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Review article

Distribution network expansion planning: An updated review of current methods and new challenges

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ABSTRACT

Many studies have been conducted on the distribution network expansion planning (DNEP) problem in recent years. The primary goal of this issue is to satisfy electric load demand, taking into account economic and technical considerations. In the past, this planning was done in a centralized manner with all the information available. The restructuring of power networks and the emergence of renewable energy sources (RESs), energy storage systems (ESSs), and new market players with different interests have led to extensive changes in the DNEP issue. Subsequently, the solving methods of the DNEP problem will be important because many new goals, constraints, and other factors have caused the problem to become non-linear and non-convex. This paper prepares a comprehensive study on the DNEP problem from different aspects such as objective functions and constraints, design variables, planning horizon and phases, planning and system types, uncertainty, distributed generations (DGs) and storage units, planning level, solving methods, load models, and environmental issues. Finally, future research trends such as handling the conflicts, solving approaches, and other points facing the DNEP problem are suggested.

1. Introduction

1.1. Motivation and aim

With the growth of human societies, the need for energy has increased dramatically, and humanity has used various forms of energy to meet this demand. Meanwhile, electric energy has received particular attention due to its unique advantages, including the ease of generation and transmission. Therefore, the power system is a set of tools and equipment responsible for the generation, transmission, and reliable distribution of electrical energy for consumers. The growth of electric energy required by consumers, the changes in electric power over time, the limitation of fuel supply to power plants, the limitation of power generation, the limitation of the power flow through the lines, and the limitation of the loading of transmission and distribution stations, reveal the necessity of conducting a detailed study in the power system. In general, these studies can be divided into two parts: operation and planning studies. In operation studies, the aim is to provide the energy needs of consumers reliably and optimally with minimum cost at present. Here, it is assumed that the existing equipment is sufficient. In other words, the existing equipment can supply electrical energy optimally. Studies such as generation planning, economic dispatch, and optimal power flow can be categorized as operation studies. Proper planning and management must be done to have a stable system and to have the appropriate level of reliability and security. In the planning studies, parts of the system have lost their ability to supply the energy needed by consumers, and the purpose is to determine the characteristics, type, time, and place of installation of new equipment in the future so that in addition to the desired adequacy of the system, the cost of expansion also decrease.

Distribution network expansion planning (DNEP) means when, where, and how much electric equipment must be installed in the network so that the economic and technical requirements of the network are met within a time horizon. One of the parts of planning in the power system is the DNEP problem, which, due to being closer to the consumer, requires detailed planning to prevent load interruptions and reduce the level of system reliability.

1.2. Background and contribution

As was stated, the increasing progress of the industries, the growth of the consumption load, as well as the lack of renewable energy and their environmental pollution, have prompted the electric companies to design and plan more precisely in a competitive environment to provide the consumption power of the customers at a reliable level with the lowest cost. Therefore, many good and comprehensive studies have been done regarding the DNEP problem.

Due to the importance of the DNEP issue, in 1993, the first review study on the DNEP methods was conducted [1]. In [2–4], a

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Abbreviation

ABC	Artificial bee colony
ACS	Ant colony system
AIS	Artificial immune system
BES	Battery energy storage
BF	Bacterial foraging
DG	Distributed generation
DNEP	Distribution network expansion planning
DP	Dynamic programming
DS	Direct solution
EA	Evolutionary algorithm
ESA	External scenario analysis
ESS	Energy storage system
EV	Electric vehicle
GA	Genetic algorithm
GWO	Grey wolf optimization
HSA	Harmony search algorithm
ICA	Imperialist competitive algorithm
LL	Lower level
LPO	Lion pride algorithm
ISA	Internal scenario analysis
LV	Low voltage
MILP	Mixed integer linear programming
MINLP	Mixed integer non-linear programming
MV	Medium voltage
NLP	Non-linear programming
OO	Ordinal optimization
PDF	Probability distribution function
PDN	Primary distribution network
PEV	Plug-in electric vehicle
PHA	Practical heuristic algorithm
PSO	Particle swarm optimization
PV	Photovoltaic
RESs	Renewable energy sources
SA	Simulated annealing
SDN	Secondary distribution network
SOCP	Second order cone programming
TS	Tabu search
UL	Upper level

comprehensive review was done regarding the distribution network expansion planning from different perspectives in 1997, 2000, and 2002, respectively. In [5], a review of the studies conducted regarding the DNEP considering distributed generation (DG) sources has been done. In [6], the DNEP models have been evaluated only from the point of view of electrical energy storage (EES) until 2017. In [7], the DNEP models are categorized and reviewed from the reliability perspective. In [8], the DNEP models have been reviewed and evaluated considering system type, planning variables, and, objective functions until 2015.

As seen in Fig. 1, over time, the number of studies in this field has significantly increased. It should be noted that in this figure, all issues related to the distribution network, including operation and planning, are taken into account, and it is not only about planning. However, due to the new structures of the power system as well as the separation of the generation, transmission, and distribution sectors from each other and the definition of new and sometimes conflicting goals by the market players, the issue of the DNEP problem has undergone many changes from various perspectives. For this reason, research works in this regard are increasing enormously, as Fig. 1 confirms this.

In this paper, about 170 studies from various aspects have been categorized, reviewed, and analyzed since 2005. An attempt has been made to express their innovations and design considerations as much as possible. Also, the approaches to solving the problems of these studies have been described in detail. After evaluating the past studies, the upcoming challenges related to the DNEP issue have been stated so that they can be examined and analyzed shortly. This review paper tries to be a good guide for distribution network planners and engineers, and it also helps the reader to plan the distribution network according to his/her criteria. The contribution of this paper can be listed as follows:

- A comprehensive survey of studies that address the distribution network expansion planning models from different aspects
- A comparison including the main contributions and features of each study
- A comparison of solution methods, including decision variables, types of system, planning horizon, planning levels, uncertainties, applying DGs/storages, and environmental issues; this comparison can be applied as a guide to using the most suitable method or aspect according to the requisites of the planner or network
- Providing suggestions for further research work, including problem-solving approaches and planning levels
- A discussion about future work/research/challenge trends for the DNEP models

1.3. Paper organization

The paper is organized as follows. Section 2 describes various aspects of the DNEP problem. Section 3 describes the objective functions and main constraints of the DNEP problem. Section 4 states the most crucial design variables in the problem of distribution network expansion. In Section 5, the horizon and phases of the DNEP problem are mentioned. In Section 6, the types of planning and the type of system are reviewed. In Section 7, one of the essential factors in network expansion planning, called uncertainty, has been investigated. In Section 8, the effect of DGs and storage units in expansion planning is stated. In Section 9, planning levels have been stated. In Section 10, different load models are described. In Section 11, environmental studies are described from the perspective of the DNEP problem. In Section 12, solving methods of the DNEP problem are comprehensively presented. In Section 13, all the studies reviewed in this paper have been wholly and comprehensively categorized and compared. In Section 14, the challenges and future works are stated, and finally, the conclusion is given in Section 15.

2. Aspects of the DNEP

Since the distribution networks are the points of contact between the electricity industry and the consumers, the technical and legal issues of such communication are more towards them. At the same time, the distribution company itself must also establish its relationship based on economic and technical relations with the power plants as a producer. Coordinate electricity and transmission companies. In addition, DGs that are directly connected to medium and low-voltage networks create complex technical issues in terms of design. Therefore, various aspects can be considered for the DNEP, and the network designer considers these aspects according to his requirements. According to Fig. 2, the DNEP can be categorized from several aspects. In the following sections, these aspects are discussed in detail.

3. Main objectives and constraints

The most crucial goal of the DNEP problem is to supply the electric load by specifying the location and time following the demand growth in a specific time horizon with the lowest cost. In other words, the purpose of the DNEP is to provide an expansion plan for satisfying the

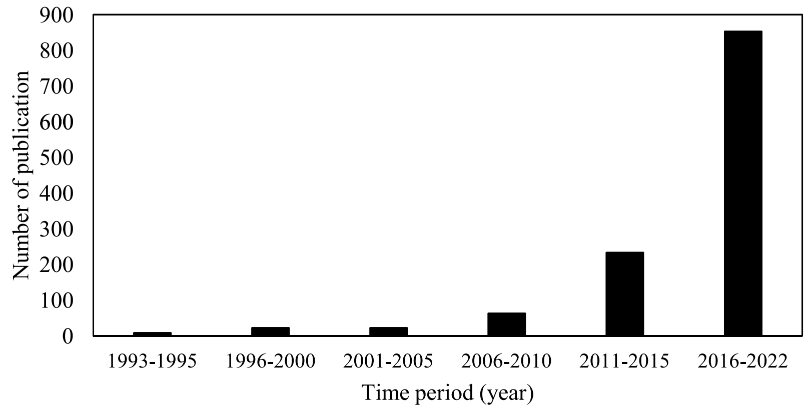

Fig. 1. Number of publication about power distribution system planning.
Source: Adapted from Google Scholar.

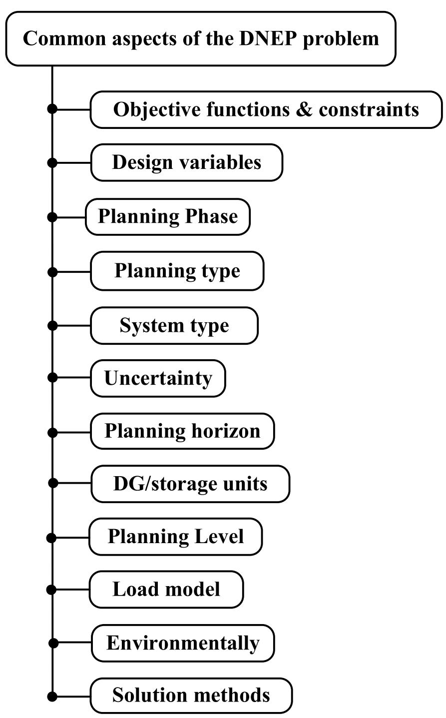

Fig. 2. Aspects of the DNEP problem.

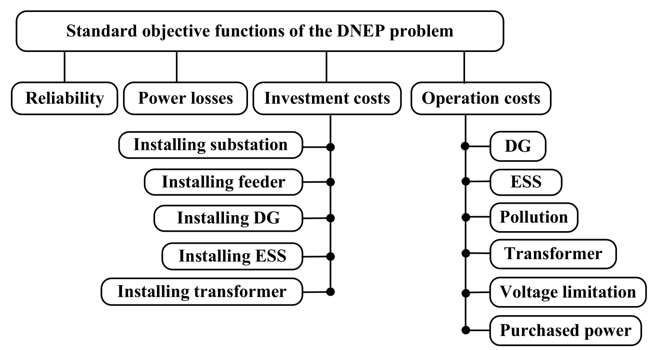

Fig. 3. Standard objective functions in the DNEP problem.

economic and technical requirements in such a way that the reliability level of the network is maintained or improved. The meaning of economic and technical requirements is that, firstly, the investment costs are minimized. Secondly, the distribution network does not limit the economic operation of the network. Therefore, the DNEP is defined as an optimization problem subject to the technical constraints of the network, and any plan that is carried out in connection with the distribution systems must meet the following minimum conditions:

- The expansion plan must be able to supply the energy required by the system, while also satisfying the required technical standards.
- Reduce investment and operation costs of the network.

The objective functions can be single-objective, multi-objective, or bi-level, depending on the problem structure. The standard objective functions in the DNEP problem are shown in Fig. 3.

The most common constraints in the DNEP problem have been shown in Fig. 4. Some of these constraints, including power flow, as well as the capacity of the used equipment, are an integral part of this issue. However, there are some optional constraints that are actually at the discretion of the network planner. In [9,10], reliability-constrained for the DNEP problem is investigated. In [11], a new reliability-constrained computational performance under uncertainties is investigated in the DNEP problem.

In [12], reliability assessment is equivalently implemented through algebraic expressions whereby decision variables of the optimization process explicitly represent the effect of the network topology. In [13], a robust model is used for the planning considering microgrids, DGs, and demand response programming, and applying a contingency/reliability-constrained method, the model is solved. In [14], a resilience-constrained approach is applied for the expansion planning of a power–heat–gas distribution network. In [15], a mathematical DNEP model is proposed in which some practical operation constraints, such as on-load tap changer tap adjusting frequency and substation voltage variation, are incorporated.

In [16,17], the DNEP considering transformers with adjusting taps, DGs, and capacitor bank is investigated. In [18,19], the *N-1* criterion is used for the proposed planning issue. In [20], AC power flow constraints have been incorporated into the proposed planning considering wind resources. In [21], the planning is solved in the presence of microgrid operation and reliability index.

4. Design variables

There are various variables in the DNEP problem. Fig. 5 shows the standard variables used in this problem. These various variables have caused various solution approaches to be used in facing this problem. For example, the combination of these variables causes the existing planning to be divided into two categories, linear and non-linear, or in combination with binary variables; the planning problem becomes mixed integer linear (or non-linear) programming.

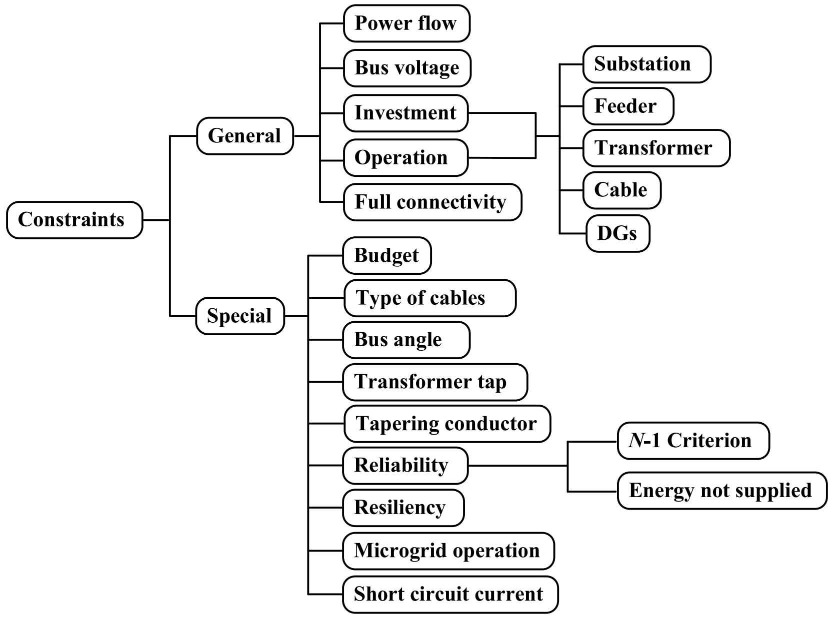

Fig. 4. Common constraints in the DNEP study.

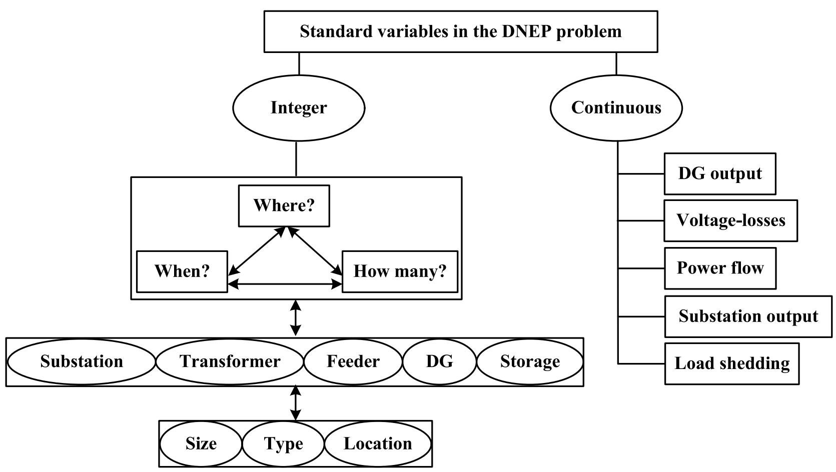

Fig. 5. Standard variables in the DNEP study.

