√	√		√	DG		Constant	√		√							IEEE 33 IEEE 69	PBIL (population-based incremental learning) for location and PSO for sizing
[30]	2018	Saudi Arabia	*Journal of Renewable & Sustainable Energy*	√	√		√	Solar/Wind		Constant	√						√			IEEE 30	MOPSO
[31]	2018	Iran	*Energy*	√	√		√	DE/FC/GT /MT/PV/WT		Constant	√						√	√		IEEE 6 IEEE 69	Improved HSA
[32]	2018	India	*IEEE Transactions on Industrial Informatics*	√	√		√	DG		Constant	√		√	√						IEEE 33 IEEE 118 IEEE 880	Improved EHO (elephant herding optimization)

Table 1. *Cont.*

Ref.	Year	Country	Journal/ Conference	Problem		DG No.		DG Type	DG Mix/ Distribution Network Mix	Load Type	Objective Function(s)								Other Objective Functions	Distribution System Model	Optimization Algorithms/Methods
				Sizing	Placement	Single	Multiple				Active Power/Energy Losses	Reactive Power/Energy Losses	Voltage Profile/Fluctuation	Voltage Stability	Loadability	Reliability	Cost/Investment	Environment			
[33]	2018	Egypt	IEEE Conf.	√	√		√	DG		Constant	√			√						IEEE 33	PSOFA/novel bat algorithm
[34]	2018	India	*Applied Energy*	√	√		√	DG		Constant	√		√	√						IEEE 33 IEEE 69 IEEE 118	Comprehensive TLBO
[35]	2017	Singapore	*Applied soft computing*	√	√		√	DG and Cap		Constant	√	√								IEEE 33 IEEE 69 IEEE 119	MOEA/D
[36]	2017	Egypt	*Renewable Energy*	√	√		√	Solar/Wind		Constant	√		√	√						IEEE 33	LSF + ALOA Ant lion OA
[37]	2017	Egypt	*Energies*	√	√		√	PV/Wind		Constant	√		√				√			Real DS	LSF + PSOGSA and MFO
[38]	2017	India	*Applied soft computing*	√	√		√	DG/Capacitor	Reconfiguration	Constant	√		√						Max. branch current capacity limit index	IEEE 69 IEEE 118	PABC and HSA Particle artificial bee colony and harmony search algorithm.
[39]	2017	India	*Energies*	√	√		√	DG		Voltage dependent load	√	√	√							IEEE 69	MOPSO
[40]	2017	China	ACMME 2017 Conference	√	√		√	Wind/Solar		Constant	√			√						IEEE33	QPSO
[41]	2016	Iran	IEEE	√	√	-	√	DG (P-MW)	-	-	√	-	√	√	-	-	√	-	-	IEEE 33 IEEE 69	PFDE
[42]	2016	USA	PSC Conference	√	√	-	√	Solar PV	-	-	√	-	√	-	-	-	-	-	-	38 -Walterboro USA feeder	-
[43]	2016	India	*Int. Journal of Electrical Power & Energy System*	√	√	-	√	P-kW Q-KVar Both	-	Constant Industrial Residential Commercial Mix	√	-	√	-	-	-	√	-	-	IEEE 33	Shuffled bat algorithm

Table 1. *Cont.*

Ref.	Year	Country	Journal/Conference	Problem: Sizing	Problem: Placement	DG No.: Single	DG No.: Multiple	DG Type	DG Mix/Distribution Network Mix	Load Type	Objective Function(s): Active Power/Energy Losses	Reactive Power/Energy Losses	Voltage Profile/Fluctuation	Voltage Stability	Loadability	Reliability	Cost/Investment	Environment	Other Objective Functions	Distribution System Model	Optimization Algorithms/Methods
[44]	2016	India	*Int. Transactions on Electrical Energy Systems*	√	√	-	√	Wind Solar Fuel Cell Micro Turbine	-	-	√	√	√	-	-	-	-	-	Optimization of line flow capacity	IEEE 38 IEEE 69	Shuffled bat algorithm
[45]	2016	Iran	*IET Generation, Transmission and Distribution*	√	√	-	√	CHP Wind	DG with Energy Storage	-	√	-	√	-	-	√	√	-	-	IEEE 33	GA GAMS
[46]	2016	China	ACPEE Conference	√	√	-	√	PV-Wind (P-kW)	-	-	√	-	√	√	-	-	-	-	-	IEEE 33	NSGA-II
[47]	2016 [1]	India	*Int. Journal of Electrical Power & Energy Systems*	√	√	-	√	Photovoltaic Wind Diesel (P-kW)	DG with Batteries	-	√	-	√	-	-	-	√	-	-	IEEE 69	i-MOPSO
				-	-	-	-				-	-	√	-	-	-	√	√	-		
[48]	2016	Iran	*Int. Journal of Electrical Power & Energy Systems*	√	√	-	-	P-kW Q-KVar Both	-	-	√	-	-	√	-	-	-	-	-	IEEE 34 IEEE 69	Improved ICA
[49]	2016	China	*Sustainability*	-	√	-	√	Small Hydro Power Plant (P-MW)	-	-	√	-	-	-	-	-	-	-	Maximizing clean energy generation ratio	IEEE 33	MODE
[50]	2016	India	*Int. Journal of Electrical Power & Energy Systems*	√	√	-	√	Photovoltaic Wind capacitor (P-kW) (Q-KVar)	-	-	√	-	√	√	-	-	-	√	Optimizing network security	28 Indian RDS	MOPSO
[51]	2016	China	*Int. Journal of Grid and Distributed Computing*	√	√	-	√	Wind-PV	-	-	√	-	√	-	-	-	-	-	-	IEEE 33	PSO HBMA-PSO
[52]	2016	Malaysia	*Energy* The Int. Journal	√	√	-	√	DG (MVA)	-	-	-	√	√	-	-	-	-	-	-	IEEE 69	GWO
[53]	2016	Iran	*Int. Journal of Electrical Power & Energy Systems*	√	√	-	√	PV Fuel cell	-	-	√	√	√	-	-	-	√	-	-	IEEE 33 IEEE 69	BBO

Table 1. *Cont.*

				Problem		DG No.					Objective Function(s)										
Ref.	**Year**	**Country**	**Journal/ Conference**	**Sizing**	**Placement**	**Single**	**Multiple**	**DG Type**	**DG Mix/ Distribution Network Mix**	**Load Type**	**Active Power/Energy Losses**	**Reactive Power/Energy Losses**	**Voltage Profile/Fluctuation**	**Voltage Stability**	**Loadability**	**Reliability**	**Cost/Investment**	**Environment**	**Other Objective Functions**	**Distribution System Model**	**Optimization Algorithms/Methods**
[54]	2016	China	*Int. Journal of Electrical Power & Energy Systems*	√	√	-	√	DG (P-kW)	-	-	-	-	√	-	-	√	√	-		37 bus system	-
[55]	2016	Iran	*Int. Journal for Computation and Mathematics in Electrical and Electronic Engineering*	√	√	-	√	DG & DSTATCOM (P-kW)	-	-	√	-	√	√	-	-	-	-	-	IEEE 33 IEEE 119	Fuzzy-ExIWO
[56]	2015	Iran	*Int. Journal of Electrical Power & Energy Systems*	√	√	-	√	DG (P-kW) Capacitor (Q-KVar)	-	-	√	-	-	√	-	-	-	-	Minimization of section current index	IEEE 33 Portuguese 94 RDS	MOPSO
[57]	2015	India	*Procedia Technology*	√	√	√		DG (P-MW)	-	-	√		√	-	-	-	-	-	-	Civanlar 16 bus and actual 12 bus	Weighted Multi-Objective Index
[58]	2015	India	*Int. Journal of Electrical Power & Energy Systems*	√	√	-	√	DG (P-kW)	-	Industrial Residential Commercial	√	√	√	√	-	-	-	-	Maximizing line flow limit index	IEEE 38 IEEE 69	CABC
[59]	2015	Spain	*Int. Journal of Electrical Power & Energy Systems*	√	√	-	√	DG (P-kW)	-	-	√	-	-	-	-	-	√	-	-	IEEE 69 IEEE 118	MINLP
[60]	2015	China	IEEE	√	√	-	-	DG (P-MW) Wind (P-MW)	-	-	√	-	√	√	-	-	-	-	-	IEEE 33 292 bus 588 bus	Improved NSGA-II
[61]	2015	China	*Int. Journal of Electrical Power & Energy Systems*	√	√	-	√	Photovoltaic Wind (P-kW)	-	-	-	-	√	-	-	-	√	-	Minimizing purchasing cost	Modified PG&E 69,292, 588 and 1180 RDS	Improved NSGA-II
[62]	2015	Iran	*Energy Conversion and Management* An Int. Journal	√	√	-	√	Gas Turbine Fuel Cell Wind Turbine (P-MW)	-	-	√	-	-	√	-	-	√	√	-	IEEE 33 IEEE 69	Hybrid ACO-ABC

Table 1. *Cont.*

Ref.	Year	Country	Journal/Conference	Problem: Sizing	Problem: Placement	DG No.: Single	DG No.: Multiple	DG Type	DG Mix/Distribution Network Mix	Load Type	Objective Function(s): Active Power/Energy Losses	Reactive Power/Energy Losses	Voltage Profile/Fluctuation	Voltage Stability	Loadability	Reliability	Cost/Investment	Environment	Other Objective Functions	Distribution System Model	Optimization Algorithms/Methods
[63]	2015	India	*Renewable Energy* An Int. Journal	√	√	-		Wind Photovoltaic (P-kW)	-	-	√	-	√	-	-	-	-	-	Minimization of network security index	28 Indian RDS	PSO
[64]	2015	Turkey	*Renewable and Sustainable Energy Reviews*	√	√	-	√	Not mentioned (P-kW)	-	-	√	-	√	-	-	-	-	-	Optimize line flows index	IEEE 30 IEEE 34 IEEE 57	Different probability states
[65]	2015	India	SASEC Conference	√	√	-	√	DG (P-kW)	-	-	√	-	√	-	-	-	-	-	-	IEEE 33 IEEE 69	BAT algorithm
[66]	2015	India	IEEE	√	√	-		DG (P-kW)	-	-	√	-	√	-	-	-	-	-	-	IEEE 33 Indian 52 RDS	Adaptive GA
[67]	2015	India	*Int. Journal of Electrical Power & Energy Systems*	√	√	-	√	Solar-PV Biomass Wind (P-kW)	-	-	√	-	√	-	-	-	√		Maximize branch current capacity index and cost factor index	51 RDS	Location- Sensitivity Index Sizing GA
[68]	2015	Egypt	*Int. Journal of Electrical Power & Energy Systems*	√	√	-	√	Photovoltaic (P-kW) Wind (P-kW) Capacitor (Q-KVar) Diesel (PQ-kW-KVar)	-	-	√	-	√	-	-	-	-	-	-	IEEE 33 IEEE 94	Fuzzy expert with BSOA
[69]	2015	Egypt	*Electrical Power Components and Systems*	√	√	-	√	Photovoltaic (P-kW) Wind (P-kW) Capacitor (Q-KVar) Diesel (PQ-kW-KVar)	-	-	√	-	√	√	-	-	-	-	-	IEEE 33 IEEE 94	Fuzzy expert with BSOA
[70]	2015	Libya	*Electrical Power Components and Systems*	√	√	-		-	-	-	√	-	-	-	-	-	√	-	-	IEEE 15	SQP
[71]	2015	China	*Neuro- computing*	√	√	-	√	DG (P-kW)	-	-	√	-	-	-	-	-	√	√	-	IEEE 33	IMPSO-PS