5. Planning horizons and phases

The DNEP horizons are divided into two parts: static planning, which does not include scheduling, and dynamic planning, which includes scheduling problems and objective functions.

Planning studies generally have two phases. In the first phase, different expansion alternatives in the planning horizon are obtained with the help of simplified models such as the DC load flow model, and in the second stage, the expansion alternatives are evaluated with more detailed analysis including AC load flow, short circuit analysis, and reliability. The various methods that are presented for the DNEP usually consider only the adequacy criterion (first phase) and consider the security part in the second phase of the planning, for example, in [22–24].

6. Planning and system types

The DNEP problem is an optimization problem, and this optimization problem can be expressed in two ways: new planning and reinforcement planning. In the new plans, the planner chooses new ways or places for the construction of new feeders or substations and DGs (design) according to the environmental limitations. In this way, new ways or power will be added to the network.

In reinforcement planning, the network is usually reinforced in some feeders. For example, double-circuiting an existing line or feeder and increasing the capacity of substations (transformers) are examples of these plans.

From the point of view of the type of system, the separation of the generation, transmission, and distribution system and the new definition of the tasks of the distribution network in the restructured environment have caused extensive changes in planning modeling and the emergence of new problems. Therefore, it is necessary to review the planning approaches of the distribution network according to the opinion of the market players [25–28].

7. Uncertainty

The basis of all planning models is information estimated by forecasting methods. For example, in the DNEP problem, several input parameters are obtained by prediction, including:

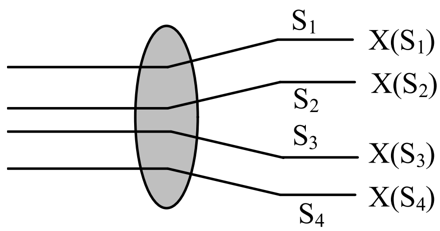

Fig. 6. Optimal scenarios and responses.

- The growth of electrical load, which itself depends on many parameters, including economic growth, the price of other energies, strategic energy supply policies
- Using renewable energy resources such as wind and photovoltaic energy
- Electricity market rules and regulations, environmental requirements, and other effective laws
- The price offered by small producers in the distribution network, which depends on several parameters, including fuel price forecast and electric energy price

7.1. Scenario analysis

The basis of scenario analysis is that the future is predicted by a limited number of scenarios. Then the expansion plan is determined in such a way that it works well in all scenarios. In other words, by examining each scenario and its optimal solution, a globally optimal solution can be achieved in which all scenarios have a suitable efficiency. It should be noted that the scenario means a possible future in which uncertain parameters are specified. In this way, depending on the number of uncertain parameters, a limited number of scenarios can be defined in a way that covers all possible events in the future. There is no specific method for defining scenarios, and in the meantime, the planner's experience plays the primary role.

7.1.1. External scenario analysis

The usual procedure in planning with the help of scenario analysis is to determine the optimal response for each scenario and then choose the best response among these optimal responses. This process is known as external scenario analysis (ESA) because the decision is made after optimization. In Fig. 6, four different scenarios and the optimal responses of each are shown. In the external scenario analysis method, with the help of different decision-making methods such as probabilistic methods, minimum maximum regret method, and other methods, one of the optimal answers $X(S_1)$ to $X(S_4)$ is selected as the best answer. More comprehensive discussions can be found in [29–31].

In [32,33], to evaluate the impact of RESs in the DNEP, the ESA has been used. In [34], to check the reliability of the DNEP in the presence of uncertainties in electric load and RESs, the ESA has been used. In [35], a method based on genetic algorithm (GA) and the ESA is proposed to consider the uncertainties in the DNEP problem. In [36,37], the placement of feeders and DGs has been done by considering the uncertainties of electric load and DGs by the ESA. In [38], to reduce the investment and operation costs, the positioning of DGs has been done by the ESA. In [39], uncertainty-based multiple scenarios are proposed by probability distribution functions (PDFs) to strengthen the robustness and reliability of the DNEP problem.

7.1.2. Internal scenario analysis

In the internal scenario analysis (ISA) method, all scenarios are considered simultaneously in the optimization process. The ISA method can be divided into two categories:

- Scenarios aggregating
- Combined method with optimization of multiple objective functions

In the scenario aggregation, firstly, the scenarios are divided into several different periods. Then, with the help of simultaneous optimization, only the optimal response of the first period is determined so that this response is the most consistent with the global response of all scenarios in future periods.

The multi-objective optimization model has an inherent ability to combine with scenario analysis because, in this model, it is possible to define risk indicators as objective functions along with other objectives. More comprehensive discussions in this regard can be found in [40].

This method has been used in [41,42] for the DNEP problem, which tries to investigate the effect of uncertainties in the proposed model. Appropriate indicators such as the maximum regret index as a measure of the robustness of the response and the maximum adaptation cost as a measure of flexibility are used, and these risk indicators are also used as the objective function in the problem.

7.2. Multi-stage stochastic programming

One of the interesting issues raised in the discussion of the DNEP problem is using two or multi-stage stochastic programming. This type of mathematical programming is used to make decisions in environments with uncertainty. This method is explained in detail in [43]. In [28,44–47], the two-stage stochastic programming is applied to the DNEP problem.

7.3. Robust optimization

Another technique of examining uncertainties in the discussion of the DNEP problem, which is of interest to researchers, is robust optimization. This method is explained in detail in [43]. In [48], a robust optimization model is proposed in which the uncertainty of RESs, load, and traffic demand are jointly considered. In [49], a robust joint DNEP problem is proposed in the presence of electric vehicle (EV) charging stations. In [50], a new robust DNEP problem that investigates non-network solutions in a deregulated retail market, including the closed-loop demand response and other controllable strategies, is proposed.

8. DG and storage units

In recent decades, to increase operating efficiency and encourage investors, the DNEP has undergone fundamental changes from the point of view of management and ownership. These developments, on the one hand, and factors such as the problems of constructing feeders, new distribution lines, and substations, on the other hand, as well as the reduction of greenhouse gases, have caused an increase in the use of small-generation units under the name of DGs.

Considering the colorful role of using battery energy storage (BES) and encouraging governments to store electric energy by RESs and use it during peak times or sell it to the electric grid and the development of electric vehicles, the DNEP problem will change. In [51], the DNEP problem in the presence of charging stations for electric vehicles is considered. In [52], a hydrogen storage system is used in the DNEP problem. In [53], the DNEP problem with centralized and distributed energy storage system (ESS) is evaluated. In [54], a new DNEP problem with high penetration of plug-in electric vehicles (PEVs) and RESs in the presence of uncertainties is presented. In [55], the ESS is employed in the proposed DNEP problem. In [56], the probabilistic DNEP model in the presence of vehicle-to-grid is investigated.

In [57], a DNEP model by considering shared electric vehicle parking lots, solar-based DGs, and BES systems is investigated. In [58], the DNEP problem is investigated by coupling EV parking lots using an

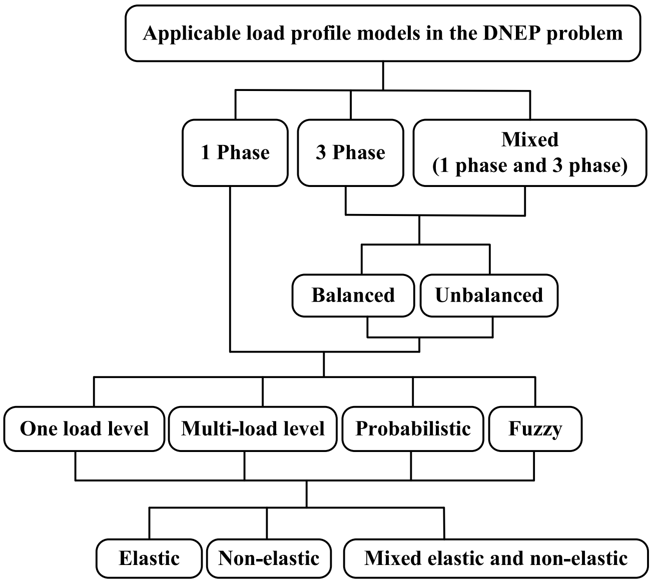

Fig. 7. Different types of load models that can be used in the DNEP problem.

efficient probabilistic algorithm. In [59], dispersed storage systems are incorporated into the proposed DNEP problem. In [60], a framework to assess the investments in BES systems for the DNEP problem in the presence of high penetration of solar photovoltaic (PV) resources is presented. In [61], the consideration of uncertainty in the DNEP problem, including EVs and the possibility of joint investment in EV charging stations in the presence of wind generators, is described. In [62], a stochastic DNEP model incorporating the wind-based DGs and storage units is presented. In [63], the DNEP problem is solved in the presence of various energy storage technologies. In [64], the DNEP problem is solved through optimally sized and placed distributed energy storages. In [65], the impact of EVs on the DNEP problem considering RESs, ESS, and charging stations is investigated. In [66], the DNEP problem in the presence of ESS is done to minimize grid losses. In [67], a multi-objective framework is proposed for the DNEP problem incorporating EV charging stations.

9. Planning level

The DNEP can be used in the primary distribution network (PDN) and secondary distribution network (SDN). The PDN and SDN distribution networks are medium voltage (MV) and low voltage (LV) networks, respectively. Regarding the levels of planning in distribution networks, it is essential to mention that in most studies, planning has been done only in the PDN or only in the SDN, and few studies have done planning in these two levels at the same time (integrated). In other words, since in most of the studies, both PDN and SDN are considered separately in the planning process, the mutual effect of each planning in the other network cannot be seen.

10. Load model

Among all the effective factors in the design and scheduling of main network reinforcements, the predicted load is the most sensitive. Therefore, it is necessary to pay special attention to formulating effective and reliable laws to cover this aspect of planning operations [68]. Different types of load models can be used in the DNEP, as seen in Fig. 7.

11. Environmentally issues

One of the important issues considered in the discussion of the DNEP is the use of RESs to reduce pollution. Therefore, this problem has caused the objective function of pollution to be considered an independent objective in the issue of the DNEP. In [42,69,70], the pollution emission has been considered in the objective functions. In [71], the DNEP problem is done in the presence of mitigating greenhouse gas emissions of power systems via carbon taxation.

12. Solution methods

Different approaches have been used to solve the DNEP. These methods can be divided into two categories: mathematical and heuristic/ meta-heuristic methods. The main reason for using heuristic/ meta-heuristic methods is due to the non-linear and non-convex nature of the DNEP problem. Network losses and the radial constraint of the distribution network are the main reasons for the non-linearity and non-convex of the DNEP problem. In Fig. 8, there is an overview of the DNEP problem-solving methods, and brief explanations are given in the following.

12.1. Mathematical methods

The mathematical methods used have the following characteristics: the optimal solution of this type of problem is mostly accurate, and the time spent on calculations is generally low. On the other hand, mathematical approaches have disadvantages, such as managing the equations used in an optimization model is complex, and to insert a new constraint, the optimization problem model must be updated and new equations added. Various mathematical methods and approaches have been presented to solve the DNEP problem, including:

- Mixed integer linear programming (MILP) [9,10,24,52,54,72–79]
- Non-linear programming (NLP) [80–83]
- Dynamic programming (DP) [84–88]
- Second-order cone programming (SOCP) [15,44,59,71,89–91]
- Ordinal optimization (OO) [51]
- Direct solution (DS) [92,93]

12.2. Heuristic and meta-heuristic methods

As mentioned, one of the main reasons for using heuristic and meta-heuristic methods in the discussion of DNEP is the non-linear nature of this problem. Considering that the answers of heuristic and meta-heuristic methods may be trapped in local optima, different methods have been used in the studies, and various comparisons of these methods have been made. The heuristic and meta-heuristic methods used to solve the DNEP problem can be described as follows:

12.2.1. Genetic algorithm (GA)

In [94–102], the GA is applied to solve the DNEP model. In [103], the location and size of the distribution transformer station are considered by a new GA developed for the DNEP problem. In [104], an algorithm-based GA is proposed to get an effective and low-cost plan for load balancing among phases, the conductors' adequate dimensioning, and the transformer located at the center of the SDN loads. In [105], the DNEP problem is investigated by applying GA to choose the best topology for the network. In [45,56,106–109], a multi-objective optimization approach based on GA named non-dominated sorting GA II (NSGA II) is used. In [110], a GA that is dedicated to the DNEP is proposed, with incremental expansion scheduling as a dynamic programming problem. In [111], a multi-objective programming-based GA and Component Geographical Information Systems is proposed for the DNEP. In [112,113], a new approach based on graph theory and GA is presented for the DNEP model. In [114,115], the DNEP problem is considered by the GA in the presence of optimal power flow. In [35], Modified GA for solving the presented DNEP model under uncertainty is proposed. In [116], a discrete GA is used to solve the proposed DNEP with high performance and accuracy. In [117], an improved GA in combination with a spanning tree method, is presented to investigate the proposed DNEP model with a manageable computational cost.

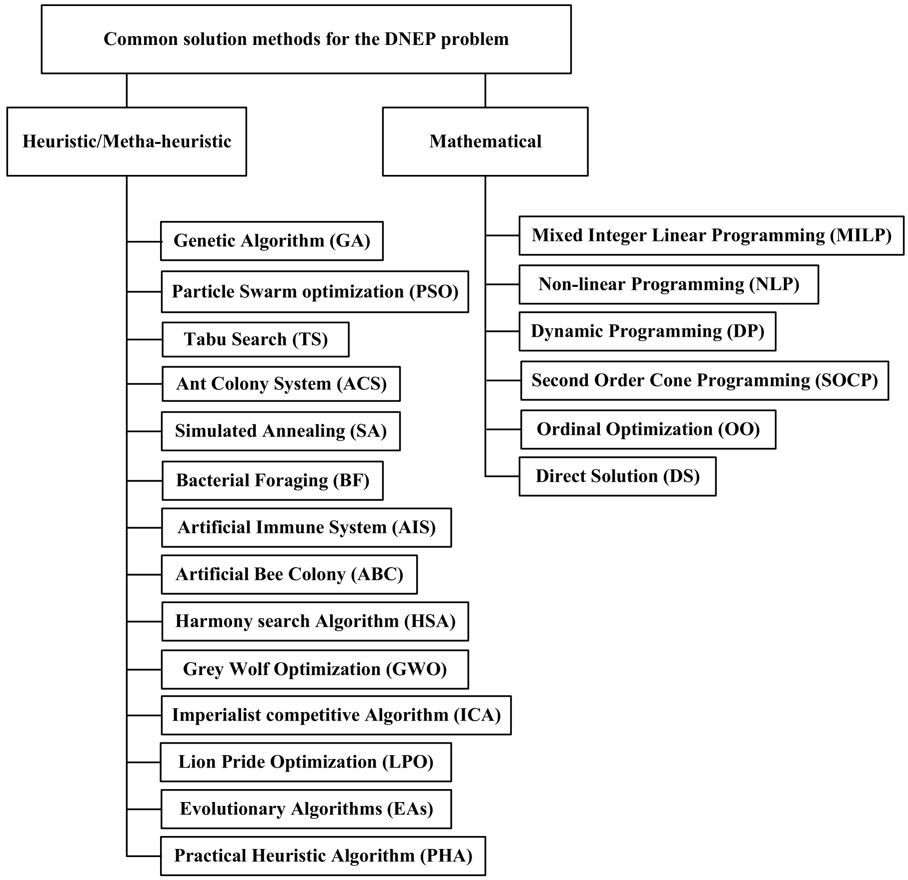

Fig. 8. An overview of the methods used to solve the DNEP problem.

12.2.2. Particle swarm optimization (PSO)

In [55], the PSO method is employed to solve a mixed integer nonlinear programming (MINLP) for the proposed DNEP in the presence of EESs. In [118], the discrete PSO method is used for solving the DNEP by finding distribution substation and transformer ratings and locations. In [93,119], the discrete PSO method is used for the DNEP problem. In [120,121], the PSO is used to solve the DNEP model presented under uncertainty considering DGs. In [122], the modified PSO is employed to solve the DNEP model considering DGs and storage units. In [123,124], the multi-objective PSO method is applied to solve the proposed DNEP model. In [125], the PSO method is applied to solve the DNEP model considering ESS.

12.2.3. Tabu search (TS)

In [126], a TS algorithm is proposed to investigate multi-objective fuzzy programming for the DNEP problem. In [127], a TS algorithm is employed in combination with a neighborhood structure developed to explore the physical characteristics of specific to consider the DNEP model on the LV side. In [128,129], the TS algorithm is combined with Voronoi polygons to investigate the DNEP model on the LV side. In [130], a TS-based method with an embedded stochastic load flow analysis is proposed to investigate the DNEP model. In [131], a multi-objective TS method is presented to investigate the multistage DNEP model. In [132], for solving the proposed DNEP model in the MV distribution system, a multi-objective programming-based TS methodology is presented. In [133], it is shown that the TS algorithm performs better than the simulated annealing algorithm for solving the used DNEP model. In [134], a TS method is applied to solve the proposed bi-level programming. In [135], a combination of the improved PSO algorithm with the TS method is investigated to solve the proposed DNEP model.

12.2.4. Ant colony system (ACS)

In [136], a dynamic ACS algorithm is presented to solve a proposed DNEP with the minimum cost distribution systems reinforcement strategy problem considering DGs.

12.2.5. Simulated annealing (SA)

In [137], A method for the DNEP problem is proposed and solved using the SA algorithm. In [138], the SA algorithm is proposed to guide the decomposition and solution process for the proposed DNEP problem.

12.2.6. Bacterial foraging (BF)

In [36], the DNEP problem provides optimal feeder routes to meet the loads by the BF technique.

12.2.7. Artificial immune system (AIS)

In [139], an AIS algorithm is proposed for solving the presented DNEP problem, and In [140], the model applied in [139] is investigated in the presence of load uncertainty.

12.2.8. Artificial bee colony (ABC)

In [141], dynamic planning for the DNEP problem in combination with the unit commitment problem is presented, and with the ABC algorithm, the planning is done.

12.2.9. Harmony search algorithm (HSA)

In [70], the proposed DNEP model considering uncertainties is investigated with improved HSA. In [41,42], the DNEP as a multi-objective planning problem in the presence of risk indices is solved by the HSA in combination with Pareto levels. Also, In [33], the DNEP as a multi-objective planning model in the presence of uncertainties is solved using the HSA. In [142], multi-objective HSA is used for the DNEP problem, considering future demand growth and DGs.

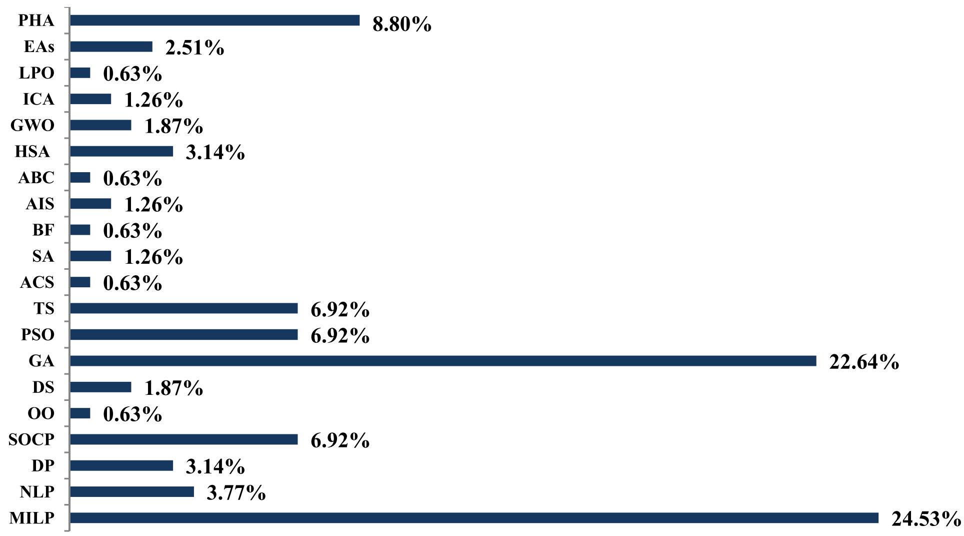

Fig. 9. Statistics of solution methods for the DNEP problem.

12.2.10. Grey wolf optimization (GWO)

In [143,144], the DNEP planning focusing on DG placement is considered by GWO. In [145], a new mutation-improved GWO model is presented for the DNEP model considering BES and RESs.

12.2.11. Imperialist competitive algorithm (ICA)

In [146], the ICA is used to minimize the proposed objective function of the presented DNEP problem for a long-term period. In [46], a binary-modified ICA is used to solve a novel two-stage DNEP model considering DGs.

12.2.12. Lion pride optimization (LPO)

In [147], the LPO algorithm is employed to investigate the DNEP model in the presence of DGs as candidate equipment avoid uncertainties of substations and expansion of feeders.

12.2.13. Evolutionary algorithms (EAs)

In [148], a recombination-based EA is proposed for finding the optimal distribution system topology. In [149], an approach based on multi-objective collaborative programming considering EV charging systems is proposed for the DNEP problem, and to solve the problem, an EA is employed to seek the Pareto answers. In [150], a novel method employing a seeker optimization algorithm (SOA) is presented for the DNEP with simultaneous automatic reclosers allocation.

12.2.14. Practical heuristic algorithms (PHA)

In [151], a value-based probabilistic approach to investigate the employed the DNEP model. In [152,153], the constructive heuristic algorithm is applied for considering the proposed DNEP model. In [154], graph theory, as a practical approach that significantly reduces the complexities of the search algorithms, is used for the proposed DNEP model. In [155], a heuristic methodology is used to increase DG penetration in the DNEP problem. In [156], a statistical method for assessing general LV networks using a fractal-based algorithm is proposed. The DNEP problem is considered by the exchange-branch approach considering the spanning tree in [157] and also the dynamic programming in [158,159]. In [160], by dividing the main problem into two subproblems of checking feeders and checking distribution substations, the DNEP model has been solved using a set of hybrid methods. In [161], a new heuristic method based on a back-propagation approach combined with cost–benefit for the DNEP problem is presented.

12.3. Discussion about solution methods

In general, it can be said that the way to choose the mathematical solution method is based on the main structure of the problem and also the mental criteria of the planner.

Fig. 9 shows the statistics of methods and approaches faced with the DNEP problem. As it is known, the use of linearization methods as well as the use of intelligent methods, is evident due to the non-linearity and non-convexity of this problem.

The main advantage of the MILP solver method is the accuracy of its solution. If the DEP problem is well defined, the solution found using the MILP solver is the best possible optimal solution. Another advantage of this method is that it does not require parameter setting.

It is also worth mentioning that if the structure of the proposed problem is convex, then applying this linearization method can be the most effective method of solving the problem.

In the NLP solution method, due to the non-linear structure of the problem and starting the search from a suggested point, it is time-consuming and less used in solving problems. The DP solution method helps programmers optimize their algorithms by dividing complex problems into smaller sub-problems and reusing the solutions of those subproblems. The SOCP is a non-linear and convex programming that includes linear convex quadratic models as exceptional cases but is less common than semi-definite models. The ordinal optimization method concentrates on looking for well, or better answers and decreases the required simulation time, dramatically. The main advantage of using DS methods is speed, the need for computer memory, and decreasing the round-off error.

If the used problem is non-convex and non-derivable, the best method can be the use of heuristic/ meta-heuristic methods. Heuristic/ Meta-heuristic algorithms try to solve the problem of getting trapped in the local optimum. These types of algorithms are not dependent on a specific problem and define a general strategy that is fixed for solving any problem with the difference that the problem in question must be defined based on the existing strategy so that it can be solved.

In general, there is no remarkable difference between meta-heuristic methods because they all start from an initial population and try to reach the optimal point by using certain operators. The critical point in these algorithms is how they are implemented.

In the DNEP problem, GA, TS, and PSO are more popular due to their more straightforward implementation. Other meta-heuristic algorithms, including ACS, SA, BF, AIS, ABC, HSA, GWO, ICA, LPO, and EAs, should perform sensitivity analysis on their parameters to get the best performance from that algorithm. One of the disadvantages of

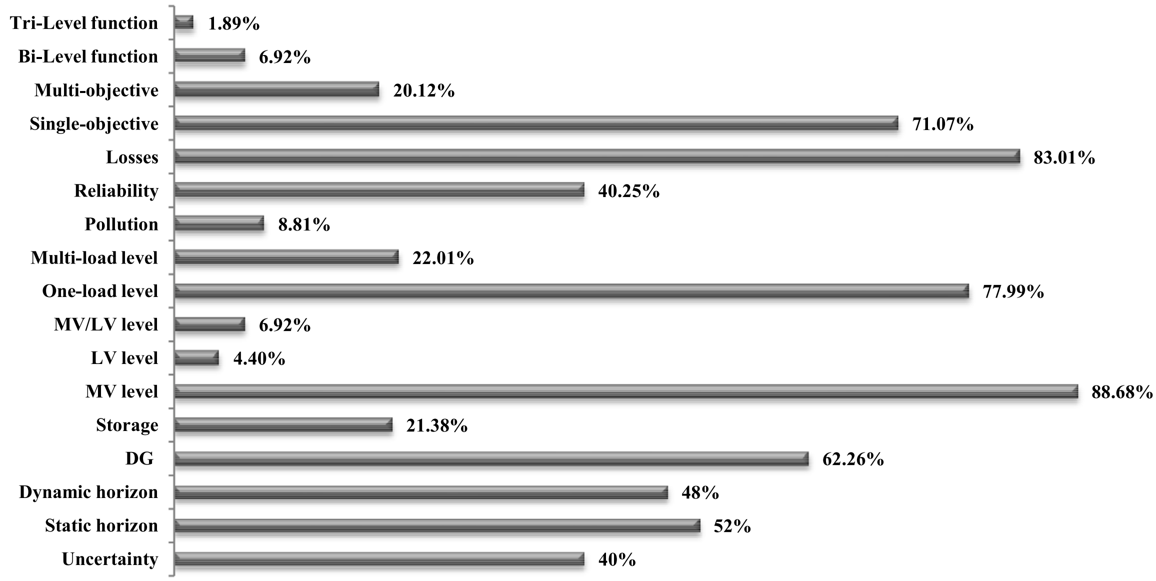

Fig. 10. Statistics of aspects used in the DNEP problem.

the ACS is that it has some shortcomings in the convergence speed and solution accuracy when dealing with a large amount of data. The ABC algorithm suffers from improper exploitation in solving complicated models. In the SA algorithm, the cooling must be prolonged to enforce the regularities of the layout. The BF algorithm has several drawbacks, including slow convergence speed, inability to jump from the local optimal state, and fixed step length. The HSA and AIS methods are very efficient in finding the global optimum, and the strength of this algorithm can be the easy adjustment of its parameters. The GWO algorithm has the advantages of fewer parameters, simple principles, and easy implementation. The ICA algorithm is computationally efficient and can be used for large datasets. The LPO algorithm provides optimal performance in terms of accuracy and speed of convergence in problems [162].

In general, the PHAs are problem-oriented and designed for a specific problem. Therefore, these algorithms cannot be used to answer different problems. In general, it can be said that MILP methods and GA are the most suitable methods for planning the DNEP problem.

13. Classification of conducted studies

In Table 1, the studies carried out regarding network expansion planning from various perspectives are detailed so that the necessary comparisons can be made quickly. In Table 2, innovations or objective functions based on design variables related to network expansion are presented, allowing the reader to analyze the studies from different aspects easily.

14. Discussion, challenges, and future works

Minimizing the investment cost has been considered from the beginning as the most crucial goal in the DNEP because it means the optimal use of financial resources and preventing excess investment. Considering the very high amount of investment required and the lack of financial resources in the infrastructure sector, which is the problem of almost all countries and distribution companies, this goal is of particularly important. All investment costs in the network will be ultimately paid by the users of the network, and therefore, an increase in investment means an increase in tariffs for the use of the distribution network. Thus, it is clear that the minimization of the investment cost of the network is the goal that is of interest to most of the stakeholders in the network, and considering it in the model will benefit most of the market players.

Since the distribution network planning model based on optimization with an objective function was presented in the seventies, until now, almost all research works have been done based on the development of this model. During the last four decades, research studies have been based on the following two approaches:

- Providing new and better efficient methods for problem-solving, including mathematical intelligence, or hybrid methods
- Changing the objective function of the initial model by adding items like operation cost, network losses, and other things

The above approaches have not changed even with the restructuring of the network and in such a way that most of the new planning models have followed the same basic structure of a single objective function and have considered objectives such as costs as the main objective function. In [42], a completely different model for the DNEP is presented for the first time. In this model, the network is modeled as an optimization problem with several objective functions, which covers many of the requirements of a suitable algorithm in the restructured environment. The proposed objective functions are non-equivalent, and it is possible that the risk indicators can be modeled as planning objectives, and compared to the cost functions, the optimal point was extracted in terms of acceptable risk.

According to Table 1, Fig. 10 summarizes the statistics of the aspects used in the DNEP problem.

As seen in Fig. 10, most of the studies conducted are at the MV level, and very few studies have integrated both LV and MV networks. In this regard, the use of bi-level models is suggested, which is a suitable tool for simultaneous planning in both MV and LV networks. A bi-level programming problem is a specific type of optimization problem where one level is embedded within another. This programming has two levels named upper level (UL) and lower level (LL). Subsequently, each level has its variables so UL variables are the optimal solution of an optimization problem in terms of LL variables. The bi-level programming can be done for the DNEP problem so that the MV network is considered at the UL, and the LV network is considered at the LL. This type of planning can be safely said to be the best type of planning, considering that different goals are pursued in the restructured distribution network. Fig. 11 proposes a general bi-level structure for the DNEP problem.

Of course, this case can be considered much more at a higher level, in other words, the simultaneous interaction of the transmission

Table 1
A comprehensive comparison of the studies done for the DNEP problem from different aspects.