Table 1. *Cont.*

				Problem		DG No.					Objective Function(s)										
Ref.	**Year**	**Country**	**Journal/ Conference**	**Sizing**	**Placement**	**Single**	**Multiple**	**DG Type**	**DG Mix/ Distribution Network Mix**	**Load Type**	**Active Power/Energy Losses**	**Reactive Power/Energy Losses**	**Voltage Profile/Fluctuation**	**Voltage Stability**	**Loadability**	**Reliability**	**Cost/Investment**	**Environment**	**Other Objective Functions**	**Distribution System Model**	**Optimization Algorithms/Methods**
[72]	2015	Egypt	*Electrical Power Components and Systems*	√	√	-	√	-	-	-	√	-	-	-	-	-	-	-	Minimizing total harmonics distortion	IEEE 31	GA
[73]	2015	Iran	*IET Generation, Transmission and Distribution*	√	√	-	√	DG (P-kW)	DG with storage and distribution system as reconfiguration	-	√	-	-	-	-	√	-	-	-	Civanlar test system Baran test system	NSGA-II
[74]	2015	Iran	IEEE	√	√	-	√	PV DSTATCOM	Distribution system as reconfiguration	-	√	-	√	-	-	-	-	-	Optimize feeder load balancing	IEEE 33	Fuzzy-ACO
[75]	2015	China	*Energies*		√	-		Wind Turbine Photovoltaic Micro Turbine	-	-	√	-	-	-	-	-	√	√	-	IEEE 33 PG & E 69	CSO-MCS
[76]	2015	China	*IET Generation, Transmission and Distribution*	√	√	-	√	DG (P-kW) Capacitor (KVar)	-	-	√	-	-	-	-	-	√	-	-	IEEE 33	HPSO
[77]	2015	India	*IET Generation, Transmission and Distribution*	√	√	-	√	DG MVA	-	-	√	√	-	-	-	-	-	-	-	IEEE 33 IEEE 69	Analytical method
[78]	2015	Egypt	*Electrical Power Components and Systems*	√	√	-		DG (P-kW) Q-KVar	-	Industrial Residential Commercial	√	√	√	-	-	-	-	-	Maximize reserve capacity of conductor index	IEEE 69 IEEE 123	Supervised big bang crunch method
[79]	2015	India	ICCPCT Conference	√	√	-	√	DG (P-kW)	-	-	√		√	-	-	-	-	-	-	IEEE 33	SA
[80]	2015	China	IIICICE Conference	√	√	-	√	DG (P-kW)	-	-	√		√	-	-	-	-	-	-	IEEE 33	AMPSO
[81]	2014	Brazil	ICHQP Conference	√	√	-	-	DG P-kW Q-KVar	-	-	√	-	√	-	-	-	-	-	-	IEEE 33	Noval COA

Table 1. *Cont.*

Ref.	Year	Country	Journal/Conference	Problem		DG No.		DG Type	DG Mix/Distribution Network Mix	Load Type	Objective Function(s)								Other Objective Functions	Distribution System Model	Optimization Algorithms/Methods
				Sizing	Placement	Single	Multiple				Active Power/Energy Losses	Reactive Power/Energy Losses	Voltage Profile/Fluctuation	Voltage Stability	Loadability	Reliability	Cost/Investment	Environment			
[82]	2014	Iran	*Renewable Energy*	√	√	-	√	Wind Photovoltaic Fuel Cell Micro Turbine Gas Turbine Diesel Engine (all P-MW)	-	-	-	-	-	-	-	-	√	√	-	9 bus system	AEC method
[83]	2014	Iran	*World Journal of Control Science and Engineering*	√	√	-	√	DG (P-MW)	-	-	√	-	√	-	-	-	-	-	-	IEEE 33	CSA
[84]	2014	India	*Int. Journal of Electrical Power & Energy Systems*	√	√	-	√	DG (P-MW)	-	-	√	-	√	√	-	-	-	-	-	IEEE 33 IEEE 69 IEEE 118	QOTLBO
[85]	2014	Canada	IEEE	√	√	-		Dispatchable DG Wind PV	DG with PEV	Mix load of Industrial, Residential and Commercial	-	-	-	-	-	-	√	√	-	IEEE 38	NDSGA
[86]	2014	India	ICAECT Conference	√	√	-		DG (P-MW) (Q-MVar)	-	-	√	-	√	-	-	-	-	-	-	IEEE 33 IEEE 69	PSO
[87]	2014	Iran	*Int. Journal of Electrical Power & Energy Systems*	√	√	-	√	DG (P-MW) capacitor (PQ-MVar)	-	-	√	-	√	√	-	-	-	-	Minimize index of balancing current of sections	IEEE 33 IEEE 69	ICA-GA
[88]	2014	India	*Swarm and Evolutionary Computation*	√	√	-	√	-	-	Constant P Constant I Constant Z	√	-	-	√	-	-	√		-	IEEE 33 IEEE 69	BFOA
[89]	2014	France	*Renewable and Sustainable Energy Reviews*	√	√	-	√	Renewable DG (wind and PV)	DG with energy storage and PEV	-	-	-	-	-	-	-	√	√	-	IEEE 13	NSGA-II

Table 1. *Cont.*

Ref.	Year	Country	Journal/ Conference	Problem: Sizing	Problem: Placement	DG No.: Single	DG No.: Multiple	DG Type	DG Mix/ Distribution Network Mix	Load Type	Objective Function(s): Active Power/Energy Losses	Reactive Power/Energy Losses	Voltage Profile/Fluctuation	Voltage Stability	Loadability	Reliability	Cost/Investment	Environment	Other Objective Functions	Distribution System Model	Optimization Algorithms/Methods
[90]	2014	China	PES-General Meeting/Conference	√	√	-		Wind PV	-	Industrial Residential Commercial Municipal	-	-	√	√	-	-	√	√	-	Modified PG&E 69 292 test system China	INSGA-II
[91]	2014	India	*Swarm and Evolutionary Computation*	√	√	-	√	DG (P-MW)	-	Constant P Constant I Constant Z	√	-	-	√	-	-	√	-	-	IEEE 33 IEEE 69	BFOA
[92]	2014	China	*IET Generation, Transmission and Distribution*	√	√	-	√	DG (P-kW)	Active Distribution Network	-	√	-	√	-	-	-	-	-	-	IEEE 30 IEEE 57 IEEE 118	GA
[93]	2014	China	IEEE	√	√	-	√	DG (P-MW)	-	-	√	-	√	-	-	-	-	-	Maximizing DG output	IEEE 33 PG&E 69 Actual 292 588 1180	TRSQP
[94]	2014	India	*Int. Journal Of Electrical Power & Energy Systems*	√	√	-		DG	Reconfiguration	-	√	-	-	√	-	-	-	-	-	IEEE 33 IEEE 69	Firework algorithm
[95]	2014	Australia	*Applied Energy*	√	√	-	√	DG (PQ-MVA)	-	Industrial	√	-	-	√	-	-	-	-	-	IEEE 69	Analytical method with multi-objective index
[96]	2014	Iran	*Applied Energy*	√	√	-	√	DG (P-MW)	-	-	√	-	-	√	-	-	-	-	-	IEEE 34	Dynamic search programing
[97]	2014	India	*Journal of Vibration and Control*	√	√	-		DG (P-kW)	-	-	√	-	√	-	-	-	-	√	-	IEEE 30	BFA
[98]	2014	China	*Journal of Zhejiang University– Science C*	√	√	-		DG (P-MW)	-	-	√	-	-	√	-	-	-	-	-	IEEE 33	Enhanced MOPSO
[99]	2014	UK	*Electrical Power Components and Systems*	√	√	-	√	DG P-kW PQ-KVar	-	-	√	-	√	-	-	-	-	-	-	IEEE 69	DPSO

Table 1. *Cont.*

Ref.	Year	Country	Journal/ Conference	Problem: Sizing	Problem: Placement	DG No.: Single	DG No.: Multiple	DG Type	DG Mix/ Distribution Network Mix	Load Type	Objective Function(s): Active Power/Energy Losses	Reactive Power/Energy Losses	Voltage Profile/Fluctuation	Voltage Stability	Loadability	Reliability	Cost/Investment	Environment	Other Objective Functions	Distribution System Model	Optimization Algorithms/Methods
[100]	2014	Malaysia	*Electrical Power Components and Systems*	√	√	-	√	-	-	-	√	√	√	-	-	-	-	-	-	IEEE 6 IEEE 14 IEEE 30	Weighted exhausted search
[101]	2014	Croatia	ENERGYCON Conference	√	√	-	√	DG (P-kW)	-	-	√	-	-	-	-	-	-	-	Maximizing daily financial profit and active energy produced by DG	IEEE 13	ES
[102]	2014	India	CIEC Conference	√	√	-	√	DG (P-kW)	-	-	√	-	√	-	-	-	-	√	-	IEEE 34	ABC
[103]	2014	China	LSMS & ICSE&E Conference	√	√	-	√	Wind solar	-	-	√	-	√	-	-	-	-	√	-	IEEE 33	DE
[104]	2014	India	CIEC Conference	√	√	-	√	Wind Solar Biomass Fuel Cell Diesel Engine	-	-	√	-	-	√	-	-	-	-	-	28 Indian RDS	MOPSO
[105]	2014	Canada	CCECE Conference	√	√	-	√	DG Solar Wind Fuel Cell	-	-	√	√	√	-	-	-	-	-	Maximize MVA capacity index	84 bus system	ShBAT
[106]	2014	China	POWERCON Conference	√	√	-	√	DG (P-MW)	-	-	√	-	√	√	-	-	-	-	-	IEEE 33	PSO
[107]	2013	China	*Journal of Applied Mathematics*	√	√	-	√	Wind Photovoltaic Diesel Engine	-	-	-	-	-	-	-	-	√	√	Minimize customer cost on electricity price	IEEE 33	Improved PEA
[108]	2013	Iran	IEEE	√	√	-	√	DG (P-MW)	-	-	√	-	√	-	-	-	-	-	-	IEEE 33 IEEE 69	Improved MOHS algorithm
[109]	2013	India	*International Journal of Electrical Power & Energy Systems*	√	√	-	x	DG (PQ-KVA)	-	-	√	-	√	-	-	-	-	-	-	IEEE 33 IEEE 69	Modified sensitivity indexes

Table 1. *Cont.*

Ref.	Year	Country	Journal/ Conference	Problem: Sizing	Problem: Placement	DG No.: Single	DG No.: Multiple	DG Type	DG Mix/ Distribution Network Mix	Load Type	Objective Function(s): Active Power/Energy Losses	Reactive Power/Energy Losses	Voltage Profile/Fluctuation	Voltage Stability	Loadability	Reliability	Cost/Investment	Environment	Other Objective Functions	Distribution System Model	Optimization Algorithms/Methods
[110]	2013	China	RAM Conference	√	√	-	√	DG (P-MW)	-	-	√	-	√	√	-	-	-	-	-	IEEE 33	MOSH
[111]	2013	Malaysia	*Przegl. Elektrotech*	√	√	-		DG (P-MW)	-	-	√	-	-	-	-	-	-	-	Minimizing total average voltage thyroid	IEEE 69	GSA
[112]	2013	India	*IET Generation, Transmission and Distribution*	√	√	-	√	DG (P-MW)	-		√	-	√	-	-	-	-	-	Minimizing voltage sag and harmonics	IEEE 33	GA
[113]	2013	Iran	*Turkish journal of Electrical Engineering & Computer Sciences*	√	√	-	√	DG (P-MW)	-	-	√	-	√	-	-		-	-	Minimizing short circuit level	Zanjian's RDS Iran	GA
[114]	2013	Iran	*Applied Energy*	√		-	√	DG (PQ-KVA)	-	-	-	-	-	-	-	√	√	-	-	-	Hybrid PSO with SFLA
[115]	2013	India	*Fuzzy Sets and Systems*	-	-	-	-	-	Sectionalizing switches	Radial Mesh	-	-	-	-	-	√	√	-	-	21 node 54 node 100 node	MOPSO
[116]	2013	Iran	*IET Generation, Transmission and Distribution*	√	√	-	√	DG (P-MW)	-	-	√	-	-	√	-	-	-	-	Minimizing maximum number of DG units	34 bus system	Non-linear programming
[117]	2013	Iran	*Energy*	√	√	-	√	Micro turbine Fuel cell Photovoltaic wind	-	-	√	-	-	-	-	-	√	√	-	IEEE 69	Hybrid SFLA-DE
[118]	2013	Iran	*International Journal of Electrical Power & Energy Systems*		√	-	√	Micro turbine	-	Industrial Residential Commercial	√	-	-	-	-	√	√	-	-	IEEE 37	NSGA-II
[119]	2013	Malaysia	*Energy Conversion and Management*	√	√	-	√	DG (P-MW)	-	-	√	-	-	√	-	-	-	-	-	IEEE 12 IEEE 30 IEEE 33 IEEE 69	PSO