Ref	Planning phase	Planning type	Planning system	Uncertainty	Planning horizon	DG	Storage	Planning level	Load model	Pollution	Reliability	Losses	Objective type
[9]	First	Reinforcement	Regulated	×	Dynamic	×	×	MV	Multi	×	✓	×	Single
[10]	First	Reinforcement	Regulated	×	Dynamic	×	×	MV	one	×	✓	×	Single
[11]	First	New & Reinforcement	Deregulated	budget	Dynamic	✓	✓	MV	Multi	×	✓	×	Tri-level
[12]	First	Reinforcement	Deregulated	Demand-RESs	Dynamic	✓	×	MV	one	×	✓	✓	Single
[13]	First	Reinforcement	Deregulated	Budget-RESs	Dynamic	✓	✓	MV	one	×	✓	×	Tri-level
[14]	First	Reinforcement	Deregulated	Demand-RESs	Dynamic	✓	✓	MV	one	×	✓	✓	Single
[15]	First	Reinforcement	Deregulated	RESs	Dynamic	✓	×	MV	one	×	×	✓	Single
[16]	First	Reinforcement	Regulated	×	Static	×	×	MV	one	×	×	✓	Single
[17]	First	Reinforcement	Regulated	×	Static	×	×	MV	one	×	×	✓	Single
[18]	First	Reinforcement	Regulated	×	Static	×	×	MV	one	×	✓	×	Single
[19]	First	Reinforcement	Regulated	×	Static	✓	×	MV	one	×	✓	✓	Multi
[20]	First	Reinforcement	Deregulated	Demand-RESs Budget	Dynamic	✓	×	MV	one	×	×	✓	Single
[21]	First	Reinforcement	Deregulated	×	Dynamic	✓	×	MV	Multi	×	✓	✓	Single
[22]	First	Reinforcement	Regulated	×	Static	×	×	MV/LV	one	×	✓	×	Single
[23]	First	Reinforcement	Deregulated	×	Dynamic	✓	×	MV	one	×	✓	✓	Multi
[24]	First	Reinforcement	Deregulated	RESs	Dynamic	✓	✓	MV	Multi	×	×	✓	Single
[25]	First	×	Deregulated	DGs	Dynamic	✓	×	MV	one	×	×	✓	Single
[26]	First	New & Reinforcement	Deregulated	×	Static	✓	✓	MV	Multi	×	×	×	Single
[27]	First	×	Deregulated	×	Static	×	×	MV	one	×	×	×	Single
[28]	First	Reinforcement	Deregulated	Demand-RESs	Static	✓	✓	MV	one	×	×	✓	Multi
[32]	First	Reinforcement	Regulated	Demand-RESs energy price	Dynamic	✓	×	MV	one	×	✓	✓	Single
[33]	First	New & Reinforcement	Regulated	Demand-RESs	Dynamic	✓	×	MV	one	✓	×	✓	Multi
[34]	First	New & Reinforcement	Regulated	Demand-RESs	Dynamic	✓	×	MV	Multi	×	✓	✓	Single
[35]	First	New & Reinforcement	Regulated	Future scenario	Static	✓	×	MV	one	×	×	×	Single
[36]	First	Reinforcement	Regulated	×	Static	×	×	MV	one	×	×	✓	Single
[37]	First	Reinforcement	Regulated	Demand-DGs	Dynamic	✓	×	MV	Multi	×	✓	✓	Multi
[38]	First	Reinforcement	Regulated	Demand, DGs Emission price	Dynamic	✓	×	MV	one	✓	×	✓	Single
[39]	First	New & Reinforcement	Regulated	Demand-RESs	Dynamic	✓	×	MV	one	✓	×	✓	Single
[41]	First	New & Reinforcement	Regulated	Demand-RESs	Dynamic	✓	×	MV	one	✓	×	✓	Multi
[42]	First	New & Reinforcement	Regulated	Demand-RESs	Dynamic	✓	×	MV	one	✓	×	✓	Multi
[44]	First	New & Reinforcement	Regulated	Demand-RESs	Dynamic	✓	×	MV	one	✓	✓	✓	Multi
[45]	First	New & Reinforcement	Regulated	×	Dynamic	✓	×	MV	one	×	×	✓	Multi
[46]	First	New & Reinforcement	Regulated	×	Dynamic	✓	×	MV	one	✓	×	✓	Single
[47]	First	New & Reinforcement	Regulated	Demand-RESs	Static	✓	✓	MV	one	×	✓	✓	Single
[48]	First	New & Reinforcement	Regulated	Demand	Dynamic	✓	✓	MV	one	×	×	✓	Multi
[49]	First	Reinforcement	Regulated	Load, EV demand	Dynamic	×	✓	MV	one	×	×	✓	Single
[50]	First	New & Reinforcement	Deregulated	Demand-RESs-budget	Dynamic	✓	✓	MV	one	×	×	×	Single
[51]	First	New & Reinforcement	Deregulated	×	Static	✓	×	MV	One	×	×	✓	Single
[52]	First	Reinforcement	Regulated	Demand-wind	Static	✓	×	MV	One	×	×	×	Single
[53]	First	New & Reinforcement	Deregulated	×	Dynamic	✓	✓	MV	Multi	×	✓	✓	Single
[54]	First	New & Reinforcement	Deregulated	RESs-PEVs	Dynamic	✓	×	MV	One	×	×	✓	Single
[55]	First	New & Reinforcement	Deregulated	×	Dynamic	×	✓	MV	Multi	×	×	✓	Single
[56]	First	New & Reinforcement	Deregulated	EVs	Static	×	✓	MV	One	×	✓	✓	Multi
[57]	First	New & Reinforcement	Deregulated	EVs	Dynamic	✓	✓	MV	One	×	×	✓	Single
[58]	First	Reinforcement	Deregulated	×	Static	×	✓	MV	One	×	×	✓	Multi
[59]	First	Reinforcement	Deregulated	PV-wind	Dynamic	✓	✓	MV	Multi	×	×	✓	Single
[60]	First	Reinforcement	Regulated	PV-load	Dynamic	✓	✓	MV	Multi	×	×	×	Single
[61]	First	New & Reinforcement	Deregulated	EVs-wind	Static	✓	✓	MV	One	×	×	×	Single
[62]	First	New & Reinforcement	Regulated	Load-wind energy price	Static	✓	✓	MV	One	×	×	×	Single
[63]	First	Reinforcement	Deregulated	PV	Dynamic	✓	✓	MV	One	×	✓	✓	Single
[64]	First	New & Reinforcement	Regulated	×	Static	×	✓	MV	Multi	×	×	×	Single
[65]	First	New & Reinforcement	Deregulated	Demand-RESs	Dynamic	✓	✓	MV	Multi	×	✓	✓	Single
[66]	First	New & Reinforcement	Deregulated	Demand-RESs	Dynamic	✓	✓	MV	Multi	×	✓	✓	Single
[67]	First	New & Reinforcement	Deregulated	×	Dynamic	×	✓	MV	One	×	✓	✓	Multi
[69]	First	New & Reinforcement	Deregulated	Load- RESs	Dynamic	✓	×	MV/LV	One	✓	×	✓	Bi-level
[70]	First	New & Reinforcement	Deregulated	Load-energy price-RESs	Dynamic	✓	×	MV	One	✓	×	✓	Single
[71]	First	New & Reinforcement	Regulated	Load-wind	Dynamic	✓	×	MV	One	✓	×	✓	Single
[72]	First	New & Reinforcement	Regulated	×	Static	×	×	MV/LV	One	×	×	✓	Single
[73]	First	New & Reinforcement	Regulated	×	Dynamic	✓	×	MV	One	×	×	×	Single
[74]	First	New & Reinforcement	Regulated	×	Dynamic	✓	×	MV	One	×	×	×	Single
[75]	First	New & Reinforcement	Regulated	×	Static	×	×	MV	One	×	×	✓	Single
[76]	First	Reinforcement	Regulated	×	Dynamic	✓	×	MV	Multi	×	✓	✓	Single
[77]	First	New & Reinforcement	Regulated	×	Static	×	×	MV	One	×	×	×	Single
[78]	First	New & Reinforcement	Regulated	Load-RESs	Dynamic	✓	×	MV	Multi	×	✓	×	Multi
[79]	First	New & Reinforcement	Regulated	×	Dynamic	×	×	MV	Multi	×	✓	✓	Single
[80]	First	New & Reinforcement	Regulated	×	Static	×	×	MV/LV	One	×	✓	✓	Single
[81]	First	New & Reinforcement	Regulated	×	Static	×	×	MV/LV	One	×	✓	✓	Single
[82]	First	New & Reinforcement	Regulated	×	Static	✓	×	MV	One	×	✓	✓	Multi
[83]	First	New & Reinforcement	Deregulated	×	Dynamic	✓	×	MV	One	×	✓	✓	Single
[84]	First	New & Reinforcement	Regulated	×	Dynamic	✓	×	MV	One	×	×	✓	Single
[85]	First	New & Reinforcement	Regulated	×	Dynamic	×	×	MV	one	×	✓	✓	Single
[86]	First	New & Reinforcement	Regulated	×	Static	×	×	MV	one	×	✓	✓	Multi
[87]	First	Reinforcement	Deregulated	Load-energy price-RESs	Dynamic	✓	×	MV	one	×	✓	✓	Tri-level
[88]	First	New & Reinforcement	Regulated	Load-RESs	Dynamic	✓	×	MV	One	×	×	×	Single
[89]	First	New & Reinforcement	Deregulated	×	Dynamic	✓	✓	MV	One	×	×	✓	Single
[90]	First	New & Reinforcement	Deregulated	RESs	Dynamic	✓	×	MV	One	×	×	✓	Single
[91]	First	New & Reinforcement	Deregulated	Load-RESs	Dynamic	✓	✓	MV	One	×	×	✓	Single
[92]	First	New	Regulated	×	Static	×	×	MV	One	×	×	✓	Single
[93]	First	New	Regulated	×	Static	×	×	MV	One	×	✓	✓	Single
[94]	First	New & Reinforcement	Regulated	Load-RESs, energy price	Dynamic	✓	×	MV	One	✓	✓	✓	Single
[95]	First	New & Reinforcement	Regulated	×	Dynamic	×	×	MV	One	×	✓	✓	Multi
[96]	First	New	Regulated	×	Static	×	×	MV	One	×	×	✓	Single
[97]	First	New	Deregulated	Load-RESs	Static	✓	×	MV	One	×	✓	✓	Single
[98]	First	New & Reinforcement	Deregulated	×	Dynamic	✓	×	MV/LV	One	×	✓	✓	Multi
[99]	First	New & Reinforcement	Regulated	×	Static	×	×	MV/LV	One	×	×	✓	Single

(*continued on next page*)

Table 1 (*continued*).

Ref	Planning phase	Planning type	Planning system	Uncertainty	Planning horizon	DG	Storage	Planning level	Load model	Pollution	Reliability	Losses	Objective type
[100]	First	New & Reinforcement	Regulated	×	Static	✓	×	MV	One	×	×	✓	Multi
[101]	First	New & Reinforcement	Regulated	×	Static	✓	×	LV	One	×	✓	✓	Single
[102]	First	New & Reinforcement	Regulated	×	Static	×	×	MV	One	×	✓	✓	Single
[103]	First	New & Reinforcement	Regulated	×	Static	×	×	LV	One	×	×	✓	Single
[104]	First	New & Reinforcement	Regulated	×	Static	×	×	LV	One	×	×	✓	Single
[105]	First	New & Reinforcement	Regulated	×	Static	×	×	MV	One	×	×	×	Single
[106]	First	New & Reinforcement	Regulated	×	Static	×	×	MV	One	×	✓	✓	Multi
[107]	First	New & Reinforcement	Regulated	×	Static	✓	×	MV	Multi	×	×	✓	Multi
[108]	First	New & Reinforcement	Regulated	×	Static	×	×	MV	One	×	✓	×	Multi
[109]	First	New & Reinforcement	Regulated	Load-RESs	Dynamic	✓	×	MV	One	✓	×	✓	Multi
[110]	First	New & Reinforcement	Regulated	×	Static	×	×	MV	One	×	×	✓	Single
[111]	First	New	Regulated	×	Static	×	×	MV	One	×	✓	✓	Multi
[112]	First	New & Reinforcement	Regulated	×	Static	×	×	MV	One	×	×	✓	Single
[113]	First	New & Reinforcement	Regulated	×	Static	✓	×	MV	One	×	✓	✓	Single
[114]	First	New & Reinforcement	Regulated	×	Dynamic	✓	×	MV	Multi	×	✓	✓	Single
[115]	First	New & Reinforcement	Regulated	×	Dynamic	✓	×	MV	Multi	×	×	✓	Single
[116]	First	New & Reinforcement	Regulated	Energy price-RESs	Dynamic	✓	×	MV	Multi	✓	×	✓	Single
[117]	First	New & Reinforcement	Regulated	RESs	Dynamic	✓	×	MV	One	×	✓	✓	Single
[118]	First	New & Reinforcement	Regulated	×	Static	×	×	MV/LV	Multi	×	✓	✓	Single
[119]	First	New & Reinforcement	Regulated	×	Dynamic	✓	×	MV	One	×	✓	✓	Single
[120]	First	New & Reinforcement	Regulated	DGs	Dynamic	✓	×	MV	One	×	✓	✓	Single
[121]	First	New & Reinforcement	Regulated	DGs	Dynamic	✓	×	MV	One	×	✓	✓	Single
[122]	First	New & Reinforcement	Regulated	×	Dynamic	✓	✓	MV	Multi	×	✓	✓	Single
[123]	First	New & Reinforcement	Deregulated	Energy price-load	Dynamic	×	×	MV	Multi	×	✓	✓	Multi
[124]	First	New & Reinforcement	Regulated	×	Static	✓	×	MV	One	×	×	✓	Single
[125]	First	New & Reinforcement	Regulated	load	Dynamic	×	✓	MV	Multi	×	✓	✓	Single
[126]	First	New & Reinforcement	Regulated	×	Static	×	×	MV	One	×	×	×	Multi
[127]	First	New & Reinforcement	Regulated	×	Static	×	×	LV	One	×	×	✓	Single
[128]	First	New & Reinforcement	Regulated	×	Static	×	×	LV	One	×	×	✓	Single
[129]	First	New & Reinforcement	Regulated	×	Static	×	×	LV	One	×	×	✓	Single
[130]	First	New & Reinforcement	Regulated	Load-energy price-RESs	Static	✓	×	MV	One	×	×	✓	Single
[131]	First	New & Reinforcement	Regulated	×	Dynamic	×	×	MV	Multi	×	✓	✓	Multi
[132]	First	New & Reinforcement	Regulated	×	Static	×	×	MV	Multi	×	✓	✓	Single
[133]	First	New & Reinforcement	Regulated	×	Static	×	×	MV	One	×	×	✓	Single
[134]	First	New & Reinforcement	Deregulated	×	Static	✓	×	MV/LV	Multi	×	×	✓	Bi-level
[135]	First	New & Reinforcement	Regulated	×	Dynamic	×	×	MV	One	×	×	✓	Single
[136]	First	New & Reinforcement	Regulated	×	Dynamic	✓	×	MV	One	×	×	✓	Single
[137]	First	New & Reinforcement	Regulated	×	Static	×	×	MV	One	×	×	✓	Single
[138]	First	New & Reinforcement	Regulated	×	Static	✓	×	MV	One	×	×	✓	Single
[139]	First	New & Reinforcement	Regulated	Load	Static	×	×	MV	Multi	×	×	✓	Multi
[140]	First	New & Reinforcement	Regulated	Load	Static	×	×	MV	One	×	×	✓	Multi
[141]	First	New & Reinforcement	Regulated	×	Dynamic	✓	×	MV	one	×	×	✓	Single
[142]	First	New & Reinforcement	Regulated	×	Static	✓	×	MV	one	×	×	✓	Single
[143]	First	New & Reinforcement	Regulated	×	Static	✓	×	MV	one	×	×	✓	Single
[144]	First	New & Reinforcement	Regulated	×	Static	✓	×	MV	one	×	×	✓	Multi
[145]	First	New & Reinforcement	Deregulated	×	dynamic	✓	✓	MV	One	×	×	✓	Single
[146]	First	New & Reinforcement	Regulated	×	Static	✓	×	MV/LV	One	×	×	✓	Single
[147]	First	New & Reinforcement	Deregulated	×	Static	✓	×	MV	One	×	×	✓	Single
[148]	First	New & Reinforcement	Regulated	×	Static	×	×	MV	One	×	✓	✓	Single
[149]	First	New & Reinforcement	Deregulated	×	Static	×	×	MV	One	×	×	✓	Multi
[150]	First	New & Reinforcement	Regulated	×	Static	×	×	MV	One	×	✓	✓	Multi
[151]	First	New & Reinforcement	Regulated	×	Static	×	×	MV	One	×	✓	✓	Single
[152]	First	New & Reinforcement	Regulated	×	Static	×	×	MV	One	×	×	✓	Single
[153]	First	New & Reinforcement	Deregulated	×	Static	×	×	MV	One	×	×	✓	Single
[154]	First	New & Reinforcement	Regulated	×	Static	✓	×	MV	One	×	✓	✓	Single
[155]	First	New & Reinforcement	Regulated	DGs	Static	✓	×	MV	One	×	✓	✓	Single
[156]	First	New & Reinforcement	Regulated	load	Static	×	×	LV	One	×	×	✓	Single
[157]	First	New & Reinforcement	Regulated	×	Static	✓	×	MV/LV	One	×	×	✓	Single
[158]	First	New & Reinforcement	Regulated	×	Static	✓	×	MV	One	×	×	✓	Single
[159]	First	New & Reinforcement	Regulated	×	Static	✓	×	MV	One	×	×	✓	Single
[160]	First	New & Reinforcement	Regulated	×	Static	×	×	MV	One	×	×	✓	Single
[161]	First	New & Reinforcement	Regulated	×	Dynamic	×	×	MV	One	×	×	✓	Single
[163]	First	Reinforcement	Regulated	×	Dynamic	✓	×	MV	Multi	×	×	✓	Single
[164]	First	Reinforcement	Deregulated	DGs	Static	✓	×	MV	Multi	×	×	✓	Single
[165]	First	New & Reinforcement	Regulated	×	Static	×	×	MV	One	×	×	✓	Single
[166]	First	Reinforcement	Deregulated	×	Static	✓	×	MV	Multi	×	×	✓	Bi-level
[167]	First	Reinforcement	Deregulated	RESs	Static	✓	×	MV	One	✓	✓	✓	Bi-level
[168]	First	Reinforcement	Deregulated	Load- RESs	Static	✓	×	MV	Multi	×	×	×	Bi-level
[169]	First	Reinforcement	Deregulated	RESs	Dynamic	✓	✓	MV	Multi	×	×	×	Bi-level
[170]	First	New & Reinforcement	Deregulated	Wind	Dynamic	✓	✓	MV	One	×	✓	✓	Bi-level
[171]	First	New & Reinforcement	Deregulated	Load- RESs	Static	✓	✓	MV	One	×	✓	✓	Bi-level
[172]	First	New & Reinforcement	Deregulated	×	Static	✓	×	MV	One	×	×	×	Bi-level
[173]	First	Reinforcement	Deregulated	RESs	Dynamic	✓	✓	MV	Multi	×	✓	×	Bi-level
[174]	First	New & Reinforcement	Deregulated	PEV	Dynamic	✓	✓	MV	One	×	✓	✓	Bi-level

and distribution networks so that both networks can be considered integrated in planning. In this case, the market players will see much bigger conflicts and goals, and after an interaction, a good optimal response can be achieved. Few studies have been done in this regard, which can be used as a suggestion for the continuation of the work, which can be used to plan the two transmission and distribution networks simultaneously with the definitions of the new goals. For further study, refer to [175,176]. Considering that one of the problems of the transmission network is the congestion of lines, the interaction with the distribution network due to the influence of RESs and ESS can change the DNEP problem. In [177] a short-term study is done on sharing ESS between transmission and distribution networks where a coordinated local ESS at the distribution level is considered to relieve transmission network congestions.