Table 1. *Cont.*

Ref.	Year	Country	Journal/ Conference	Problem: Sizing	Problem: Placement	DG No.: Single	DG No.: Multiple	DG Type	DG Mix/ Distribution Network Mix	Load Type	Objective Function(s): Active Power/Energy Losses	Reactive Power/Energy Losses	Voltage Profile/Fluctuation	Voltage Stability	Loadability	Reliability	Cost/Investment	Environment	Other Objective Functions	Distribution System Model	Optimization Algorithms/Methods
[120]	2013	Iran	*International Journal of Electrical Power & Energy Systems*	√	√	-	√	Solar PV	-	Constant P Constant I Constant Z Industrial Residential Commercial	√	√	-	-	-	√	√	-		IEEE 33	Improved PSO
[121]	2013	Iran	ICEE Conference	√	√	-		DG	-	-	-	-	√	-	-	-	√	√	-	IEEE 33	PSO
[122]	2013	China	APPEEC Conference	√	√	-	√	Wind Solar	-	-	-	-	√	-	-	-	√	√	-	IEEE 33	SVM-MOPSO
[123]	2013	Iran	EEEIC Conference	√	√	-	√	DG (P-MW)	-	-	√	-	√	√	-	√	√	-	-	IEEE 33	MOPSO
[124]	2013	France	ESREL	√	√	-	√	Wind Solar	EV storage	-	-	-	-	-	-	-	√	√	-	IEEE 13	NSGA-II
[125]	2013	Iran	EPDC Conference	√	√	-	√	DG (P-MW)	-	-	√	-	√	-	-	-	-	√	-	13 bus system	NSGA-II
[126]	2013	Malaysia	ICCCE Conference	√	√	-	√	DG (P-MW)	-	-	√	-	-	-	-	-	-	-	Minimizing short circuit current index	IEEE 69	ABC
[127]	2012	China	CTPP Conference	√	√	-	√	DG (P-MW)	-	-	-	-	-		-	-	√	√	-	IEEE 33	MOPSO
[128]	2012	India	ICAEE	√	√	√		DG (P-kW)	-	-	√	-	-	-	-	-	√	-	-	IEEE 38	SFLA
[129]	2012	Iran	ICACEE Conference	√	√	-	√	DG (P-MW)	-	-	√	-	√	√	-	-	-	-	-	IEEE 33 IEEE 69	BFA
[130]	2012	Iran	*Int. Journal of Electrical and Computer Engineering*	√	√	-	√	DG (P-MW) Capacitors (KVar)	-	-	√	-	√	-	-	-	-	-	Increasing available transfer capability	IEEE 41	GA
[131]	2012	Romania	*International Journal of Electrical Power & Energy Systems*	√	√	-	√	Small hydro Plant Photovoltaic Combined heat and power (P-kW)	-	-	√	-	√	-	-	-		-	-	24 node RDS	Exhaustive search optimization algorithm

Table 1. *Cont.*

Ref.	Year	Country	Journal/ Conference	Problem		DG No.		DG Type	DG Mix/ Distribution Network Mix	Load Type	Objective Function(s)								Other Objective Functions	Distribution System Model	Optimization Algorithms/Methods
				Sizing	Placement	Single	Multiple				Active Power/Energy Losses	Reactive Power/Energy Losses	Voltage Profile/Fluctuation	Voltage Stability	Loadability	Reliability	Cost/Investment	Environment			
[132]	2012	Iran	CIRED Workshop	√	√	-	√	Wind Engine Diesel Engine (P-MW)	-	-	√	-	√	-	-	√	√	√	-	-	NSGA-II
[133]	2012	Brazil	*Electrical Power Systems Research An Int. Journal*	√	√	-	√	Synchronous Generator (P-kW)			√	-	-	-	-	-	-	-	Minimizing short circuit current	IEEE 123 IEEE 34	MEPSO
[134]	2012	Iran	ICSG Conference	√	√	√		Biomass Solar Thermal	-	-	√	-	√		-	-	-	-	-	IEEE 33	COA
[135]	2012	China	*Przeglad Elektrotechnizny*	√	√	-	√	Micro Gas Turbine	-	-	√	-	-	-	-	-	√	√	-	IEEE 33	NSGA-II
[136]	2011	India	*Electrical Power Components and Systems*	√	√	√	-	DG	-	Constant Industrial Residential Commercial	√	-	√	-	√	√	√		-	-	-
[137]	2011	Iran	*Int. Transactions on Electrical Energy Systems*	√	√	-	√	PV Wind Micro Turbine Fuel Cell Gas Turbine	-	-	-	-	-	-	-	√	√	-		IEEE 30	MINLP
[138]	2011	Iran	*Applied Energy*	√	√	-	√	PV Wind Fuel cell	-	-	√		√				√	√	-	70 bus system	Improved HBMO
[139]	2011	Iran	*Research Journal of Applied Sciences, Technology and Engineering*	√	√	-	√	DG (P-MW)	-	-	√	-	-	-	-	√	-	-	-	IEEE 12 bus	PSO
[140]	2011	Iran	EPDC Conference	√	√	-	√	DG (P-MW)	-	-	√	-	-	-	-	-	√	-	-	IEEE 27	NSGA-II
[141]	2011	Egypt	*Swarm and Evolutionary Computation*	√	√		√	DG (P-MW)	-	Constant Industrial Residential Commercial	√	√	√	-	-	-	-	-	Optimization of MVA capacity index and short circuit level index	38 bus system IEEE 30	PSO

Table 1. *Cont.*

Ref.	Year	Country	Journal/ Conference	Problem		DG No.		DG Type	DG Mix/ Distribution Network Mix	Load Type	Objective Function(s)								Other Objective Functions	Distribution System Model	Optimization Algorithms/Methods
				Sizing	Placement	Single	Multiple				Active Power/Energy Losses	Reactive Power/Energy Losses	Voltage Profile/Fluctuation	Voltage Stability	Loadability	Reliability	Cost/Investment	Environment			
[142]	2010	Thailand	ECTI-CON Conference	√	√		√	DG (P-MW)	-	-	√	-	-	√	-	-	-	√	-	IEEE 30	SA
[143]	2010	Iran	Recent Research in Environment and Biomedicine	√	√	-	√	DG (P-MW)	-	-	√	-	√	-	-	-	-	-	-	IEEE 33	MOPSO
[144]	2010	India	*IET Generation, Transmission and Distribution*	√	√	-	√	Conventional Distributed Generation	-	-	√	-	-	-	-	-	-	-	Minimizing fuel cost real and reactive nodal price	IEEE 24	MOPSO
[145]	2010	India	*Energy Systems*	√	√	-	√	DG (P-kW)	-	Radial Mesh	–	-	-	-	-	√	-	-	Minimizing installation and operation cost of DG	100 node 21 node	Step-1: First no. of feeder, routes, and sectionalizing of switch conducted, then Step:2 MOPSO method used
[146]	2010	Brazil	*Int. Journal of Electrical Power & Energy Systems*		√	-	-	DG	-	-	√	-	√	-	-	-	-	-	Optimizing current levels	-	DG location by Bellman–Zadeh algorithm and fuzzy logic
[147]	2010	Egypt	PES General Meeting	√	√	-	√	DG (P-kW)	-	-	√	-	√	-	-	-	-	-		68 RDS	SA
[148]	2010	India	CCECE Conference	√	√	-	√	DG (P-MW)	-	-	√	-	√	-	-	-	-	-	Minimizing total harmonic distortion	12 bus system	has
[149]	2010	Iran	PECON Conference	√	√		√	DG (P-MW)	-	-	-	-	√	-	-	-	-	√	Minimizing network upgrading, network purchase, energy losses, and capacity release	IEEE 37	DE

Table 1. *Cont.*

Ref.	Year	Country	Journal/Conference	Problem: Sizing	Problem: Placement	DG No.: Single	DG No.: Multiple	DG Type	DG Mix/Distribution Network Mix	Load Type	Objective Function(s): Active Power/Energy Losses	Reactive Power/Energy Losses	Voltage Profile/Fluctuation	Voltage Stability	Loadability	Reliability	Cost/Investment	Environment	Other Objective Functions	Distribution System Model	Optimization Algorithms/Methods
[150]	2009	China	SUPERGEN' Conference	√	√		√	DG (P-MW)	-	-	√	-	-	-	-	-	-	√	-	IEEE 33	PSO
[151]	2008	Iran	PEMC Conference	√	√	-	-	Micro Turbine Combustion Turbine IC Fuel cell PV	-	-	√	-	√	-	-	-	√	-	-	13 node	NSGA-II
[152]	2008	Italy	PMAPS Conference	√			√	Gas Turbine CHP Wind Turbine	-	Industrial Residential Commercial Tertiary	√	-	-	-	-	-	-	√	-	60 node real RDS	NSGA-II
[153]	2008	Saudi-Arabia	IEEE/PES Conference	√	√		√	DG	-	-	-	-	√	-	-	-	-	√	-	9 bus system	BPSO
[154]	2008	China	IEEE/DRPT Conference	√	√		√	DG	-	-	√	-	-	√	-	√	-	√	-	43 bus system	GA and MO

[1] Int. =International.

2. Literature Analysis

The literature in Table 1 was organized and presented in chronologically descending order. The optimal placement and sizing of the DGs is influenced by many parameters, such as the DG sources, the number of DG units, the optimization algorithm, and the type of load used. The integration of DG changes the operational and control behaviors of the distribution system. Moreover, the objective functions are classified on an operational, commercial, and regulatory basis. The current and future trends of the presented research summary are portrayed in a graphical layout shown in Figure 1i–ix.

2.1. Objective Function

Various objective functions have been considered using multi-objective distributed generation placement and sizing problems. Figure 1i depicts the percentage of objective functions that have been used for the optimal multi-objective DG placement and sizing problems. The active power loss reduction and the energy loss reduction are 32%, the voltage profile is 21%, the cost and investment is 15%, the voltage stability is 9%, the environment is 9%, the reliability is 4%, and the power flow capacity and the reactive power loss are 3%. Moreover, a few authors have also considered the decrease in reactive power losses, harmonic distortion, and short circuit levels as an objective function for their study.

2.2. Optimization Algorithm

To attain the trade-off among the various contradictory objective functions of DG planning, optimization algorithms have been utilized and are depicted in Figure 1ii, with PSO (16.22%) optimization being the most used algorithm, followed by MOPSO (11.49%), NSGA-II (10.14%), and GA (8.78%). It has also been observed that over the last decade meta-heuristic optimization algorithms have become popular for resolving the DG planning challenges.