According to the statistics shown in Fig. 10, it is necessary to pay more attention to the category of uncertainty in the DNEP problem. According to Table 1, about 40% of the studies have included uncertainty in different parameters, and the statistics of these parameters are shown in Fig. 12.

One of the reasons that caused uncertainty to receive less attention from planners is that the methods of predicting parameters with uncertainty in the restructured power system are very complex, and their analysis method is not easy. However, not considering uncertainty causes the final design to face technical and economic risks. Especially

Table 2
The classification of past studies which is based on the design variables and the contribution/ objective functions.

Ref	Variable	Contribution/Objective function
[9]	Location of feeders and substations	Presenting a linear model for DNEP considering the reliability constraint
[10]	Location of feeders and substations	A new multistage DNEP problem for mesh distribution systems is presented in which reliability assessment is explicitly implemented as constraints
[11]	Location of feeders, capacitors and switches	A novel reliability sensitivity matrix to improve computational performance and the hourly presentation inside the expansion planning formulation is illustrated
[12]	Location of substations, feeders, transformers	The multistage DNEP problem is proposed considering reliability
[13]	Location of feeders, DGs and ESS	Presenting a robust model by considering multiple microgrids and demand response programming, as well as *N-1* reliability constraint
[14]	Size and location of storage units	Presenting a stochastic expansion model for integrated distribution networks in the presence of gas distribution networks in order to reduce investment and operation costs
[15]	Location of substations, feeders and DGs	Presenting a network expansion planning model in order to reduce investment and operation costs by considering the adjustment of tap-changing of transformers
[16]	Location of feeders, voltage regulators and capacitors	Presenting a linear programming model for network expansion planning considering the allocation of power switches as well as voltage regulators
[17]	Location of feeders, voltage regulators and capacitors	Numerical results of [16]
[18]	Location of feeders and transformers	A methodology for the DNEP problem under $N-1$ criterion is proposed, which presents both open & close-looped plans
[19]	Location of feeders and DGs	An approach to get one optimal solution for the DNEP problem by considering $N-1$ system contingencies
[20]	Location of DGs and feeders	Presenting a robust and adaptive model for distribution expansion planning by considering the uncertainty in electrical load and wind energy subjected to AC power flow constraints in order to reduce operating costs
[21]	Location of feeders and DGS	Providing a distribution network expansion planning model by considering reliability indicators and the presence of DGs and microgrids in order to reduce costs
[22]	Secondary substation, length of feeders	Presenting a distribution network expansion planning considering a risk index based on length of the feeders and the number of customers
[23]	Feeder, substation	To supply existing and new loads confidently against hurricanes
[24]	Location of storages	Maximization of the net social benefit
[25]	Location and size of DGs	Presenting a distribution network expansion planning model in the presence of rational behaviors of electric energy distribution participants
[26]	Location and size of DGs	Applying different policies to encourage electric energy distribution companies to invest in local resources in order to increase network flexibility
[27]	Mandatory investments	Presenting an approach to approximate the mandatory investments which the operator of the system must do in the system
[28]	Location and size of RESs	This paper proposes an incentive price to buy energy from private investors so that it attracts them to participate in the planning projects
[32]	Location of DGs, feeders and substations	Minimizing total cost and evaluating reliability
[33]	Location of DGs, feeders and substations	Minimization of total costs and pollution emission as a multi-objective optimization problem
[34]	Location of DGs, feeders and transformers	Total investment and operation costs/reliability
[35]	Location of DGs & feeders	Minimum cost set of network configurations which are robust to uncertainty
[36]	Location of feeders	Minimize the total installation cost and power losses
[37]	Location of DGs and feeders	Providing an expansion planning model in order to reduce investment and operation costs
[38]	Location and size of DGs	Providing an expansion planning model in order to reduce investment and operation costs, minimizing emission and improving the reliability
[39]	Location of DGs, feeders and substations	Minimizing investment and losses costs
[41]	Location of DGs, feeders and substations	Providing an expansion planning model in order to reduce investment and operation costs, minimizing emission and considering risk indices
[42]	Location of DGs, feeders and substations	Providing an expansion planning model in order to reduce investment and operation costs, minimizing emission and considering risk indices

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Table 2 (*continued*).

Ref	Variable	Contribution/Objective function
[44]	Location, size of feeders, substations& DGs	Reducing costs in the presence of SVCs and on-load tap changers
[45]	Location of DGs, feeders and substations	(1) minimum of economic cost and network adaptability, and (2) maximum of operation adaptability
[46]	Distribution feeders, sizing and location of DGs	Total investment, operation and emission costs
[47]	Location of new feeders & energy storages	Minimizing investment and operation costs and also load curtailment to improve the reliability
[48]	Location od Substation &DGs	Reduction of operating and investment costs due to the placement of distribution substations in the presence of electric vehicle stations and capacitor banks
[49]	Construction/reinforcement of feeders and EVs	Reduction of operating and investment costs in the planning horizon
[50]	Investment and systematic variable sets in planning	Providing a resilient network expansion planning model in order to reduce costs
[51]	Location of feeders and substations	The effect of vehicle to grid is considered, i.e., the EV is treated as both the load and the source, respectively
[52]	Locations of feeders, wind turbines, and hydrogen storages	The DNEP incorporating wind power and hydrogen storage is investigated
[53]	Location of feeders and storages	A multi-stage DNEP model that employs the MILP methodology for integrating storages is presented
[54]	Location of DGs, EVs, and substations	Proposing a DNEP model to estimate the electric vehicle parking lot demand, a new methodology for plug-in electric vehicle charging model is proposed
[55]	Location of feeders and ESS	Reduction of operating and investment costs in the presence of electrical energy storage sources
[56]	Location of feeders and substations	Presenting a stochastic model for distribution network expansion planning considering the connection of electric vehicles to the grid in order to reduce costs as well as improve reliability
[57]	Location of feeders and EVs	Presenting a model for planning the expansion of the distribution network in order to reduce operating and investment costs in the presence of electric vehicles
[58]	Location of EVPLs and feeders	Maximizing Profit of EVPLs owners and minimizing operational cost of distribution network
[59]	Location storage systems	Total network energy losses, total energy cost, feeders loading and total load curtailment
[60]	Sitting and sizing of battery energy storages	Investment cost for each expansion, the cost of energy losses, and the cost of energy supplied with poor quality
[61]	Location of EVs, feeders and wind sources	Minimization of the expected total cost
[62]	Location of feeders and substations	Using the lowest possible cost to provide electric load in the presence of renewable energy sources and also electric energy storage
[63]	Location of ESS and RESs	Minimize the cost of installing RESs as well as ESS and also the operation cost
[64]	Location of ESS and feeders	Minimize the total investment and operation costs
[65]	Location of EVs, RESs, feeders	Minimize the total investment and operation costs
[66]	Location of ESS and feeders	Presenting a model for planning the expansion of the distribution network in order to reduce electrical energy losses
[67]	Location of electric vehicle charging stations, feeders, substations	Maximization of the charging station utilization, and maximization of the reliability level
[69]	Location of DGs, feeders, transformers and substations	Reducing investment and operating costs as well as reducing pollution caused by used energy sources
[70]	Location of DGs, feeders and substation	Investment and operation costs and emission
[71]	Location of DGs, feeders and substations	Presenting a conic programming with consideration uncertainties for the DNEP problem to improve the performance of the system in the presence of environmental factors
[72]	Location of feeders and substations	Presenting a model for planning the expansion of the distribution network in order to reduce electrical energy losses and also operation and investment costs
[73]	Location of substations, DGs and feeders	Minimizing investment and operation costs for the DNEP problem
[74]	Location of substations, DGs and feeders	Minimizing investment and operation costs for the DNEP problem

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Table 2 (*continued*).

Ref	Variable	Contribution/Objective function
[75]	Location of substations	Investment costs
[76]	Location of feeders and substations	Minimizing investment and operation costs for the DNEP problem
[77]	Location of feeders	Minimize line investment cost
[78]	Location and size of transformers, feeders, DGs	Minimizing investment and operation costs for the DNEP problem and also maximum Utilization of RESs
[79]	Location of feeders and substations	Reliability assessment is explicitly incorporated into the objective function with aim of minimizing costs
[80]	Location of substations, transformers, feeders	Minimizing investment and operation costs for in the planning horizon
[82]	Location of substations, DGs and feeders	Reducing expansions costs in the presence of distributed generation units
[83]	Location of substations, DGs and feeders	Reducing expansions costs in the presence of distributed generation units
[84]	Location of substations, DGs and feeders	Applying a dynamic model to reduce the cost of investment and operation in the presence of distributed energy resources
[85]	Location of feeders	Presenting a dynamic model for expansion planning and decomposing it into several static problems with the aim of reducing costs
[86]	Location of feeders	Presenting a model for the DNEP problem to Minimize costs and improve reliability
[87]	Location of DGs and substations	Presenting a tri-level model for expansion planning in order to reduce costs of distribution companies, reduce planning costs and also reduce operating costs by considering uncertainties
[88]	Location of feeders, substations, and DGs	Presenting a planning model for distribution network expansion by Markov decision-making in order to reduce costs in the presence of electric load uncertainty
[89]	Location of feeders, substations, and DGs	Presenting a convex model for a DNEP problem including adjustment of tap-changer, DGs and reactive power control
[90]	Type, location and size of all the infrastructures	A probabilistic scenario generation approach is presented considering the robustness with the aim of minimizing costs
[91]	Location of feeders, substations, and DGs	Presenting a DNEP problem considering multiple active distribution network and optimal load shedding
[92]	Location of substations and feeders	Providing a planning model for distribution network with the aim of reducing annual costs
[93]	Location of substations and feeders	A DNEP problem is presented to specify the trade-off between higher reliability and minimum total costs
[94]	Location of feeders substations and DGs	Minimizing cost of investment, operation, emission and improving reliability
[95]	Location of feeders and substations	Presenting a DNEP model considering adequacy of the system in the presence of contingencies
[96]	Location of feeders and size	Presenting a mixed integer linear programming to minimize fixed and variable costs
[97]	Feeders location and DGs & size, switches status	Proposing a DNEP problem considering integration of DGs and DR program
[98]	Substations, DGs, and feeders location & size	Presenting a DNEP model considering adequacy of the system in the presence of contingencies in a restructured system
[99]	Substations and feeders location & size	Providing a planning model for network expansion in order to reduce the cost of operation and investment
[100]	Location of feeders and DGs	Presenting a multi-objective model in order to improve voltage deviation, reduce losses and also make the most possible use of distributed generations
[101]	Substations and feeders location & size	Reliability improvement in unbalanced low voltage network in the presence of small distributed generation sources
[102]	Location of transformers, feeders and substations	Providing an expansion planning model to reduce operating costs
[103]	Substations and feeders location & size	A general mathematical formulation is modified for a low voltage DNEP
[104]	Substations location, feeders size, load allocation	Providing an expansion planning model in the presence of unbalanced loads
[105]	Substations location, feeders location & size	Providing an expansion planning model to minimize fixed and variable costs
[106]	Substations and feeders location & size	Providing a multi objective model including minimizing of costs and system failure index

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Table 2 (*continued*).

Ref	Variable	Contribution/Objective function
[107]	Location of feeders, substations, and DGs	A multi-objective optimization expansion planning tries at finding the Pareto-set of distributed generation locations
[108]	Substations and feeders location & size	Applying two methods of solving multi-objective optimization problems, including non-dominated GA and strength Pareto evolutionary algorithm, in network expansion planning
[109]	Location of feeders & DGs	Presenting an expansion planning model in order to increase the benefits of distributed generation resources and also minimizing the losses and costs
[110]	Feeders location & size	Presenting a DNEP model which is solved by the DP and GA to minimize costs
[111]	Feeders location & size	Presenting a multi-objective model for the DNEP problem by applying geographic information networks
[112]	Substations location and size, feeders location	Presenting heuristic methods to solve the DNEP problem
[113]	DGs location & size, feeders location	Solving the problem of expansion planning by using genetic algorithm in combination with graph theory in the presence of distributed generation resources
[114]	Substations, DGs, and feeders location & size	DG integrated multistage DNEP model in the presence of distributed generation resources operating strategy, load variation, and reliability improvement
[115]	Substations, DGs, and feeders location & size	Solving the expansion planning problem in order to reduce operating costs in the presence of distributed generation resources
[116]	Location of feeders &DGs	Employing RESs in the DNEP problem to reduce CO2 and total costs in the presence of DR program
[117]	Location of feeders and circuit breakers	Presenting a novel DNEP employing equipment's health index and non-network solutions considering uncertainties in load demand and RESs
[118]	Location of feeders and substations	Minimizing investment and operation costs
[119]	Location of feeders and substations	minimizing investment and operation costs and also improving the reliability
[120]	Location of feeders, substations, and DGs	Implementation of real options valuation to maximum a return-per-risk index
[121]	Location of feeders, substations, and DGs	Numerical results of [120]
[122]	Location of feeders, substations, and DGs	Presenting a DNEP model with aim of minimizing total costs in the presence of reserve feeders
[123]	Location of capacitors and switches	Presenting a DNEP model with aim of improving reliability and power quality
[124]	Location of DGs, transformers and feeders	A new method for solving single and multi-objective DNEP problem including DG and conventional method simultaneously which the aims of the proposed problem are expansion costs, voltage deviation, and network losses
[125]	Location of feeder and ESS	A DNEP in the presence of ESS considering uncertainty in load demand of the network and also reliability index is investigated for composite network of feeders and ESS
[126]	Location of feeders and substations	A Fuzzy DNEP problem is proposed which optimizes reliability, the economic cost, and the risk of overloading, simultaneously
[127]	Location of feeders and substations	Presenting a non-linear model for network expansion in order to reduce losses and costs
[128]	Substations and feeders location & size	Presenting a network expansion model in order to reduce losses and costs
[130]	Feeders location & size	A DNEP problem is presented to minimize total costs considering uncertainties of RESs, load demand, and energy price
[131]	Substations and feeders location & size	Presenting a dynamic and multistage DNEP problem to minimize total costs
[132]	Substations and feeders location & size	Presenting a DNEP problem in the presence of sectionalizing switches to improve the reliability
[133]	Substations size, feeders location & size	The comparison of two meta heuristic algorithms SA and TS and the results show that the TS algorithm is more efficient than SA
[134]	Location of DGs, feeders, transformers and substations	Investment and operation costs
[135]	Location of feeders and substations	A novel improved hybrid TS/PSO algorithm is presented to optimize the applied DNEP problem
[136]	Size of DGs, feeders and substations	A DNEP problem is presented which aims to minimize total costs minus total revenues
[137]	Location of feeders	The SA approach is applied to solve the DNEP problem to minimize investment costs & losses and maximize the reliability
[138]	Feeders location & size	Presenting a DNEP problem to minimize total costs (fixed and variable)

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Table 2 (*continued*).