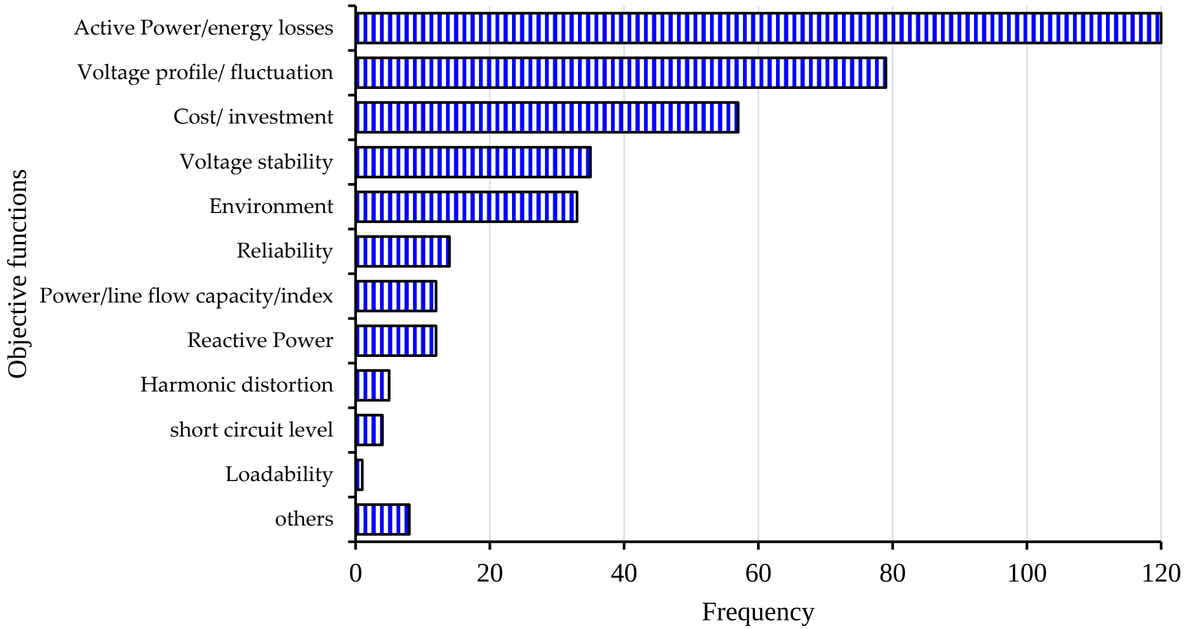
2.3. Distributed Generation (DG) Type

The DG types have been categorized into those of dispatchable and those of non-dispatchable energy sources. The dispatchable DG refers to the output power at the DG end being available whenever it is required by the distribution network operators. Eighty-eight percent of the literature considers dispatchable DGs in the studies, as shown in Figure 1iii, whereas only 12% have studied the non-dispatchable DGs; these studies refer to a particular type and size of DGs to be integrated into the distribution system.

Mostly, the studies refer to DG watts (46%) in their considerations, as shown in Figure 1iv. Multiple dispatchable DGs, which consider PV, wind, CHP, MT, SHP, GT, FC, and capacitors, have been studied in 28% of the literature, whereas real-time multiple DGs have been studied in only 12%. In addition, the trend towards compensating reactive power along with capacitors and D-STATCOM has been considered in 8% and 6%, respectively.

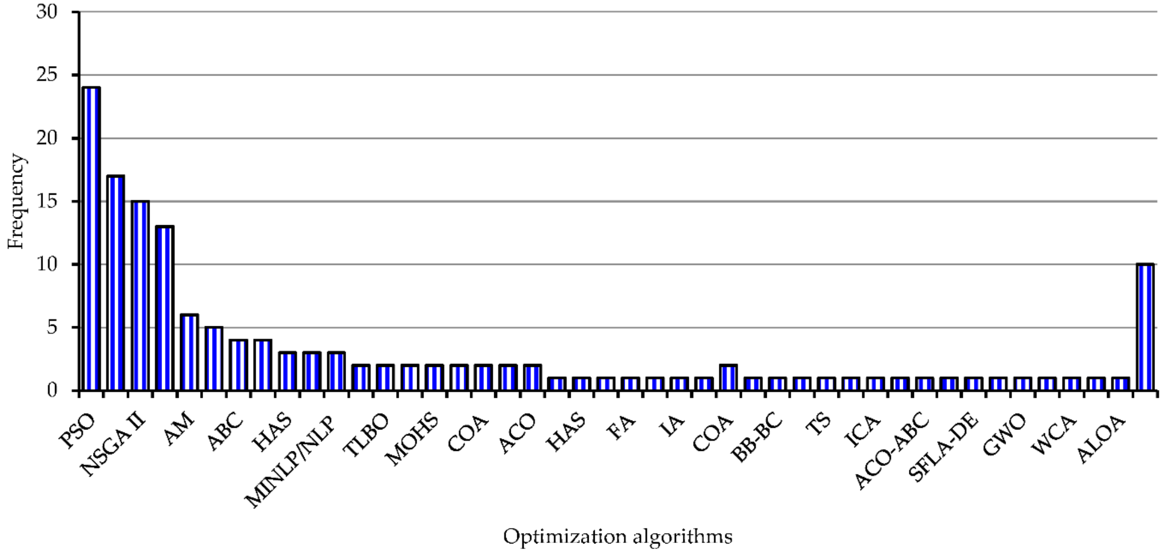
2.4. Distribution System Model

The distribution systems are mostly radially configured in nature; hence, the literature considered for this study is on the radial distribution system. Most of the literature has been on standard IEEE radial distribution systems, such as IEEE 9, 12, 14, 15, 33, 69, 113, etc. In this literature, 33.66% of the authors have used the IEEE 33, and an estimated 21.78% of the authors have simulated the IEEE 69 bus, as shown in Figure 1v.

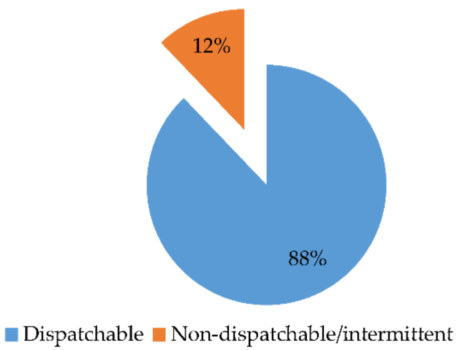


(**i**)

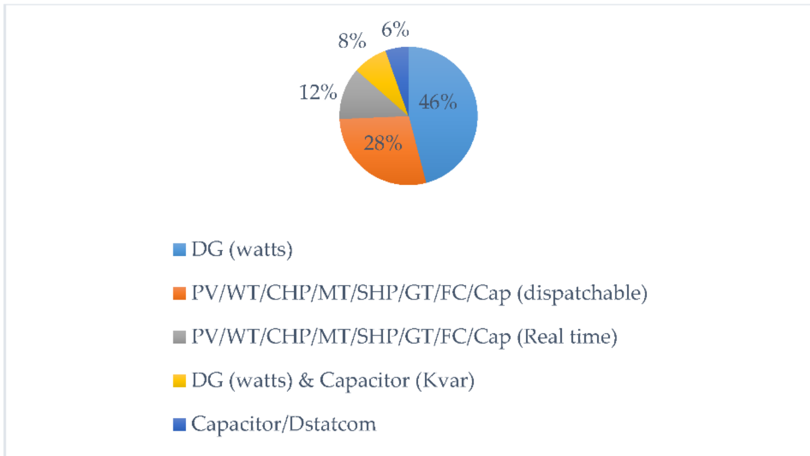
Figure 1. *Cont*.



(ii)

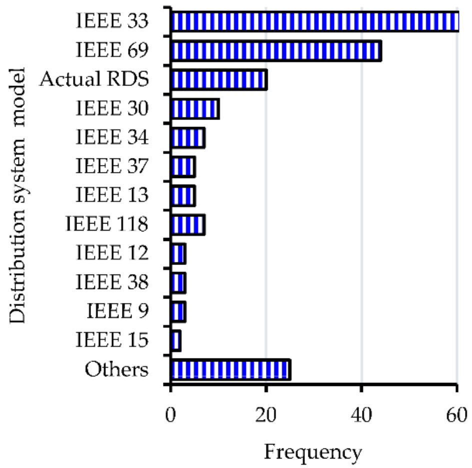


(iii)

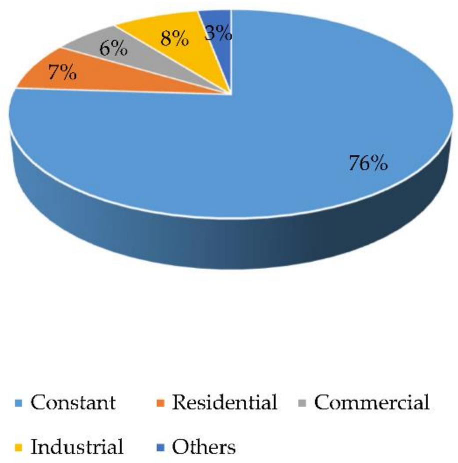


(iv)

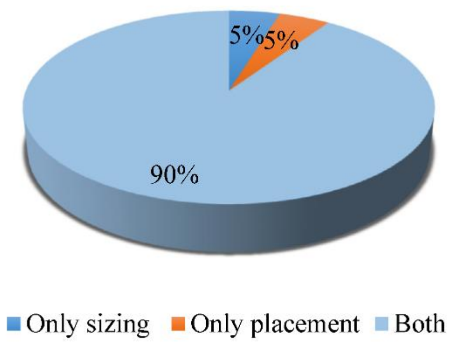
Figure 1. *Cont.*



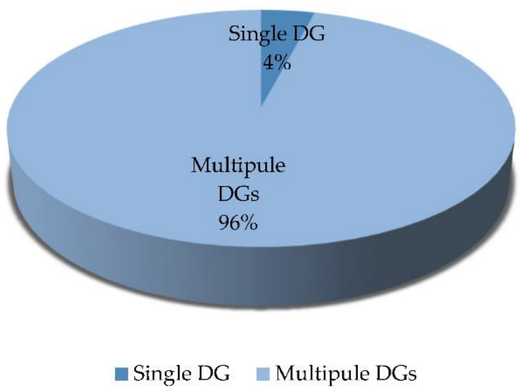
(**v**)



(**vi**)

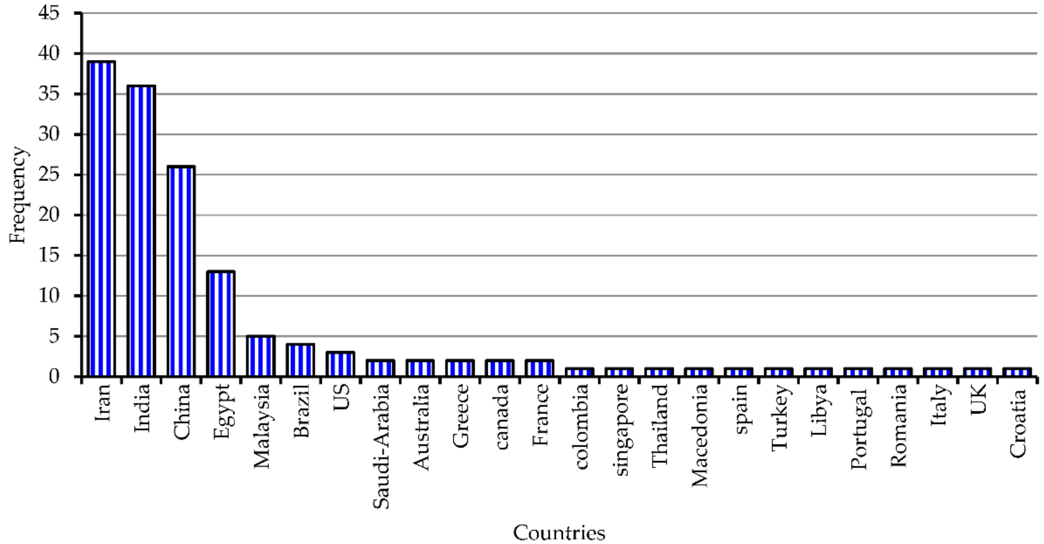


(**vii**)



(**viii**)

Figure 1. *Cont*.



(**ix**)

Figure 1. Summary of the literature works gathered from Table 1. (**i**) Objective function used for optimal multi-objective DG placement and sizing. (**ii**) Different optimizations used for optimal multi-objective DG placement and sizing. (**iii**) Types of DG used for optimal multi-objective DG placement and sizing problem. (**iv**) Dispatchable and real-time DG sources used for optimal multi-objective DG placement and sizing problem. (**v**) Different IEEE test systems used for optimal multi-objective DG placement and sizing problem. (**vi**) Different load models used for optimal multi-objective DG placement and sizing problem. (**vii**) Sizing/placement, or both, problems carried out for optimal multi-objective DG placement and sizing problem. (**viii**) Single large or multiple DGs used for optimal multi-objective DG placement and sizing problem. **(ix**) Research for optimal multi-objective DG placement and sizing problem conducted in different countries.

2.5. Load Model

The optimal placement and sizing of DGs is greatly affected by the types of load used. The load model design is largely constant, residential, commercial, and agricultural, and it is a ZIP model. Figure 1vi shows the pattern of load models considered for the studies; they are referred to as peak constant load (76%), industrial load (8%), residential load (7%), and commercial load (6%).

2.6. Optimal DG Variables

Maximum returns from the DGs are possible when both variables, i.e., placement and sizing, are taken into consideration. It should be noted that 90% of the authors have worked on both variables, whereas 5% of each of the works reported on the placement or only on the sizing variables, respectively, as shown in Figure 1vii.

2.7. No. of DG Units

The number of DGs considered to be allocated would offer different characteristics, which would be challenging and significant. The study reveals that around 96% of the authors have worked on multiple DGs, whereas only 4% of studies are found to be on the single DG, as shown in Figure 1viii.

2.8. Countries Working on DG

The countries which have participated actively in understanding optimal DG integration in their current distribution systems are shown in Figure 1ix. Information about these countries will help researchers and power experts follow and share updates on the highlighted problem. It is interesting to see that Iran and India are the countries most interested in integrating DG into their grids. The research on the optimal DG problem for both of these countries is found to be 26.35% and 24.32%, respectively. China is the third country on the list, with research accounting 17.56%. Similarly, Egypt and Malaysia hold up to 8.78% and 3.38%, respectively. On the other hand, Western countries (Europe, the Americas, and so forth) remain at 1–3%.

3. Objective Functions and Constraints

The optimal integration of DG is necessary to obtain the maximum benefit from it. This section discusses the impacts of DG on the different parameters in terms of, e.g., power loss, voltage profile improvement, voltage stability improvement, reliability improvement, reduction in harmonics distortion, emission reduction, minimization of the cost associated with the investment, maximization of network security, and the short circuit current index, etc.

3.1. Power Loss

Power losses are a waste of resources and a product of inefficiency in power output. It is reported that conventional distribution systems cause approximately 13% of the power losses from the total power generation [69,155–157]. The main reason for these power losses is the high resistance-to-reactance ratio and the radial structure. The optimal placement of DG in the distribution systems reduces these power losses, whereas non-optimal placement can increase the occurrence of power losses, relatively speaking. Many authors have paid attention to both types of active and reactive power loss reduction, as mentioned below.

3.1.1. Active Power Loss Reduction

The previous literature has largely focused on active power loss reduction as a single-objective function, with regard to the optimal placement and sizing of the DG [158–168]. However, considering the increasing trend of incorporating DGs in current distribution systems, work needs to be carried out with the multi-objective functions, as reported in [13,15,41–51,53,55–60,62–81,83,84,86–88,91–106,108–113,116–120,123,125–136,138–144,146–148,150–152,154,169–176].

The mathematical expression for the minimization of power loss at each branch and on the total network can be computed using Equations (1) and (2).

$$P_{i\ loss} = R_i \times \frac{\left(P_i'^2 + Q_i'^2\right)}{|V_n|^2} \tag{1}$$

where $P_{i\ loss}$ is the real power loss for the branch i, respectively.

3.1.2. Reactive Power Loss Reduction

The integration of certain types of DGs, such as solar PVs and traditional wind farms (i.e., asynchronous generators), etc., is incapable of supplying reactive power to the system. Hence, a sophisticated control requirement is needed to fulfill the need for reactive power. Therefore, in many studies, it has been observed that the combination of the active and reactive type of DGs is used to balance the reactive power losses and that it also improves system performance [76,177,178]. It has also been observed that invertor-based technology is sufficiently robust for reactive power management and has the capabilities to export or consume reactive power to and from the system. The reactive power losses associated with the other objective functions, such as the multi-objective functions mentioned in Table 1, have been covered in [44,52,53,58,77,78,100,105,120,141].

$$Q_{i\ loss} = X_i \times \frac{\left(P_i'^2 + Q_i'^2\right)}{|V_n|^2} \tag{2}$$

where $Q_{i\ loss}$ is the reactive power losses of branch i in the network.

3.2. Voltage Profile Improvement

The voltage profile is largely related to the power quality of the system. The voltage in the distribution systems usually remains in a fluctuating mode due to the variable nature of the connected load. Nowadays, with the integration of various types of DG, the voltage quality in the distribution system becomes more unpredictable. The non-optimal placement and sizing of DGs causes more rises and dips in the system voltages. Hence, it is necessary to properly investigate and maintain the nominal range, as described in IEEE 1547. In the literature, many authors have considered it to be a system constraint. However, a few authors have used it as a separate objective function for the multi-objective DG problem, as presented in [41–47,50–55,57,58,60,61,63–69,74,78–81,83,84,86,87,90,92,93,97,99,100,102,103,105,106,108–110,112,113,121–123,125,129–132,134,136,138,141,143,146–149,151,153,172,174,179,180]. The mathematical index for the minimization of the voltage deviation can be formulated as in Equation (3).

$$\text{VD} = \min \sum_{mi}^{Nb} |1 - real(V_{mi})| \tag{3}$$

where V_{mi} is the voltage of node m, of branch i in the m-n two nodes network.

3.3. Voltage Stability Improvement

Voltage stability improvement is a very important factor for maintaining a good transmission and distribution system performance. Voltage instability usually occurs due to the incompatibility of the reactive power supplies. When the load on the system increases, the reactive power demand also increases. Eventually, the system voltage declines and reaches a point where a blackout happens. In the last two decades, there have been many incidents where a complete blackout had been observed [181]. However, the optimal integration of the DGs and the proper load forecasting can improve the voltage stability index and provide safe and consistent power delivery. The authors in [41,46,48,50,55,56,58,60,62,69,84,87,88,90,91,94–96,98,104,106,110,116,119,123,129,142,154,172,175] have contributed significantly to the study of the voltage stability improvement for the multi-objective DG problem. The voltage stability index at bus n can be written as shown in Equation (4).

$$VSI_n = |V_m|^4 - 4(P_i^{\prime} X_i - Q_i^{\prime} R_i)^2 - 4(P_i^{\prime} R_i + Q_i^{\prime} X_i)|V_m|^2 \quad (4)$$

VSI_n is the VSI for bus n.

3.4. Reliability Improvement

The continuous fluctuations and discontinuity of electric power at peak hours creates serious concerns for utilities and consumers. However, the introduction of DG in the current distribution system provides better, safe, and more reliable power delivery options. The integration of DGs not only improves the overall reliability of the existing systems but also improves the socio-economic standard of any country that adopts it. The improvement in reliability, as an objective function in optimal DG placement, is solved via multiple reliability indices, including SAIFI, SAIDI, CAIFI, CAIDI, AENS, ENS, EENS, etc. These are fully described in [45,54,73,114,115,118,120,123,127,132,136,137,139,145,154].

$$SAIDI = \frac{Ui \cdot Ni}{Ni} (h/c \cdot year) \quad (5)$$

$$SAIFI = \frac{\sum Ni \times \lambda i}{Ni} (f/c \cdot year) \quad (6)$$

$$CAIDI = \frac{\sum Ui \times Ni}{\sum Ni \times \lambda i} (h/c \cdot int) \quad (7)$$

$$ASAI = \frac{\sum Ni \times 8760 - \sum UiNi}{\sum Ni \times 8760} (p \cdot u) \quad (8)$$

$$EENS = \sum EENS \; (MWh/year) \quad (9)$$

$$ECOST = \sum ECOST \; (\$/MWh) \quad (10)$$

3.5. Reduction in Harmonics Distortion

The high penetration of renewable and non-renewable DGs and electronics-based power converters causes the introduction of harmonics and transients into the conventional distribution systems. According to Karimyan et al., 2014, distribution systems need to satisfy the minimum harmonics and transients standards, as defined in the IEEE 1547 interconnection [166,171,173,177,180,182]. Therefore, the severity of harmonic distortion can be reduced with the appropriate DG technology. Many authors have studied optimal placement and sizing for power loss reduction with total harmonics distortion (THD) [72], power loss reduction, improvement in voltage profile and minimization of THD [148], power loss reduction with total voltage thyroid minimization [111], power loss, voltage sag, and harmonics reduction with the maximization of the voltage profile [112]. The author in [183] presented work conducted on cost and undesirable transient voltage performance and the proximity to steady-state voltage collapse.

3.6. Emission Reduction

DG integration into current power distribution systems is congruous with the ongoing plans for greenhouse gas (GHG) emission reduction. The degree of GHG emission reduction depends on the type of DG technology used. For example, solar PVs and the use of batteries create no emission, whereas CHP and fuel cells increase the efficiency of power supplies and can be utilized for co-generation in order to meet thermal and cooling necessities [184]. The following authors in [50,62,71,75,82,85,89,90,97,102,103,107,117,121,122,124,125,127,132,135,138,142,149,150,152–154,185,186] have considered the reduction in GHG emissions as the multi-objective optimization for the optimal DG planning scenario.

3.7. Minimization of Cost Associated with Investment

The proper integration of DGs can reduce investment costs, upgrading costs, and operational and management costs. Many authors in the literature, such as [41,43,45,47,53,54,59,61,62,67,70,71,75,76,82,85,88–91,107,114,115,117,118,120–124,127,128,132,135–140,144,145,149,151,170,171,173,183,185–194], have considered the investment, or costs, as an objective function, in association with the other objective functions for the optimal placement and sizing of DG.

3.8. Maximization of Network Security

The current distribution system was designed to operate as a one-way power delivery system. However, with the integration of DGs, the power flows bi-directionally. Hence, there is a need to set a power flow limit so that networks do not create over/under loading conditions. In the literature, an IC index is introduced, which carries the information of line flows and currents in the network. The index has a 0–1 range, which shows the minimum and maximum limit for power flow, as investigated in [44,50,56,58,63,64,74,78,87,105,141,146].

3.9. Short Circuit Current Index

The distributed generators are interconnected in parallel to the distribution system. It is, therefore, expected that at the time of the fault the current flowing from the substation may add to the current flowing from the DGs. This may increase the fault current and rupture the connected protection schemes. Hence, the authors in [113,126,133,141] have suggested that a level of short circuit current should be included as an element in the in multi-objective DG placement problem.

3.10. Network Constraints

The equality and non-equality constraints for the proposed problem can be described as below.

3.10.1. Power Balance

The mathematical formulation of power balance can be formulated as in Equations (11) and (12).

$$P_{substation} + \sum P_{DG} = \sum P_{loss} + \sum P_{load} \tag{11}$$

$$Q_{substation} + \sum Q_{DG} = \sum Q_{loss} + \sum Q_{load} \tag{12}$$

where $P_{substation}$ and $Q_{substation}$ are the total real and reactive power injection by a substation into the network. ΣP_{DG} and ΣQ_{DG} are the total real and reactive power, injected by distributed generation. ΣP_{loss} and ΣQ_{loss} are the total real and reactive power loss in the network. ΣP_{load} and ΣQ_{load} are the total real and reactive power losses of the network, respectively.

3.10.2. Position of DG

Bus 1 is the substation or slack bus; so, the position of the DG should not be used at bus 1.

$$2 \leq DG_{position} \leq n_{buses} \tag{13}$$

3.10.3. Voltage Profile

In order to maintain the quality of the power supplies, the voltage profile of every bus in the network should satisfy the following constraint.

$$V^{\min} \leq V \leq V^{\max} \tag{14}$$

3.10.4. Boundary Condition of Distributed Generation

The boundary conditions of the real and reactive power DGs are also restricted; this is given in Equations (15) and (16).

$$P_{DG}^{\min} \le P_{DG} \le P_{DG}^{\max} \tag{15}$$

$$P_{DG}^{\min} \le P_{DG} \le P_{DG}^{\max} \tag{16}$$

3.10.5. Thermal Limit

The temperature of the cable or conductor must be less than the rated value, as expressed by Equation (17).

$$S_{\text{line}} \le S_{\text{rated}} \tag{17}$$

4. Optimization Methods

The appropriate configuration of DG placement and sizing would yield optimal returns. Due attention is required for DG sizing and placement since their non-optimal installation may result in various technical, economic, and environmental challenges [158–168,195,196]. In addition, it is considered as a mixed integer, non-linear, extremely constrained, complex, and combinatorial multi-objective problem. In order to attain an optimal trade off among the various challenges simultaneously, multi-objective optimization algorithms can play a vital role. The common objectives have been considered by various authors and include the reduction in power losses, the improvement in voltage profile or voltage deviation, the strengthening of the voltage stability, the improvement of reliability, and the reduction in costs and emissions. Recently, a widespread development has been observed for DG placement and sizing, and various scientists have established several optimization algorithms to optimize this multi-objective problem. This review considers the optimization algorithms that have been used in the literature and provides an in-depth readership and viewpoint for the researchers to derive the most appropriate multi-objective optimization algorithms for the said challenge.