Ref	Variable	Contribution/Objective function
[139]	Location of feeders	Solving the DNEP problem by AIS algorithm considering load demand uncertainty
[140]	Feeders location & size	An immune system algorithm is used to solve the DNEP presented in [139]
[141]	location of DGs, substations and feeders	The proposed DNEP model is solved by artificial bee colony algorithm to minimize total costs
[142]	Location of feeders and DGs	The DNEP problem of the Debre Markos city is done by using HSA for minimizing voltage deviation and losses
[143]	Location of DGs	The GWO algorithm is applied for solved a DNEP problem to optimize real power losses and voltage profile
[144]	Location of DGs	Application of GWO algorithm to solve the DNEP problem to minimize power losses and improve the voltage deviation
[145]	Location of ESS	Application of GWO algorithm to solve the DNEP problem to minimize power losses and improve the voltage deviation in the presence of ESS and RESs
[146]	Location of feeders and substations	Minimizing investment and operation costs
[147]	Location of feeders and DGs	A new methodology is presented to solve a DNEP problem, where DGs are also incorporated to minimize economic and operational requirements using lion pride optimization algorithm
[148]	Feeders location	Presenting a DNEP problem to minimize total costs and improve the reliability
[149]	Location of substations and feeders	Providing a model for network development planning in order to reduce costs and urban traffic, as well as reduce losses and annual investment costs
[150]	Feeders location	Simultaneous size and location of reclosers in the expansion planning by seeker optimization algorithm
[151]	Substations size, feeders location & size	Presenting a DNEP problem to minimize total costs including investment losses and reliability costs
[152]	Substations and feeders location & size	Presenting a non-linear model for the DNEP problem and solve it by a heuristic approach to minimize fixed and variable costs
[153]	Feeders location & size	Presenting a model for network expansion planning to improve capability considering microgrid connectivity
[154]	Feeders location	Presenting a model for network expansion planning in order to evaluate reliability using graph theory in the presence of distributed generations
[155]	Feeders location	Presenting a model for network development planning in order to make the most use of distributed production resources
[156]	Substations and feeders location & size	Presenting a statistical model for the expansion of low voltage network in order to reduce the costs
[157]	Substations and feeders location &size	Integrated planning for the distribution network applying the street map for cables layout
[158]	Feeders location & size	Presenting DNEP models to minimize investment and energy loss cost
[159]	Feeders location & size	Implementation and numerical results of [158]
[160]	Substations and feeders location & size	Hybrid models decouple the DNEP problem to minimize investment and energy loss cost
[161]	Location of substations, DGs, and feeders	Presenting a DNEP problem in the presence of DG integration to minimize total costs using cost–benefit analysis
[163]	Location and size of DGs	Evaluation the technical impacts which PVs provokes on the applied planning
[164]	Location of DGs	Using a different structure than using distributed generation units to achieve the maximum possible capacity of them subjected to operation constraints
[165]	Location of feeders	Minimizing investment and operation costs
[166]	Location of feeders and DGs	Reducing investment and operating costs by including energy exchange with the connected microgrid
[167]	Location of feeders and DGs	Minimize annual comprehensive investment and operation costs
[168]	Location of feeders, DGs and substations	Providing a bi-level model in order to reduce investment costs at the upper level and reduce the costs paid by customers at the lower level
[169]	Location of feeders and transformers	Applying a bi-level model for expansion planning so that the upper level goal is to reduce costs and the lower level goal is to increase social welfare in the presence of ESS and DGs
[170]	Location of RESs and ESS	Improving the reliability
[171]	Location of feeders, DGs and ESS	Presenting a bi-level model so that at the upper level the investment costs are minimized in the long term and at the lower level the operating costs are minimized in the short term

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Table 2 (*continued*).

Ref	Variable	Contribution/Objective function
[172]	Location of DGs, feeders and substations	Investment and operation costs
[173]	Location of substations, transformers, feeders	Applying a bi-level model so that operating costs are reduced at the upper level and other expansion programs of market players are minimized at the lower level
[174]	Location of feeders, substation, plug-in EVs, and charging stations	Providing a bi-level model so that planning costs are minimized at the upper level and the profits of electric vehicle parking lots owners are maximized at the lower level

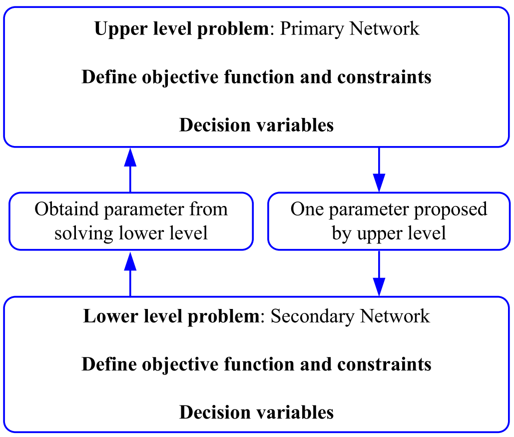

Fig. 11. Propose a general bi-level structure for the DNEP.

with the use of RESs and the investment of market players in this field, it is inevitable to include the uncertainty of their production in the DNEP problem. The internal scenario analysis method described in Section 7.1.2 can be one of the most effective methods in analyzing uncertainties in the DNEP problem. So, it is recommended to model the uncertainties of the input information, which are much more and more effective than in the past, and somehow establish an effective interaction with the planning of other parts, especially the transmission system. Regarding uncertainty analysis, it is suggested that the correlation between uncertainties is included in planning because this case has not been investigated so far, and it can be an attractive option for expansion planning by considering it.

One of the things suggested to be included in the DNEP issue is the use of storage devices. Due to voltage fluctuations, uncertainty caused by RESs, overload conditions, and other cases, the use of storage devices is unavoidable in the DNEP problem. One of the reasons that caused the ESS to receive less attention in the DNEP issue may be the investment costs for their installation and maintenance costs, and the expense of power electronic equipment can be another reason.

Considering the global laws regarding reducing greenhouse gas production, it is important to examine the models in the DNEP problem. As shown in Fig. 10, the problem of pollution reduction has been less considered in the discussion of DNEP.

It can be said about the approaches to the DNEP problem that in most of the studies, priori methods have been used to solve the problem. In these methods, the planner first ranks the objective functions with the help of qualitative information available to him, which is known as high-level information. In other words, the individual or the decision-making group determines the weight of each of the functions according to the experience, requirements, and qualitative information before performing the optimization. With the help of these weights, they turn the optimization problem into a problem with an objective function, which will be much easier to solve. The main problem of this class of methods is that the decision-maker must determine the importance of the functions before obtaining the pseudo-optimal answers. Until the pseudo-optimal answers are obtained, the decision-maker does not know about the dependence and relationship between the objective functions, and therefore, choosing the weights in this way can lead to inappropriate answers. For example, improving an objective function beyond a specific limit may significantly increase costs. If this is not known in advance, the decision maker may achieve a very costly response by choosing a high importance for this objective function, which is slightly different from the less costly responses.

However, as a suggestion, it is recommended to use a posteriori approaches for the DNEP problem in such a way that first, the pseudo-optimal points are determined and, then with, the help of the information extracted from the relationships between the objective functions and the help of high-level information, choose the final answer from among the pseudo-optimized points. In [178], comprehensive information is given in this regard. Therefore, it is recommended that in the objective functions of the DNEP problem, risk modeling is placed as a goal, and it is possible to determine its economic level and to involve private funds in the expansion planning.

Since the distribution network is the basis of power exchange and the market competition is for the benefit of all traders (as the social welfare), the goal of removing obstacles to competition in the market and also considering different and sometimes conflicting goals of market players and investors can be investigated as future researches and that Since most DNEP models seek to reduce costs, it is better to do a cost–benefit (technical-economic) analysis at the end of planning so that the plans are closer to reality.

Regarding DG units, it is suggested that special attention should be paid to the study area regarding expansion planning and its effect on planning costs. Also, by applying and installing DGs, the distribution network may go out of the radial state, requiring directional relays that increase costs. Considering this constraint, the effect of placing this relay on the planning costs can be seen. Considering the presence of private investments in the field of DGs, especially RESs, and the subsequent conflicts between them, it is recommended to conduct a comprehensive analysis in this regard, and this issue becomes necessary when the utility is not the owner of the DGs. In other words, Modeling the behavior of private investors in the DNEP problem is suggested.

Since the power system is moving towards intelligentization, it is possible to investigate the use of automation equipment and its effects on the planning process in the DNEP.

So, in summary, it can be said that the changes, requirements, and new discussions related to the DNEP issue can be listed as follows:

- The entry of private sector investors and moving towards a decentralized approach
- Emergence of different needs and goals of different actors and stakeholders
- Increasing uncertainties, especially with the separation of production and transmission systems
- The need to consider the needs of the electricity market in the DNEP issue
- The need to use cost–benefit analysis methods instead of minimizing costs
- Presenting a model to interact with private small-scale power plants

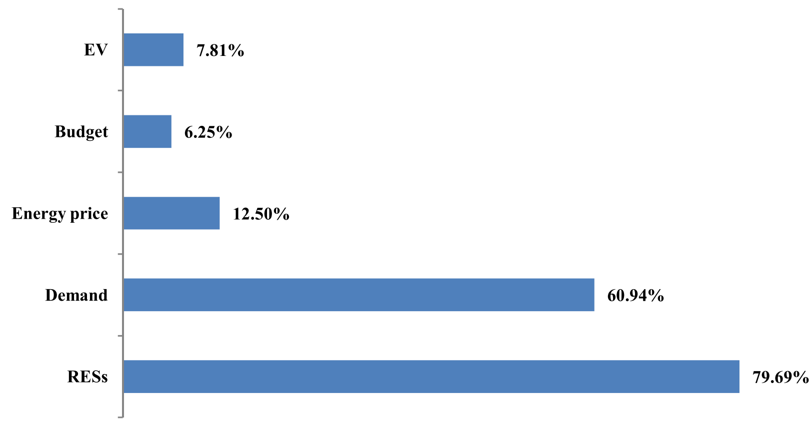

Fig. 12. Statistics of the uncertain parameters in the papers which considered the uncertainties.

15. Conclusion

In this paper, a comprehensive overview of the issue of distribution network expansion planning was discussed. So, about 170 studies were comprehensively reviewed from various aspects, including objective functions and constraints, planning level, uncertainty, distributed generations and storages, and the planning horizon; this issue was thoroughly investigated. The necessary comparisons were made in the tables so the reader can easily make the necessary comparisons. After reviewing the studies, it was found that less attention has been paid to the investigation of private investments, the analysis of uncertainties, the correlation between uncertainties, and the involvement of storage units in distribution planning. Also, due to the different and sometimes conflicting goals of the market players, the need to review the problem-solving methods is inevitable. It was suggested that the network planners analyze the problem from the posterior approaches along with the cost–benefit analysis. Also, considering that most of the studies have been done at medium voltage levels and very few studies have considered both medium-voltage and low voltage levels together, it is recommended that planners investigate the problem by using bi-level models and consider medium and low-voltage networks as one integrated network.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

References

[1] Temraz HK, Quintana VH. Distribution system expansion planning models: An overview. Electr Power Syst Res 1993;26(1):61–70.
[2] Khator SK, Leung LC. Power distribution planning: A review of models and issues. IEEE Trans Power Syst 1997;12(3):1151–9.
[3] Vaziri M, Tomsovic K, Gönen T. Distribution expansion problem revisited. Part 1 categorical analysis and future directions. Math Program 2000;13:26.
[4] Sempértegui R, Bautista J, Cubero RG, Pereira J. Models and procedures for electric energy distribution planning. A review. IFAC Proc Vol 2002;35(1):395–400.
[5] Georgilakis PS, Hatziargyriou ND. Optimal distributed generation placement in power distribution networks: models, methods, and future research. IEEE Trans Power Syst 2013;28(3):3420–8.
[6] Saboori H, Hemmati R, Ghiasi SMS, Dehghan S. Energy storage planning in electric power distribution networks–A state-of-the-art review. Renew Sustain Energy Rev 2017;79:1108–21.
[7] Aschidamini GL, da Cruz GA, Resener M, Ramos MJ, Pereira LA, Ferraz BP, et al. Expansion planning of power distribution systems considering reliability: A comprehensive review. Energies 2022;15(6):2275.
[8] Georgilakis PS, Hatziargyriou ND. A review of power distribution planning in the modern power systems era: Models, methods and future research. Electr Power Syst Res 2015;121:89–100.
[9] Jooshaki M, Abbaspour A, Fotuhi-Firuzabad M, Muñoz-Delgado G, Contreras J, Lehtonen M, Arroyo JM. An enhanced MILP model for multistage reliability-constrained distribution network expansion planning. IEEE Trans Power Syst 2021;37(1):118–31.
[10] Li Z, Wu W, Tai X, Zhang B. A reliability-constrained expansion planning model for mesh distribution networks. IEEE Trans Power Syst 2020;36(2):948–60.
[11] Pinto RS, Unsihuay-Vila C, Tabarro FH. Reliability-constrained robust expansion planning of active distribution networks. IET GenerTransm Distrib 2022;16(1):27–40.
[12] Munoz-Delgado G, Contreras J, Arroyo JM. Distribution network expansion planning with an explicit formulation for reliability assessment. IEEE Trans Power Syst 2017;33(3):2583–96.
[13] Pinto RS, Unsihuay-Vila C, Tabarro FH. Coordinated operation and expansion planning for multiple microgrids and active distribution networks under uncertainties. Appl Energy 2021;297:117108.
[14] Saravi VS, Kalantar M, Anvari-Moghaddam A. Resilience-constrained expansion planning of integrated power–gas–heat distribution networks. Appl Energy 2022;323:119315.
[15] Xing H, Fu Y, Cheng H. Active distribution network expansion planning integrating practical operation constraints. Electr Power Compon Syst 2017;45(16):1795–805.
[16] Resener M, Haffner S, Pereira LA, Pardalos PM, Ramos MJ. A comprehensive MILP model for the expansion planning of power distribution systems–Part I: Problem formulation. Electr Power Syst Res 2019;170:378–84.
[17] Resener M, Haffner S, Pereira LA, Pardalos PM, Ramos MJ. A comprehensive MILP model for the expansion planning of power distribution systems–Part II: Numerical results. Electr Power Syst Res 2019;170:317–25.
[18] Lin Z, Hu Z, Song Y. Distribution network expansion planning considering $n-1$ criterion. IEEE Trans Power Syst 2019;34(3):2476–8.
[19] Mubarak H, Mansor NN, Mokhlis H, Mohamad M, Mohamad H, Muhammad MA, et al. Optimum distribution system expansion planning incorporating DG based on n-1 criterion for sustainable system. Sustainability 2021;13(12):6708.
[20] Amjady N, Attarha A, Dehghan S, Conejo AJ. Adaptive robust expansion planning for a distribution network with DERs. IEEE Trans Power Syst 2017;33(2):1698–715.
[21] de Souza JV, Monteiro FMdS, de Godoy PT, Asada EN. Active distribution network expansion planning considering microgrid operation and reliability. In: 2022 IEEE power & energy society general meeting. IEEE; 2022, p. 1–5.
[22] Bosisio A, Berizzi A, Amaldi E, Bovo C, Morotti A, Greco B, et al. A GIS-based approach for high-level distribution networks expansion planning in normal and contingency operation considering reliability. Electr Power Syst Res 2021;190:106684.
[23] Nasri A, Abdollahi A, Rashidinejad M. Multi-stage and resilience-based distribution network expansion planning against hurricanes based on vulnerability and resiliency metrics. Int J Electr Power Energy Syst 2022;136:107640.
[24] Asensio M, de Quevedo PM, Muñoz-Delgado G, Contreras J. Joint distribution network and renewable energy expansion planning considering demand response and energy storage—Part I: Stochastic programming model. IEEE Trans Smart Grid 2016;9(2):655–66.