These are primarily categorized into two broad methods for solving the optimization problems: the analytical methods and the numerical methods. The analytical methods are also referred to as classical approaches, involving mathematical derivation and proofs which allow to attainment of the exact solution. This method is rigorous and strict, with problematic characteristics that may not realistically match, and hence, it may not be able to accurately optimize the system. These analytical methods have been further classified as classic approaches and basic search methods. The numerical method mainly applies the iterative approach to obtain the approximate optimal solution, which requires decision and objective variables from the optimization problem. The numerical method has basically been derived by mimicking natural evolution or specific processes that occur naturally in an ecological environment. These have been further been classified into biologically inspired algorithms, physics-inspired, geography-inspired, social–cultural inspired, music inspired, and hybrid intelligent algorithms [197]. The flow chart depicting how the heuristic algorithm has been modeled for the said problem is shown in Figure 2, whereas the multi-objective optimization algorithm taxonomy is depicted in Figure 3.

4.1. Analytical Method

The analytical approach is the way of solving the distribution network solutions with the help of mathematical formulas and expressions. These formulas and expressions are further used to design the required objective functions. The analytical approach is non-iterative, easy to handle, and guarantees the convergence of the solutions. The analytical approach is widely used in single-objective optimization for the optimal placement and sizing of distributed generation with multiple objectives, such as power loss reduction, voltage deviation improvement, voltage stability index improvement, etc. [160,167,198–203]. It is also reported in the multi-objective index, where two expressions are brought into a single objective, and the required objective function is calculated. For example, the authors in [77,95] used the multi-objective index for an active power loss reduction and a reactive power loss reduction in the optimal multi-objective placement and sizing of the DG problem. The efficiency and accuracy of the simplistic systems are very high, with less computational time. However, it is not true in case of complex system. The method can be used in conjunction with the modern meta-heuristic algorithm, as suggested in [77,95,100]. Various classic approaches have been categorized, such as the mixed integer linear programming, nonlinear programming, and dynamic programming.

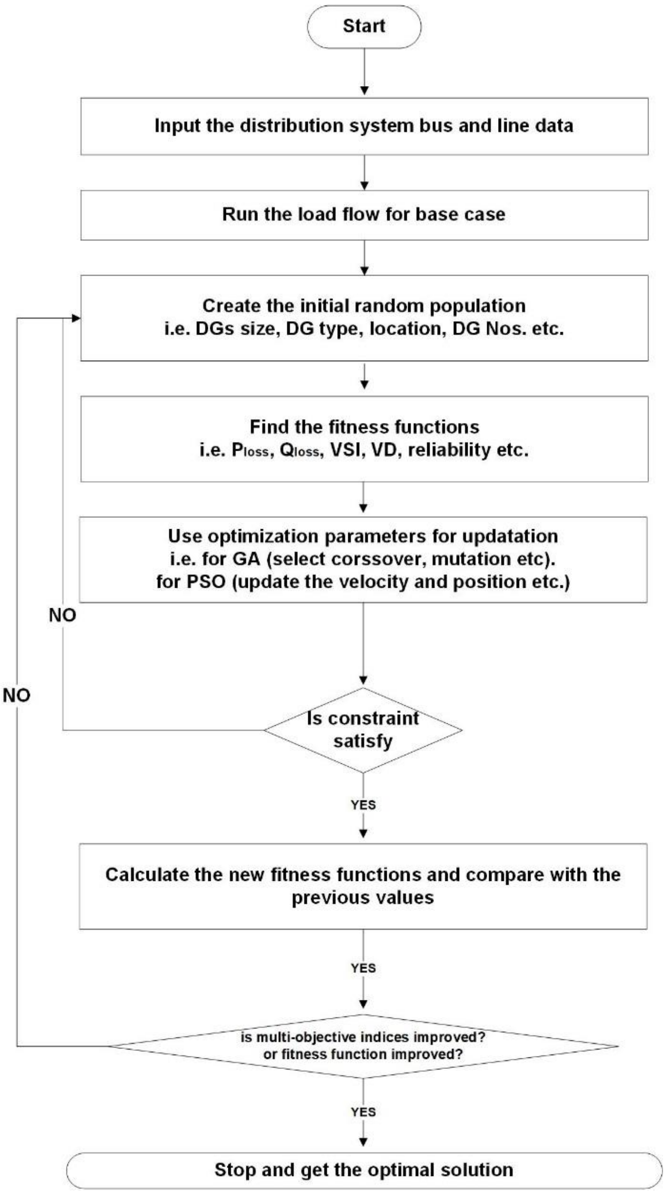


Figure 2. Heuristic algorithm for optimal multi-objective placement and sizing problem.

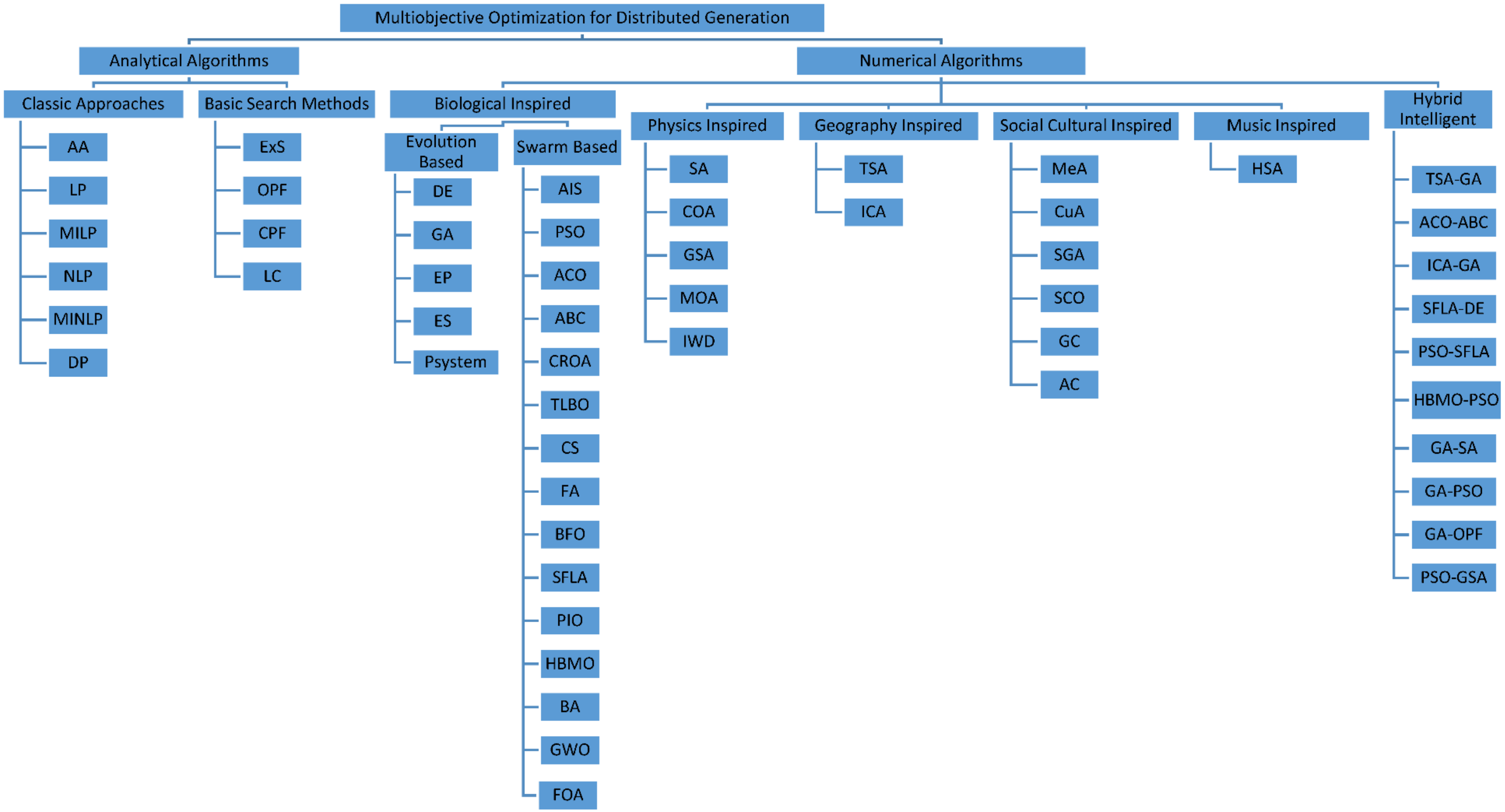


Figure 3. Taxonomy of optimization algorithm used for optimal DG placement problem. Note: Algorithm abbreviations: LP—linear programming, MILP—mixed integer linear programming, NLP—non-linear programming, MINLP—mixed integer non-linear programming, DP—dynamic programming, OPF—optimal power flow, CPF—continuous power flow, DE—differential evolution, GA—genetic algorithm, EP—evolutionary programming, ES—evolutionary search, PSO—particle swarm optimization, ACO—ant colony search, ABC—ant bee colony, TLBO—teacher learning-based optimization, SFLA—shuffled frog leaping algorithm, HBMO—honey bee mating algorithm, BA—bat algorithm, GWO—grey wolf optimizer, SA—simulated annealing, FOA—fly optimization algorithm, COA—cuckoo optimization algorithm, TSA—tree speed algorithm, HAS—harmony search algorithm.

The linear programming technique is a mathematical model which uses linear equations for objective functions and linear constraints. This method is used in some literature for optimal DG planning to maximize DG penetration and for energy loss reduction purposes, such as that reported in [204,205]. However, this method fails when finding the exact solution and optimal power flow calculations for a required network. As a result, this method is not used in the literature for the optimal multi-objective optimization of DG placement and sizing problems.

The mixed integer linear programming method involves the linearization of the power flow calculations and sets the objective functions and constraints in the form of a discrete and continuous variable. For instance, in Ref. [206], the author developed the two agents, i.e., the optimal placement and the financial contract model between DISCO's and the owner, and converted the two agent problems into a single level and solved them with the MILP method.

The non-linear programming method works on the principle of derivatives, where the first step is to choose the search direction for an iterative process. In the literature, this method is solved with many techniques. For instance, the author in [207] used the first-order method with the generalized reduced gradient method for the optimal power flow. The author in [208] employed this method for solving the power flow equations with second-order derivatives by serial quadratic programming with the Newton–Raphson method. The nonlinear programming-based optimal placement and sizing of the distributed generation for a minimum number of DG units and power loss reductions has been proposed by [116]. The author converted multiple objectives into a single-objective function using the fuzzification method. Moreover, it is cited in [209] that this method has several disadvantages in the computations for large and complex power networks. For instance, it may be trapped into local minima, and it also has slow convergence. The reason for these disadvantages is its irregular searching capabilities.

In real-world applications, problems may either be discrete in nature or have non-linear system dynamics. Hence, the mixed integer non-linear programming method is composed of linear programming (LP), non-linear programming, and mixed integer programming (MIP). MINLP solves discrete problems, continuous problems, and non-linear functions. The drawback of the LP is that it can handle linear objective functions and constraints only, as proposed by the author [116], whereas the efficiency and performance of the non-linear optimization algorithm are tested by the authors [59,137]. The author in [144] proposed the mixed integer non-linear programming method for finding the optimal placement and number of DG units in a radial distribution system. First, the most suited nodes are identified on the basis of real power losses and the nodal power nodal price-based sensitivity method. Later, the MINLP method is applied. The results are tested on the IEEE 24 radial distribution system. The optimal placement and sizing of distributed generation for the energy loss reduction [210] and the minimization of the total fuel cost and energy loss have been proposed by [144]. The proposed model in both cases used the mixed integer non-linear programming method. It is suggested in Ref. [211] that the traditional computational technique can guarantee the better results for simple and ideal problems. However, in the case of real-world problems or problems with an increased number of variables, the MINLP method may fail to guarantee the global optima.

The dynamic programming type of technique is the most suited and gives feasible solutions for multistage decision-level problems [212]. The DP method is used in both mathematical and computer applications. The dynamics of this method involve dividing the complex problem into several sub-problems and then solving them in the different time domains. The author in [96] proposed the optimal location and sizing of distributed generation for the voltage stability index improvement and power loss reduction using dynamic programming search technique. First, the most critical node in terms of voltage instability is found, which then chooses the optimal location. However, the best sizing is found using the dynamic programming-based method.

4.2. Basic Search Method

The exhaustive search method type of method is best suited for the single-objective optimization problem [213]. For the optimal DG placement and sizing problem, the final solutions are taken using the process of exhaustively searching the whole search space. The method is computationally effective when it is solved for a lower search space. However, it is difficult to find the final solutions in more complex optimizations problems [214]. For instance, the author in [100] uses the ES method to find the optimal sitting and sizing of distributed generation with three DG units, and the MO optimization problem is solved with the weighted sum approach. The author minimizes the active and reactive power losses and voltage deviation, and the model is tested on the standard IEEE 6, IEEE 14, and IEEE 30 bus system.

The optimal power flow (OPF) method is a non-linear programming method, which is normally used for the economic dispatch problem [214]. However, this method has also been used to optimize the distribution system parameters; the author in [93] used the OPF method for the optimal placement and sizing of distributed generation in a distribution system with multi-objective optimization. The different objectives, i.e., power losses, voltage deviation, and maximum DG output, are formulated in the MO problem; later, it is transferred into single-objective optimization. In order to reduce the complexity in such a large convex problem, the optimization is reduced with the sensitivity method using trust region sequential quadratic (TRSQ) programming.

The continuous power flow method (CPF) is mostly used to optimally place the DG units on the most sensitive bus, whereas the optimal size of the DG units could not be addressed [19]. The optimization problem works by searching the sensitivity of the bus or at a maximum loading leading to voltage collapse. Initially, a specific size of DG unit is proposed at a sensitive bus and then a load flow is run iteratively to satisfy the objective and the constraints. If any of the objectives and constraints are not satisfied then the algorithm will move towards another sensitive bus, and finally, satisfactory results will be obtained.

The sensitivity based analysis (SBA) technique is used in engineering applications to reduce the search space. It is widely used in conjunction with heuristic and meta-heuristic techniques. In DG optimal placement and location problems, many authors have used power loss minimization-based sensitivity analysis or maximization of voltage stability-based sensitivity analysis. The main objective is to find the optimal location for DG, with as little computational time as possible. After deriving the optimal location, the meta-heuristic algorithm is used for finding the optimal DG sizing, as recommended by authors in [109,111,131].

4.3. Numerical Methods

The attainment of the optimal solutions through the iterative approach, utilizing decision and objective variables, has been designated as the numerical method. These have generally been derived through imitating the evolutionary process. These have been classified as follows.

4.3.1. Biologically Inspired Algorithms

The biologically inspired algorithms are referred to as the sub-branch of the numerical intelligent optimization algorithm, inspired by natural evolution or biological characteristics in the micro and macro world [215]. These algorithms are also referred to as memetic algorithms since they are derived from behaviors, structural features, or substantial developments [197]. These have broadly been categorized as evolution-based algorithms and swarm-based algorithms.

Evolutionary algorithms are meta-heuristic optimization algorithms which mimic the process of natural or biological evolution and the social behavior of species. These species learn and adapt through the process of evolution [197]. The DE, GA, EP, ES, and Psystem are algorithms discussed under this category.

The genetic algorithm (GA) is a meta-heuristic optimization algorithm inspired by natural evolution. It works on the three fundamental principles of selection, crossover, and mutation. Initially, a large number of random candidate solutions are generated. These solutions are processed with a genetic operator for the selection process. Each candidate solution is termed as a chromosome. In each iteration (i.e., generation), the fitness of each individual chromosome improves, and the highest fitness in any generation will be the optimal solution in the search pool. The best chromosomes are selected to be put through crossover process. The number of chromosomes undergoing these crossover processes depends on the crossover probability. The mutation operator is introduced, which maintains the diversity of the solution set. It may alter the previous solution and bring forth the most favorable solution. The multi-objective DG placement and sizing problem with GA has been proposed by [45,66,67,72,112,113,127,130,170,190]. The demand for multiple objective function solutions in a single run raises the need for newly adopted evolutionary algorithms. Therefore, the non-sorting genetic algorithm (NSGA) is proposed; it is relatively competent, as compared to the other optimization algorithms, and reaches the global optimal solutions of any multi-objective problem. The most famous NSGA-II was introduced by Deb et al. [216]. The working principle is defined as (1) generating the initial population, (2) finding the fitness function of an initial population, (3) filtering out the non-dominated solution set in the serrate archive, (4) choosing the best leaders among the solutions in the archives, (5) updating the current population, (6) introducing the mutation factor for diversity in the population and finding the fitness values of the newly updated solution, (7) filtering out the non-dominated solution, and finally, with the help of decision-making, the best solution from the Pareto optimal set is to be chosen. The authors in [46,60,61,73,85,89,90,118,124,125,132,135,140,151,152,194] have recommended using NSGA and NSGA-II for the optimal placement and sizing of DG in the multi-objective problem.

GA, R. Storn, and K. Price [217] introduced the differential evolution optimization algorithm. This was developed to optimize the real parameter and real-valued functions that are non-linear, noisy, non-differentiable, and non-continuous and have many local minima, constraints, and stochasticity. The comprehensive working environment for DG placement through optimal differential evolution has been mentioned in [103,149,150,153,218]. Moreover, there is the need to optimize multiple objectives simultaneously that are incommensurable and conflicting in nature. The results of these problems may not yield a single optimal solution. Hence, the both MODE and PFDE algorithms use the non-dominated sorting and fitness functions and yield a Pareto optimal solution set for the ODGP problem, as described in [41,49,218].

The author in [107] uses an adaptive crossover and mutation factor in the evolutionary process of the improved Pareto evolutionary programming (PEA), with simulated annealing for the multi-objective DG optimization problem. Moreover, the constraints of objective functions are penalized in order to find the best results.

4.3.2. Swarm-Based Optimization Algorithm

The swarm-based optimization algorithm is the sub-branch of artificial intelligence. The theory of these algorithms is derived from the natural behaviors of birds, ants, bees, and fish. These algorithms are most feasible for lowering costs, with high convergence speeds, and they give a robust solution to many non-linear and complex problems. The swarm-based optimization algorithms are PSO, MOPSO, ABC CABC, BAT, BFOA, QTLBO, SFLA, IA, COA, and HBMOA.

Particle swarm optimization is a subset of artificial intelligence. The theory of this algorithm stems from the natural behaviors of birds, ants, bees, and fish. It is a population-based algorithm and is inspired by birds maneuvering and fish schooling. The algorithm was introduced by Kennedy et al. [219] in 1995. The working principle of this algorithm is defined in the following points: (1) randomly generating swarm population, (2) finding the fitness function of the initial population, (3) checking the pbest and gbest in the solution and in the entire search space, (4) updating the velocity and position vector, (5) finding the pbset and gbest of the newly yielded solution, and introducing the stopping criteria, as described in [51,63,71,76,80,86,106,119–121,133,139,141,172,189,191,192].

As with the NSGA-II or MODE, the multi-objective PSO is a well-known and efficient algorithm for solving the multi-objective optimization problem. With MOPSO, the author in [220] introduces the non-sorting mechanism to find the optimal solution set from a Pareto optimal set in the MOPSO optimization algorithm. Moreover, the MOPSO-based optimization algorithm for optimal DG placement problem is highlighted in [47,50,56,98,99,104,115,122,123,127,143–145,174].

The artificial immune algorithm is an evolutionary optimization algorithm, inspired by the complex mechanism of the immune system. Immunity protects the body from foreign invaders and also helps maintain requisite antibodies within the body. The author in [173] proposed this optimization algorithm for the optimal DG placement and sizing problem.

The ant colony optimization is a bio-inspired computing technique. The functioning principle is analogous to the rummaging behavior of real ants. Initially, ants find food close to their nest. This helps them to ascertain the location of the food source, and they always take some of the food back to their nest. During this journey (from food source to nest), the ants release a pheromone trail on the ground. The potency of the pheromone trail depends on the quality and quantity of the food. This pheromone behaves as a guide for the other ants and determines the shortest route to the food source for the other ants. Inspired by this, the author in [221] introduces the optimization algorithm for the combinatorial optimization problem and further implements this in the DG placement problem in [74,169].

The artificial bee colony is an iterative-based optimization algorithm and part of swarm optimization. The algorithm was presented by Karaboga [222] in 2005 and was inspired by a real honey bee cluster's wage dance and the way bees source for food in hives. The cluster for this algorithm is divided into three groups called scout bees, employed bees, and onlooker bees. The inhabitants of the ABC are divided into halves; one-half behave as scouts, searching for a food source (called the new position of the optimization problem). After locating a new food source, the scout bees then become employed bees and assemble the other bees to the new food source position by communicating with them. In a specific time span, if the employed bees are not able to improve the new food position, then these bees are nominated as scout bees, and the above procedure is repeated. Finally, the onlooker bees decode the new location of the food source. The authors in [58,102,126,175] have incorporated the ABC optimization algorithm for the problem.

The teaching–learning-based optimization and the quasi-teaching–learning optimization algorithms are meta-heuristic optimization algorithms, inspired by a teaching–learning activity in a student's classroom. The working principle of these algorithms basically depend on two steps: (1) the teaching phase and (2) the learning phase. In the former step, the learner acquires knowledge from the teacher, and in the latter step, the learner can be guided by his classmates [223]. The competency of these algorithms is highlighted in [84].

The cuckoo optimization algorithm is a meta-heuristic evolutionary algorithm, inspired by the way cuckoos lay their eggs in hosts' nests. It is the cuckoos' inventiveness which compels them to find the best place for laying their eggs and where the eggs are subject to minimum danger. The algorithm is broadly used in the optimizations of engineering applications and specifically in the DG problem, as proposed in [81,134].

The firefly algorithm is inspired by the swarm optimization algorithm; it mimics the process of setting off fireworks. This can be found detailed in [94].

The bacterial foraging optimization algorithm was presented by [224] in 2002 and was inspired by the foraging characteristics of the bacteria *Escherichia coli* (*E. coli*). The accuracy and reliability of this algorithm is tested by [88,91,97] in the multi-objective optimal placement and sizing of a DG problem.

The shuffled frog leaping algorithm (SFLA) is a memetic meta-heuristic optimization algorithm, inspired by the food-searching capabilities of frogs. The performance of the algorithm is highly applicable in computing and in finding a global search ability [128].

The honeybee mating optimization algorithm is inspired by the natural mating flight process of the honeybee. The author [138] uses this algorithm, with a further modification (called modified-HBMOA) for the multi-objective placement of DGs in the distribution system.

The bat algorithm is inspired by the sonar and echolocation qualities of micro-bats, with a variation of the pulse rate of the emissions and the loudness. The algorithm was first introduced in 2010 by [225]. The movement of bats depends upon their velocity and position. Once they reach their prey, the pulse rate emission and loudness increase. The working principle of this algorithm is similar to the PSO optimization method, as used by [43,44,65,105].

The gray wolf optimization algorithm (GWO) simulates the hunting and social leadership of grey wolves in nature [226]. The algorithm is simple and robust and has been used in various complex problems. The MODG placement problem with GWO is proposed by the author in [52].

The fireworks optimization algorithm is inspired by the swarm optimization algorithm, which mimics the process of setting off fireworks. This can be found detailed in [94].

4.3.3. Physics-Inspired Algorithm

These algorithms are motivated by the physical properties, or physical characteristics, of matter. Sometimes, these algorithms mimic the laws of physics. The details of these algorithms are well defined in [197]. The types of physics-inspired optimization algorithms are detailed as follows.