[25] Tian H, Wang R, Gao H, Song X, Yang R, Lv X. Distribution network expansion planning with the presence of interactive trading among multiple market participants. In: 2020 IEEE sustainable power and energy conference. IEEE; 2020, p. 423–8.
[26] Karimi-Arpanahi S, Jooshaki M, Moeini-Aghtaie M, Abbaspour A, Fotuhi-Firuzabad M. Incorporating flexibility requirements into distribution system expansion planning studies based on regulatory policies. Int J Electr Power Energy Syst 2020;118:105769.
[27] Macedo PM, Fidalgo JN, Saraiva JT. Estimation of the global amount of mandatory investments for distribution network expansion planning. In: 2021 IEEE Madrid powertech. IEEE; 2021, p. 1–6.
[28] Ashoornezhad A, Falaghi H, Hajizadeh A, Ramezani M. A two-stage multi-period distribution network expansion planning considering the integration of private investors. Int Trans Electr Energy Syst 2021;31(12):e13226.
[29] CIGRE Task Force 380508 and Sandrin, Patrick. Techniques for power system planning under uncertainties. CIGRE; 2002.
[30] Andrews CJ. Evaluating risk management strategies in resource planning. IEEE Trans Power Syst 1995;10(1):420–6.
[31] Haimes YY. Risk modeling, assessment, and management. John Wiley & Sons; 2005.
[32] Bagheri A, Monsef H, Lesani H. Evaluating the effects of renewable and non-renewable DGs on DNEP from the reliability, uncertainty, and operational points of view by employing hybrid GA and OPF. Int Trans Electr Energy Syst 2015;25(12):3304–28.
[33] Rastgou A, Moshtagh J, Bahramara S. Probabilistic power distribution planning using multi-objective harmony search algorithm. J Oper Autom Power Eng 2018;6(1):111–25.
[34] Muñoz-Delgado G, Contreras J, Arroyo JM. Multistage generation and network expansion planning in distribution systems considering uncertainty and reliability. IEEE Trans Power Syst 2015;31(5):3715–28.
[35] Wang DT-C, Ochoa LF, Harrison GP. Modified GA and data envelopment analysis for multistage distribution network expansion planning under uncertainty. IEEE Trans Power Syst 2010;26(2):897–904.
[36] Singh S, Ghose T, Goswami S. Optimal feeder routing based on the bacterial foraging technique. IEEE Trans Power Deliv 2011;27(1):70–8.
[37] Borges CLT, Martins VF. Multistage expansion planning for active distribution networks under demand and distributed generation uncertainties. Int J Electr Power Energy Syst 2012;36(1):107–16.
[38] Santos SF, Fitiwi DZ, Bizuayehu AW, Shafie-Khah M, Asensio M, Contreras J, et al. Novel multi-stage stochastic DG investment planning with recourse. IEEE Trans Sustain Energy 2016;8(1):164–78.
[39] Zhou S, Han Y, Yang P, Mahmoud K, Lehtonen M, Darwish MM, et al. An optimal network constraint-based joint expansion planning model for modern distribution networks with multi-types intermittent RERs. Renew Energy 2022;194:137–51.
[40] Willis HL, Rackliffe GB. Introduction to integrated resource T&D planning. 1994.
[41] Rastgou A, Moshtagh J, Bahramara S. A robust and flexible approach for distribution expansion planning in the presence of distributed generations and the uncertainties associated with demand, energy price and renewable resources. TABRIZ J Electr Eng 2019;49(1):165–80.
[42] Rastgou A, Bahramara S, Moshtagh J. Flexible and robust distribution network expansion planning in the presence of distributed generators. Int Trans Electr Energy Syst 2018;28(12):e2637.
[43] Conejo AJ, Carrión M, Morales JM, et al. Decision making under uncertainty in electricity markets, vol. 1. Springer; 2010.
[44] Xie S, Hu Z, Zhou D, Li Y, Kong S, Lin W, et al. Multi-objective active distribution networks expansion planning by scenario-based stochastic programming considering uncertain and random weight of network. Appl Energy 2018;219:207–25.
[45] Feng L, Dong Y, Wang S, Jian Q, Zhao L, Liu R, et al. A two-layer multi-stage expansion planning method for adaptability enhancement of distribution networks. IOP Conf Ser: Earth Environ Sci 2021;645(1):012080.
[46] Ahmadigorji M, Amjady N, Dehghan S. A novel two-stage evolutionary optimization method for multiyear expansion planning of distribution systems in presence of distributed generation. Appl Soft Comput 2017;52:1098–115.
[47] Canizes B, Soares J, Lezama F, Silva C, Vale Z, Corchado JM. Optimal expansion planning considering storage investment and seasonal effect of demand and renewable generation. Renew Energy 2019;138:937–54.
[48] Xie S, Hu Z, Wang J. Two-stage robust optimization for expansion planning of active distribution systems coupled with urban transportation networks. Appl Energy 2020;261:114412.
[49] Arias NB, Tabares A, Franco JF, Lavorato M, Romero R. Robust joint expansion planning of electrical distribution systems and EV charging stations. IEEE Trans Sustain Energy 2017;9(2):884–94.
[50] Huang C, Wang C, Xie N, Wang Y. Robust coordination expansion planning for active distribution network in deregulated retail power market. IEEE Trans Smart Grid 2019;11(2):1476–88.
[51] Lin X, Sun J, Ai S, Xiong X, Wan Y, Yang D. Distribution network planning integrating charging stations of electric vehicle with V2G. Int J Electr Power Energy Syst 2014;63:507–12.
[52] Mehrjerdi H, Hemmati R. Wind-hydrogen storage in distribution network expansion planning considering investment deferral and uncertainty. Sustain Energy Technol Assess 2020;39:100687.
[53] Shen X, Shahidehpour M, Han Y, Zhu S, Zheng J. Expansion planning of active distribution networks with centralized and distributed energy storage systems. IEEE Trans Sustain Energy 2016;8(1):126–34.
[54] Karimi-Arpanahi S, Jooshaki M, Moein-Aghtaie M, Fotuhi-Firuzabad M, Lehtonen M. Considering forecasting errors in flexibility-oriented distribution network expansion planning using the spherical simplex unscented transformation. IET Gener Transm Distrib 2020;14(24):5970–83.
[55] Saboori H, Hemmati R, Abbasi V. Multistage distribution network expansion planning considering the emerging energy storage systems. Energy Convers Manag 2015;105:938–45.
[56] Nasri A, Abdollahi A, Rashidinejad M, Hadi Amini M. Probabilistic–possibilistic model for a parking lot in the smart distribution network expansion planning. IET Gener Transm Distrib 2018;12(13):3363–74.
[57] Wang S, Dong ZY, Chen C, Fan H, Luo F. Expansion planning of active distribution networks with multiple distributed energy resources and EV sharing system. IEEE Trans Smart Grid 2019;11(1):602–11.
[58] Mozaffari M, Abyaneh HA, Jooshaki M, Moeini-Aghtaie M. Joint expansion planning studies of EV parking lots placement and distribution network. IEEE Trans Ind Inf 2020;16(10):6455–65.
[59] Nick M, Cherkaoui R, Paolone M. Optimal allocation of dispersed energy storage systems in active distribution networks for energy balance and grid support. IEEE Trans Power Syst 2014;29(5):2300–10.
[60] Samper ME, Vargas A, Eldali F, Suryanarayanan S. Assessments of battery storage options for distribution expansion planning using an opendss-based framework. In: 2017 IEEE Manchester powertech. IEEE; 2017, p. 1–6.
[61] de Quevedo PM, Muñoz-Delgado G, Contreras J. Joint expansion planning of distribution networks, EV charging stations and wind power generation under uncertainty. In: 2017 IEEE power & energy society general meeting. IEEE; 2017, p. 1–5.
[62] Bagheri A, Osali N, Noroozian R. Distribution system expansion planning incorporating storage units in the presence of wind-based distributed generation. In: 2016 21st conference on electrical power distribution networks conference. IEEE; 2016, p. 194–201.
[63] Sabzehgar R, Amirhosseini DZ, Manshadi SD, Fajri P. Stochastic expansion planning of various energy storage technologies in active power distribution networks. Sustainability 2021;13(10):5752.
[64] Alsaidan I, Gao W, Khodaei A. Distribution network expansion through optimally sized and placed distributed energy storage. In: 2018 IEEE/PES transmission and distribution conference and exposition. IEEE; 2018, p. 1–5.
[65] de Quevedo PM, Muñoz-Delgado G, Contreras J. Impact of electric vehicles on the expansion planning of distribution systems considering renewable energy, storage, and charging stations. IEEE Trans Smart Grid 2017;10(1):794–804.
[66] Yi JH, Cherkaoui R, Paolone M, Shchetinin D, Knezovic K. Expansion planning of active distribution networks achieving their dispatchability via energy storage systems. Appl Energy 2022;326:119942.
[67] Xiang Y, Yang W, Liu J, Li F. Multi-objective distribution network expansion incorporating electric vehicle charging stations. Energies 2016;9(11):909.
[68] Lakervi E, Holmes EJ. Electricity distribution network design, no. 212. IET; 1995.
[69] Rastgou A, Hosseini-Hemati S, et al. Simultaneous planning of the medium and low voltage distribution networks under uncertainty: A bi-level optimization approach. Int Trans Electr Energy Syst 2022;2022.
[70] Rastgou A, Moshtagh J, Bahramara S. Improved harmony search algorithm for electrical distribution network expansion planning in the presence of distributed generators. Energy 2018;151:178–202.
[71] Home-Ortiz JM, Melgar-Dominguez OD, Pourakbari-Kasmaei M, Mantovani JRS. A stochastic mixed-integer convex programming model for long-term distribution system expansion planning considering greenhouse gas emission mitigation. Int J Electr Power Energy Syst 2019;108:86–95.
[72] Paiva P, Khodr H, Dominguez-Navarro J, Yusta J, Urdaneta A. Integral planning of primary-secondary distribution systems using mixed integer linear programming. IEEE Trans Power Syst 2005;20(2):1134–43.
[73] Haffner S, Pereira LFA, Pereira LA, Barreto LS. Multistage model for distribution expansion planning with distributed generation—Part I: Problem formulation. IEEE Trans Power Deliv 2008;23(2):915–23.
[74] Haffner S, Pereira LFA, Pereira LA, Barreto LS. Multistage model for distribution expansion planning with distributed generation—Part II: Numerical results. IEEE Trans Power Deliv 2008;23(2):924–9.
[75] El-Fouly T, Zeineldin H, El-Saadany E, Salama M. A new optimization model for distribution substation siting, sizing, and timing. Int J Electr Power Energy Syst 2008;30(5):308–15.
[76] Lotero RC, Contreras J. Distribution system planning with reliability. IEEE Trans Power Deliv 2011;26(4):2552–62.
[77] Shu J, Wu L, Li Z, Shahidehpour M, Zhang L, Han B. A new method for spatial power network planning in complicated environments. IEEE Trans Power Syst 2011;27(1):381–9.

[78] Ugranlı F. Analysis of renewable generation's integration using multi-objective fashion for multistage distribution network expansion planning. Int J Electr Power Energy Syst 2019;106:301–10.
[79] Tabares A, Muñoz-Delgado G, Franco JF, Arroyo JM, Contreras J. Multi-stage reliability-based expansion planning of AC distribution networks using a mixed-integer linear programming model. Int J Electr Power Energy Syst 2022;138:107916.
[80] Fletcher RH, Strunz K. Optimal distribution system horizon planning–part I: Formulation. IEEE Trans Power Syst 2007;22(2):791–9.
[81] Fletcher RH, Strunz K. Optimal distribution system horizon planning–Part II: Application. IEEE Trans Power Syst 2007;22(2):862–70.
[82] Khodr H, Vale ZA, Ramos C. A benders decomposition and fuzzy multicriteria approach for distribution networks remuneration considering dg. IEEE Trans Power Syst 2009;24(2):1091.
[83] Wong S, Bhattacharya K, Fuller JD. Electric power distribution system design and planning in a deregulated environment. IET Gener Transm Distrib 2009;3(12):1061.
[84] Celli G, Mocci S, Pilo F, Bertini D, Cicoria R, Corti S. Multi-year optimal planning of active distribution networks. In: Proc. CIRED, vol. 216. Citeseer; 2007.
[85] Popović Ž, Popović D. Graph theory based formulation of multi-period distribution expansion problems. Electr Power Syst Res 2010;80(10):1256–66.
[86] Ganguly S, Sahoo N, Das D. Multi-objective planning of electrical distribution systems using dynamic programming. Int J Electr Power Energy Syst 2013;46:65–78.
[87] Giglou PA, Jannati-Oskuee M-R, Fateh H, Najafi-Ravadanegh S. IGDT-based dynamic programming of smart distribution network expansion planning against cyber-attack. Int J Electr Power Energy Syst 2022;139:108006.
[88] Sun Q, Wu Z, Gu W, Zhu T, Zhong L, Gao T. Flexible expansion planning of distribution system integrating multiple renewable energy sources: An approximate dynamic programming approach. Energy 2021;226:120367.
[89] Xing H, Cheng H, Zhang Y, Zeng P. Active distribution network expansion planning integrating dispersed energy storage systems. IET Gener Transm Distrib 2016;10(3):638–44.
[90] Wang J, Hu Z, Xie S. Expansion planning model of multi-energy system with the integration of active distribution network. Appl Energy 2019;253:113517.
[91] Xie S, Hu Z, Yang L, Wang J. Expansion planning of active distribution system considering multiple active network managements and the optimal load-shedding direction. Int J Electr Power Energy Syst 2020;115:105451.
[92] Samui A, Singh S, Ghose T, Samantaray S. A direct approach to optimal feeder routing for radial distribution system. IEEE Trans Power Deliv 2011;27(1):253–60.
[93] Samui A, Samantaray S, Panda G. Distribution system planning considering reliable feeder routing. IET Gener Transm Distrib 2012;6(6):503–14.
[94] Bagheri A, Monsef H, Lesani H. Integrated distribution network expansion planning incorporating distributed generation considering uncertainties, reliability, and operational conditions. Int J Electr Power Energy Syst 2015;73:56–70.
[95] Nazar MS, Haghifam MR. Multiobjective electric distribution system expansion planning using hybrid energy hub concept. Electr Power Syst Res 2009;79(6):899–911.
[96] Jiménez-Estévez GA, Vargas LS, Marianov V. Determination of feeder areas for the design of large distribution networks. IEEE Trans Power Deliv 2010;25(3):1912–22.
[97] Martins VF, Borges CL. Active distribution network integrated planning incorporating distributed generation and load response uncertainties. IEEE Trans Power Syst 2011;26(4):2164–72.
[98] Nazar MS, Haghifam MR, Nažar M. A scenario driven multiobjective primary–secondary distribution system expansion planning algorithm in the presence of wholesale–retail market. Int J Electr Power Energy Syst 2012;40(1):29–45.
[99] Mendoza JE, López ME, Pena HE, Labra DA. Low voltage distribution optimization: Site, quantity and size of distribution transformers. Electr Power Syst Res 2012;91:52–60.
[100] Chen T-H, Lin E-H, Yang N-C, Hsieh T-Y. Multi-objective optimization for upgrading primary feeders with distributed generators from normally closed loop to mesh arrangement. Int J Electr Power Energy Syst 2013;45(1):413–9.
[101] Mendoza JE, López ME, Fingerhuth SC, Peña HE, Salinas CA. Low voltage distribution planning considering micro distributed generation. Electr Power Syst Res 2013;103:233–40.
[102] Rad HK, Moravej Z. An approach for simultaneous distribution, sub-transmission, and transmission networks expansion planning. Int J Electr Power Energy Syst 2017;91:166–82.
[103] Türkay B, Artaç T. Optimal distribution network design using genetic algorithms. Electr Power Compon Syst 2005;33(5):513–24.
[104] Cossi AM, Romero R, Mantovani JRS. Planning of secondary distribution circuits through evolutionary algorithms. IEEE Trans Power Deliv 2005;20(1):205–13.
[105] Carrano E, Takahashi R, Cardoso E, Saldanha R, Neto O. Optimal substation location and energy distribution network design using a hybrid GA-BFGS algorithm. IEE Proc, Gener Transm Distrib 2005;152(6):919–26.
[106] Carrano EG, Soares LA, Takahashi RH, Saldanha RR, Neto OM. Electric distribution network multiobjective design using a problem-specific genetic algorithm. IEEE Trans Power Deliv 2006;21(2):995–1005.
[107] Pilo F, Celli G, Mocci S, Soma G. Multi-objective programming for optimal DG integration in active distribution systems. In: IEEE PES general meeting. IEEE; 2010, p. 1–7.
[108] Mendoza F, Bernal-Agustin JL, Domínguez-Navarro JA. NSGA and SPEA applied to multiobjective design of power distribution systems. IEEE Trans Power Syst 2006;21(4):1938–45.
[109] Zidan A, Shaaban MF, El-Saadany EF. Long-term multi-objective distribution network planning by DG allocation and feeders' reconfiguration. Electr Power Syst Res 2013;105:95–104.
[110] Carrano E, Cardoso R, Takahashi R, Fonseca C, Neto O. Power distribution network expansion scheduling using dynamic programming genetic algorithm. IET Gener Transm Distrib 2008;2(3):444–55.
[111] Kong T, Cheng H, Hu Z, Yao L. Multiobjective planning of open-loop MV distribution networks using comgis network analysis and MOGA. Electr Power Syst Res 2009;79(2):390–8.
[112] Najafi S, Hosseinian SH, Abedi M, Vahidnia A, Abachezadeh S. A framework for optimal planning in large distribution networks. IEEE Trans Power Syst 2009;24(2):1019–28.
[113] Ouyang W, Cheng H, Zhang X, Yao L, Bazargan M. Distribution network planning considering distributed generation by genetic algorithm combined with graph theory. Electr Power Compon Syst 2010;38(3):325–39.
[114] Falaghi H, Singh C, Haghifam M-R, Ramezani M. DG integrated multistage distribution system expansion planning. Int J Electr Power Energy Syst 2011;33(8):1489–97.
[115] Naderi E, Seifi H, Sepasian MS. A dynamic approach for distribution system planning considering distributed generation. IEEE Trans Power Deliv 2012;27(3):1313–22.
[116] Zeng B, Zhang J, Yang X, Wang J, Dong J, Zhang Y. Integrated planning for transition to low-carbon distribution system with renewable energy generation and demand response. IEEE Trans Power Syst 2013;29(3):1153–65.
[117] Zhou L, Sheng W, Liu W, Ma Z. An optimal expansion planning of electric distribution network incorporating health index and non-network solutions. CSEE J Power Energy Syst 2019;6(3):681–92.
[118] Ziari I, Ledwich G, Ghosh A. Optimal integrated planning of MV–LV distribution systems using DPSO. Electr Power Syst Res 2011;81(10):1905–14.
[119] Ziari I, Ledwich G, Ghosh A, Platt G. Integrated distribution systems planning to improve reliability under load growth. IEEE Trans Power Deliv 2012;27(2):757–65.
[120] Samper ME, Vargas A. Investment decisions in distribution networks under uncertainty with distributed generation—Part I: Model formulation. IEEE Trans Power Syst 2013;28(3):2331–40.
[121] Samper ME, Vargas A. Investment decisions in distribution networks under uncertainty with distributed generation—Part II: Implementation and results. IEEE Trans Power Syst 2013;28(3):2341–51.
[122] Sedghi M, Aliakbar-Golkar M, Haghifam M-R. Distribution network expansion considering distributed generation and storage units using modified PSO algorithm. Int J Electr Power Energy Syst 2013;52:221–30.
[123] Karimi M, Jannati-Oskuee M-R. Risk-based dynamic expansion planning of distribution network's reliability and power quality. Int J Ambient Energy 2022;43(1):4138–52.
[124] Nayeripour M, Hasanvand S, Fallahzadeh-Abarghouei H. Optimal expansion planning of distribution system capacity with respect to distributed generations. Int J Renew Energy Res (IJRER) 2016;6(3):817–24.
[125] Kumari S, Jain P, Saxena D, Bhakar R. Dynamic distribution network expansion planning under energy storage integration using PSO with controlled particle movement. In: Advanced Engineering optimization through intelligent techniques: select proceedings of AEOTIT 2018. Springer; 2020, p. 497–514.
[126] Ramírez-Rosado IJ, Domínguez-Navarro JA. New multiobjective tabu search algorithm for fuzzy optimal planning of power distribution systems. IEEE Trans Power Syst 2006;21(1):224–33.
[127] Cossi AM, Romero R, Mantovani JRS. Planning and projects of secondary electric power distribution systems. IEEE Trans Power Syst 2009;24(3):1599–608.
[128] Navarro A, Rudnick H. Large-scale distribution planning—Part I: Simultaneous network and transformer optimization. IEEE Trans Power Syst 2009;24(2):744–51.
[129] Navarro Espinosa AA, Rudnick van de Wyngard H. Large-scale distribution planning-part I: Simultaneous network and transformer optimization. IEEE; 2009.
[130] Koutsoukis N, Georgilakis P, Hatziargyriou N. A tabu search method for distribution network planning considering distributed generation and uncertainties. In: 2014 international conference on probabilistic methods applied to power systems. IEEE; 2014, p. 1–6.
[131] Pereira Junior BR, Cossi AM, Contreras J, Mantovani JRS. Multiobjective multistage distribution system planning using tabu search. IET Gener Transm Distrib 2014;8(1):35–45.
[132] Cossi A, Da Silva L, Lazaro R, Mantovani J. Primary power distribution systems planning taking into account reliability, operation and expansion costs. IET Gener Transm Distrib 2012;6(3):274–84.

[133] Parada V, Ferland JA, Arias M, Schwarzenberg P, Vargas LS. Heuristic determination of distribution trees. IEEE Trans Power Deliv 2009;25(2):861–9.
[134] Mantovani JR, et al. A decomposition approach for integrated planning of primary and secondary distribution networks considering distributed generation. Int J Electr Power Energy Syst 2019;106:146–57.
[135] Ahmadian A, Elkamel A, Mazouz A. An improved hybrid particle swarm optimization and tabu search algorithm for expansion planning of large dimension electric distribution network. Energies 2019;12(16):3052.
[136] Favuzza S, Graditi G, Ippolito MG, Sanseverino ER. Optimal electrical distribution systems reinforcement planning using gas micro turbines by dynamic ant colony search algorithm. IEEE Trans Power Syst 2007;22(2):580–7.
[137] Nahman JM, Peric DM. Optimal planning of radial distribution networks by simulated annealing technique. IEEE Trans Power Syst 2008;23(2):790–5.
[138] Popović Ž, Kerleta VD, Popović D. Hybrid simulated annealing and mixed integer linear programming algorithm for optimal planning of radial distribution networks with distributed generation. Electr Power Syst Res 2014;108:211–22.
[139] Carrano EG, Guimarães FG, Takahashi RH, Neto OM, Campelo F. Electric distribution network expansion under load-evolution uncertainty using an immune system inspired algorithm. IEEE Trans Power Syst 2007;22(2):851–61.
[140] Souza BB, Carrano EG, Neto OM, Takahashi RH. Immune system memetic algorithm for power distribution network design with load evolution uncertainty. Electr Power Syst Res 2011;81(2):527–37.
[141] El-Zonkoly AM. Multistage expansion planning for distribution networks including unit commitment. IET Gener Transm Distrib 2013;7(7):766–78.
[142] Agajie TF, Khan B, Alhelou HH, Mahela OP. Optimal expansion planning of distribution system using grid-based multi-objective harmony search algorithm. Comput Electr Eng 2020;87:106823.
[143] Ansari MM, Guo C, Shaikh MS, Chopra N, Haq I, Shen L. Planning for distribution system with grey wolf optimization method. J Electr Eng Technol 2020;15:1485–99.
[144] Sultana U, Khairuddin AB, Mokhtar A, Zareen N, Sultana B. Grey wolf optimizer based placement and sizing of multiple distributed generation in the distribution system. Energy 2016;111:525–36.
[145] Sidea DO, Picioroaga II, Bulac C. Optimal battery energy storage system scheduling based on mutation-improved grey wolf optimizer using gpu-accelerated load flow in active distribution networks. IEEE Access 2021;9:13922–37.
[146] Gholizadeh-Roshanagh R, Najafi-Ravadanegh S, Hosseinian SH. A framework for optimal coordinated primary-secondary planning of distribution systems considering MV distributed generation. IEEE Trans Smart Grid 2016;9(2):1408–15.
[147] Moazzami M, Bagherzadeh L, Barzandeh A, Shahinzadeh H, Gharehpetian GB. Active distribution system expansion planning using lion pride optimization algorithm. Int J Renew Energy Res (IJRER) 2019;9(3):1548–59.
[148] Carvalho PM, Ferreira LA. Distribution quality of service and reliability optimal design: Individual standards and regulation effectiveness. IEEE Trans Power Syst 2005;20(4):2086–92.
[149] Yao W, Zhao J, Wen F, Dong Z, Xue Y, Xu Y, et al. A multi-objective collaborative planning strategy for integrated power distribution and electric vehicle charging systems. IEEE Trans Power Syst 2014;29(4):1811–21.
[150] Kumar D, Samantaray S. Design of an advanced electric power distribution systems using seeker optimization algorithm. Int J Electr Power Energy Syst 2014;63:196–217.
[151] Chowdhury A, Custer D. A value-based probabilistic approach to designing urban distribution systems. Int J Electr Power Energy Syst 2005;27(9–10):647–55.
[152] Lavorato M, Rider MJ, Garcia AV, Romero R. A constructive heuristic algorithm for distribution system planning. IEEE Trans Power Syst 2010;25(3):1734–42.
[153] Millar RJ, Kazemi S, Lehtonen M, Saarijarvi E. Impact of MV connected microgrids on MV distribution planning. IEEE Trans Smart Grid 2012;3(4):2100–8.
[154] Kumar D, Samantaray S, Joos G. A reliability assessment based graph theoretical approach for feeder routing in power distribution networks including distributed generations. Int J Electr Power Energy Syst 2014;57:11–30.
[155] Alvarez-Herault M-C, Caire R, Raison B, Hadjsaid N, Bienia W. Optimizing traditional urban network architectures to increase distributed generation connection. Int J Electr Power Energy Syst 2012;35(1):148–57.
[156] Gan CK, Mancarella P, Pudjianto D, Strbac G. Statistical appraisal of economic design strategies of LV distribution networks. Electr Power Syst Res 2011;81(7):1363–72.
[157] Domingo CM, San Roman TG, Sánchez-Miralles A, Gonzalez JPP, Martinez AC. A reference network model for large-scale distribution planning with automatic street map generation. IEEE Trans Power Syst 2010;26(1):190–7.
[158] Moreira J, Miguez E, Vilacha C, Otero AF. Large-scale network layout optimization for radial distribution networks by parallel computing. IEEE Trans Power Deliv 2011;26(3):1946–51.
[159] Moreira J, Miguez E, Vilacha C, Otero AF. Large-scale network layout optimization for radial distribution networks by parallel computing: Implementation and numerical results. IEEE Trans Power Deliv 2012;27(3):1468–76.
[160] Zhao H, Wang Z, Yu DC, Chen X. New formulations and hybrid algorithms for distribution system planning. Electr Power Compon Syst 2007;35(4):445–60.
[161] Bin Humayd AS, Bhattacharya K. Comprehensive multi-year distribution system planning using back-propagation approach. IET Gener Transm Distrib 2013;7(12):1415–25.
[162] Kaveh A, Mahjoubi S. Lion pride optimization algorithm: A meta-heuristic method for global optimization problems. Sci Iranica 2018;25(6: Special Issue Dedicated to Professor Goodarz Ahmadi):3113–32.
[163] Camargos RSC, Shayani RA, de Oliveira MAG. Evaluation whether photovoltaic distributed generation postpones or anticipates reinforcements detected by distribution network expansion planning. IET Gener Transm Distrib 2019;13(7):1036–48.
[164] Al Kaabi SS, Zeineldin H, Khadkikar V. Planning active distribution networks considering multi-DG configurations. IEEE Trans Power Syst 2013;29(2):785–93.
[165] Marcos A, Sanches JR. Integrated planning of electric power distribution networks. IEEE Lat Am Trans 2009;7(2):203–10.
[166] Masoumi-Amiri SM, Shahabi M, Barforoushi T. Interactive framework development for microgrid expansion strategy and distribution network expansion planning. Sustain Energy Grids Netw 2021;27:100512.
[167] Wang H, Ren Z, Gao L, Hu X, Fan M. A four-terminal interconnected topology and its application in distribution network expansion planning. Int J Electr Power Energy Syst 2022;141:108177.
[168] Asensio M, Muñoz-Delgado G, Contreras J. Bi-level approach to distribution network and renewable energy expansion planning considering demand response. IEEE Trans Power Syst 2017;32(6):4298–309.
[169] Kabirifar M, Fotuhi-Firuzabad M, Moeini-Aghtaie M, Pourghaderi N, Dehghanian P. A bi-level framework for expansion planning in active power distribution networks. IEEE Trans Power Syst 2021;37(4):2639–54.
[170] Moradijoz M, Moghaddam MP, Haghifam M. A flexible active distribution system expansion planning model: A risk-based approach. Energy 2018;145:442–57.
[171] Wang H, Shi L, Ni Y. A bi-level programming model for distribution network expansion planning with distributed generations and energy storage systems. In: 2018 IEEE power & energy society general meeting. IEEE; 2018, p. 1–5.
[172] Akbari T, Moghaddam SZ. Coordinated scheme for expansion planning of distribution networks: A bilevel game approach. IET Gener Transm Distrib 2020;14(14):2839–46.
[173] Kabirifar M, Fotuhi-Firuzabad M, Moeini-Aghtaie M, Pourghaderi N, Shahidehpour M. Reliability-based expansion planning studies of active distribution networks with multiagents. IEEE Trans Smart Grid 2022;13(6):4610–23.
[174] Moradijoz M, Moghaddam MP, Haghifam M-R. A flexible distribution system expansion planning model: A dynamic bi-level approach. IEEE Trans Smart Grid 2017;9(6):5867–77.
[175] El-Meligy MA, Sharaf M, Soliman AT. A coordinated scheme for transmission and distribution expansion planning: A tri-level approach. Electr Power Syst Res 2021;196:107274.
[176] Moradi-Sepahvand M, Amraee T, Aminifar F, Akbari A. Coordinated expansion planning of transmission and distribution systems integrated with smart grid technologies. Int J Electr Power Energy Syst 2023;147:108859.
[177] Elliott RT, Fernandez-Blanco R, Kozdras K, Kaplan J, Lockyear B, Zyskowski J, et al. Sharing energy storage between transmission and distribution. IEEE Trans Power Syst 2018;34(1):152–62.
[178] Deb K. Multi-objective optimisation using evolutionary algorithms: An introduction. In: Multi-objective evolutionary optimisation for product design and manufacturing. Springer; 2011, p. 3–34.