Kirkpatrick et al., in 1983, and Cerny et al., in 1985, proposed the probabilistic method for finding the global minimum of the cost function using the simulated annealing method. The method is inspired by the metallurgy processes of the heating–cooling material. According to the author, the metal is first heated up to its melting point and then cooled down very slowly. The reason for moderated the cooling is to attain the best solution and to reduce the probability of an unfavorable solution. The efficiency and performance of this algorithm for the DG placement problem are focused on by the authors in [79,142,147,187].

The big bang–big crunch optimization algorithm is inspired by the theory behind the creation of the universe and was presented in 2006 by [227]. The idea is carried out in two phases: (1) the big bang phase—where the initial randomness is entrenched in the problem and spread along the search space and the (2) big crunch phase—which works as the center of mass and has a convergence operator that brings many inputs to one output. The algorithm is similar to GA in the initializing of the random particles, as described by the authors in [53,78].

The invasive weed optimization algorithm (IWO) is inspired by the process of the colonization by invasive weeds. Considering the behavior, biology, and ecology of weeds, a meta-heuristic optimization algorithm is formed. The IWO with the fuzzy decision for the MODG placement problem is proposed by [55].

4.3.4. Geography-Inspired Algorithm

The geography-based optimization algorithms generate random solutions in the topographical search space. These meta-heuristics optimization algorithms are classified as follows.

Tabu search is a meta-heuristic optimization algorithm proposed by Fred et al. in 1986 to solve a local search for mathematical problems. The algorithm has a tendency to move iteratively towards better solutions in its neighborhood. The algorithm stops once it satisfies the stopping criteria. It is possible that the local search may be stuck in the plateau region or in the poor scoring region. Therefore, it uses a distinct type of memory structure so that the new neighborhood solution can be further explored for better solutions, as highlighted in [185].

The imperialistic competitive algorithm (ICA) was introduced by Atashpaz et al. in 2007 as an evolutionary optimization algorithm. The algorithm starts with a number of countries in the world; the best countries among them are selected for the 'imperialists' category, and the others act as colonies. The initialization of countries, or empires, is similar to the particles in PSO or to the chromosomes in GA, and the best countries resemble the fitness function in PSO/GA. The colonies then move towards the relevant imperialists according to the powers they have. With this competition between the colonies and their chosen empires, a state will occur where all the countries will become colonies, and the only country left as the imperialist will become the empire. The solving of the issue of the multi-objective placement and sizing of DGs using ICA is recommended by the authors in [48,87].

4.3.5. Music-Inspired Optimization Algorithm

These algorithms are derived from the concept of music. The harmony search algorithm/multi-objective harmony search algorithm is a music-inspired optimization algorithm. The aim of music is to find the perfect state of harmony. This is analogous to the search for the optimal solution in any computer or engineering problem. The HSA/MOHSA-based solution for the optimal placement and sizing for the multi-objective DG problem is found in [108,110,148,171].

4.3.6. Math-Inspired Algorithm

These algorithms are inspired by the working principles of mathematical laws and their expression solving. The math-inspired optimization algorithms can be classified as follows.

The backtracking search optimization algorithm (BSOA) is an evolutionary new algorithm. It is applied to find out the solutions of real-valued, non-linear, non-differential, and complex numerical optimization functions. It is simpler, more effective, faster, and more easily adaptable to different numerical optimization techniques, as advised by the authors in [68,69].

The sequential quadratic programming (SQP) algorithm is a relatively famous algorithm devised half a century ago to solve non-linear, constrained mathematical problems. The algorithm is also called iterative quadratic programing or recursive quadratic programing. The quadratic sub-problem is used to make an approximate solution, e.g., x^k, with the help of non-linear programming. Then, the process is iterated in the hope that the solution will converge to a better solution, e.g., x^*. Solving the optimal sizing of the DG issue is suggested by the authors in [70,93].

4.3.7. Hybrid Optimization Algorithms

In earlier days, the power system problems were mostly solved with conventional computational methods, such as the N-R method, the linear and non-linear programming methods, the quadratic and interior point methods, etc. [228]. However, in the last decade there has been a progressive evolution towards the use of the numerical algorithms with the physics-inspired, geography-inspired, social-culture inspired, and music-inspired optimization algorithms. Nevertheless, the fuzzy-based approach and the neural network-based computation has also been used largely. The obvious reason to use of these numerical optimization algorithms over the conventional computational methods is their robustness, their handling of large sets of data, and their initial search and convergence levels [228]. However, in the most recent years, there has been an increasing trend towards the hybridization of two or more optimization algorithms to solve the real-world problems. The results of these hybridizations give the most feasible solutions by utilizing the advantages of each algorithm or method. Moreover, it also increases the possible accuracy and computation time. The most generic hybrid optimization algorithms for the optimal placement and sizing of distributed generations in the distribution system are realized as: GA–PSO [27]; LSF + ALOA Ant lion OA [36]; LSF + PSOGSA and MFO [37]; PABC and HAS particle artificial bee colony and harmony search algorithm [38]; hybrid—tabu search and GA [188]; GA–GAMS [45]; PSOHBMA–PSO [51]; hybrid ACO–ABC [62]; location sensitivity index–GA [67]; CSO–MCS [75]; ICA–GA [87]; GA–PEM with chance constraints [193]; hybrid PSO with SFLA [114]; hybrid SFLA–DE [117]; SVM–MOPSO [122]; MCS–GA [186]; and GA and MO [154]

5. Tools Used for Optimal Multi-Objective Planning of DGs

It has been observed that most of the authors used MATLAB software for both load flow analysis and the optimization tool. However, a few authors used the PSAT, Digsilent, OpenDSS, etc., software for load flow analysis, and multi-objective optimization was carried out with MATLAB environment. The breakdown of most of the literature is shown in the following in Table 2.

Table 2. Tools used for optimal multi-objective planning of DGs.

S.No.	Tools Used for Optimal Multi-Objective Planning of DGs	References
1	MATALB	[21–23,25,41–44,47,50,52–54,56–69,75,77,80,125,143,161,169–172,177,178,183,191,229–244]
2	Digsilent and GARP3	[146]
3	MATPOWER and MATLAB	[245]
4	Digsilent and MATLAB	[246]
5	MATLAB and GAMS	[45,144]
6	OpenDSS and Matlab	[101]
7	PSAT ad MATLAB	[247]
8	Did not report in their manuscripts	[24,142,145,147–154,248–253]

6. Review Findings/Critical Analysis

The review considers the continuous developments and the research on utilizing multi-objective optimization algorithms for the optimal placement and sizing of DG for radial distribution networks. The attempts to utilize either the analytic method or the numerical intelligence algorithms require a considerable amount of time and effort. The selection of the optimization algorithm and the trade-off for DG placement and sizing are mainly based on the expert knowledge in and experiences of the available research. However, there are still certain challenges and opportunities that exist in coping with the DG optimization problem.

The existing research limitations in this domain:

- The studies considered for DG placement and sizing mainly consider two or three objectives; beyond that, the optimization problem becomes complex. Therefore, some methods need to be adopted for problem decomposition, handling constraints, reduction in dimensions, and convexification to simplify the convoluted optimization problem without damaging the optimized solutions.
- The hybridization of two or more optimization algorithms has the benefit of increasing the search space and giving the most feasible solution, and it has a good level of convergence. It has been observed from the literature that the optimal placement and sizing of DG in the distribution system has not been explored much with different optimization algorithms.
- The most commonly and widely used multi-objective optimization algorithms are the genetic algorithm and particle swarm optimization. In addition to that, their hybridization with other algorithms is the current trend among the researchers and scientists working with DG placement and sizing.

- Exploring the use of hybrid optimization algorithms for the intermittent renewable generation will be more effective in finding the optimal placement and sizing of renewable generations and will decrease its computational time.
- Mainly, the researchers working with multi-objective optimization do not report algorithm efficiency, efficacy, convergence, iterations, and computational time and system requirements. In addition, the performance metrics of the optimized solutions are necessary to justify their optimized results. In contrast to that, the researchers compare their results with respect to the objective functional optimized values.
- Some new algorithms inspired by various physical and biological phenomena have been focused on which also need attention for their performances in DG placement and sizing. Moreover, a few of the algorithms, such as the pigeon-inspired, membrane computing, load concentration, and evolutionary strategy have been utilized in other applications; these can be employed for this multi-objective optimization problem.
- The optimal DG placement and sizing has preferably deployed dispatchable generation systems while conducting simulation studies. However, there are renewable energy sets which have an intermittent power supply and are uncertain in their delivery of power when required. The research can be extended to both dispatchable and non-dispatchable types of DG units.
- Most of the study considers the generations with unity power factor, However, there is a need to include the power factor for observing the non-unity operation.
- The literature shows that 88% of researchers had incorporated a constant peak load for the optimal installation of distributed generations. However, there is an acute need to check uncertain generation with stochastic load demand variations.
- The reactive power compensation with capacitors banks considered for the optimization of DG proposes some continuous values for their size. However, there are standard rated capacitors available in the market which pose significant system challenges when the exact capacitor size has not been installed.
- The intermittent nature of renewable resources may have certain challenges in coping with the load demand; however, the hybridization of multiple renewable DGs would offer the challenge of optimization. The co-existence of hybrid renewable resources should be considered with a practical network configuration strategy for their smooth operation. These can be integrated with conventional generation; therefore, an economic modeling and optimization would be the prime consideration in future research.

7. Conclusions

In this paper, an attempt was made to review the multi-objective optimal placement and sizing of DG in the radial distribution system. The presented literature review draws the attention of power experts, investigators, and researchers to analyze the trends of a decade's worth of surveys for the optimal placement and sizing problem of DGs in distribution systems. The most important factors are the decision variables and the objective functions, the optimization techniques and comparisons, the algorithms that are validated on various types of load and in different distribution systems, and the integration of dispatchable DGs and non-dispatchable DGs, along with the kinds of uncertainty modeling. Moreover, it is also observed that the analytical methods are giving accurate results for small networks. However, for large and complex systems new and hybrid optimization techniques need to be adopted for effective and reliable solutions.

8. Future Recommendations

From the systematic literature review and critical analysis it is found that following future areas for the optimal multi-objective placement and sizing problem of distributed generation need to be explored:

- From the review, it was found that a lot of research efforts from developing countries have already been included to model the optimization tools for optimal integration of DG in the distribution system. Among the optimization methods, the analytical methods are not computationally efficient for large and complex systems. On the other hand, the researchers have also put forward and proposed the meta-heuristic optimization algorithm, which has an effective and reliable optimum solution. Due to the nature of the problem, it can be said that there is still room for improvement and recommendations for more efficient optimization algorithms that have strong competencies in the exploration of the global optimum.

- It has also been observed that many parameters in the electrical power system are uncertain by nature, i.e., wind and solar DG, electrical load, and the market price for fuel and electricity, etc. However, most of the presented literature does not include the uncertainty parameters in the studies For secure and reliable power delivery, it is highly recommended that the proposed models of the future should include the stochastic nature of inputs in solving the DG placement problem.
- Fluctuations in the primary source of renewable DGs in peak time give rise to the concept of energy storage. The presented literature lacks the usage of DGs and energy storage as a combined model. The addition of DGs and energy storage in distribution systems provides continuous, ecologically friendlier power, and reduces the intermittency of renewable DG inputs. Hence, it is highly recommended to explore the effects of renewable DGs on energy storage.
- Among the renewable DER used in the literature, the use of micro-turbines, combined heat, power, and biomass are rarely used in the studies. The suggested renewable-based DG in distribution system needs to be explored, and it is expected that the integration of these DGs could have a positive impact on long-term planning.
- The DG placement and sizing varies with different load models, and most of the existing literature uses the static load model. As such, the study also needs to focus on different types of voltage-dependent load models.
- Practically speaking, the distribution network is large and complex. A large number of buses and branches exist, but most of the present literature has validated its optimization algorithms on a very small-scale distribution network. Hence, it is recommended that the forthcoming models should be applied to real or larger distribution systems.
- It is also recommended that the application of the installation of DGs be further extended for the expansion and protection of the existing distribution systems.

Author Contributions: M.K. conceptualized and prepared original draft, A.M.S. review and edit, W.U. and L.K. carried formal analysis and provides funding. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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