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Review Article

A Review of Distribution Network Expansion Planning

Wan Yusrizal Wan Yusoff[1,2]*, Mohammad Lutfi Othman[1,2], Mohd Zainal Abidin Ab Kadir[1], Noor Izzri Abdul Wahab[1] and Aidil Azwin Zainul Abidin[3]

[1]*Department of Electrical and Electronics Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia*
[2]*Advanced Lightning, Power and Energy Research (ALPER), Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia*
[3]*Engineering College, Universiti Tenaga Nasional, 43000 Kajang, Selangor, Malaysia*

ABSTRACT

Distribution Networks Expansion Planning (DNEP) is very complex and involves improving the system to meet the increasing demand using the most cost-effective strategy. Among the planned choices are the extension of substations, upgrade of distribution feeders, installation of additional Distributed Energy Resources (DERs), installation of Capacitor Banks (CBs) and many other methods. Distribution planners in contemporary networks must have faith in the reversibility of investments where Renewable Energy Resources (RERs) inject clean and cost-effective for DNEP to meet growing demand and environmental requirements. The comprehensive review of DNEP carried out in this paper covers all possible objective functions and problem constraints. With the rise of electric vehicles (EVs), there is a growing need to assess the impact of EV charging on distribution networks. Understanding how EV loads affect the network helps plan future expansions to efficiently accommodate the charging infrastructure. Integrating DERs, such as solar panels, wind turbines, and energy storage systems, is changing how electricity is generated, distributed, and consumed. Assessing the integration of DERs into distribution networks is crucial for optimal network planning and operation. In addition, CBs are essential for power factor correction and voltage regulation in distribution networks. Including CBs in expansion planning helps improve network efficiency, reliability, and overall power quality. By analyzing the impact of EV loads, DERs, and CBs in DNEP, researchers and planners can develop more accurate models and strategies for designing sustainable and resilient power systems to efficiently meet the growing energy demands.

Keywords: Capacitor banks, distributed energy resources, distribution networks, electric vehicles load, expansion planning

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E-mail addresses:
yusrizaly@tnb.com.my (Wan Yusrizal Wan Yusoff)
lutfi@upm.edu.my (Mohammad Lutfi Othman)
mzk@upm.edu.my (Mohd Zainal Abidin Ab Kadir)
izzri@upm.edu.my (Noor Izzri Abdul Wahab)
aidilazwin@uniten.edu.my (Aidil Azwin Zainul Abidin)
* Corresponding author

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INTRODUCTION

According to the World Energy Transitions Outlook published by the International Renewable Energy Agency (IRENA) in 2021, significant cuts in greenhouse gas emissions are required to achieve the Paris Agreement's aim of keeping the rise in global temperature well below 2°C. Reducing emissions over the coming decades will need more energy transition expenditures, such as expanding renewable energy sources and enhancing the energy infrastructure. Plans for the national and regional energy transformation are provided, together with projections for 2030 and 2050, by the IRENA program Renewable Energy Map (REmap), which creates roadmaps for renewable energy. Developing regional studies aims to comprehend how a region can support an energy transition pathway that respects countries' unique energy resources, socioeconomic status, and institutional and regulatory endowments. It also contributes to the global emission reduction goal and leverages opportunities to meet regional energy and investment goals. A roadmap for the REmap has been developed for the Association of Southeast Asian Nations (ASEAN) to meet its target of 23% renewable energy in the energy mix by 2025 (IRENA, 2023).

Over the past few decades, carbon dioxide (CO_2) emissions have gradually increased. In 2018, the transportation industry contributed more than one-fourth of all Global Greenhouse Gas (GHG) emissions (Francisco et al., 2020). As a signatory to the Paris Agreement, Malaysia is dedicated to establishing a low-carbon society. The Malaysian government wants to cut greenhouse gas emissions by 45% by 2030 compared to GDP (gross domestic product) in 2005 (UNFCC, 2015). The most recent National Transport Policy (NTP 2019–2030), with the goal of "Advance Toward Green Transport Ecosystem," reflects this aim (MOT, 2019). As a result, the Malaysian government is encouraging the use of Energy Efficient Vehicles (EEV), which includes Electric Vehicles (EVs), with the goal of having all EEVs on the road by 2030 (KeTTHA, 2017). In order to solve this problem, it has been shown that EVs are a cleaner, quieter and more energy-efficient alternative to Internal Combustion Engine Vehicle (ICEV). The benefits of EVs to the environment and economy are particularly strong (Francisco et al., 2020).

Protecting the reliability of the power distribution network is an ongoing problem. Higher expectations for supply stability and resilience, increasing energy prices, supporting demand growth, ensuring environmental sustainability and keeping up with new distributed generating technologies are all obstacles (Pinto et al., 2019). Also, the reform of the energy supply business and the increase in market competitiveness need greater efficiency and the introduction of new, cutting-edge consumer goods and services. Utilities may change the conventional network distribution system as a result of the increased user engagement made possible by the development of smart and digital technologies. However, this necessitates a new set of network design requirements and disturbs established methods of grid management. Smart developing technologies like renewable energy resources, battery energy system storage, and Volt-VAR optimization are gaining traction as potential alternatives to expanding existing networks to improve system dependability. Using non-network solutions to lower network demand and postpone network investment may be the most cost-effective option when the price of conventional network solutions is prohibitive (Liu et al., 2017).

One of the topics that must be investigated is the expansion planning of the Active Distribution Network (ADN). The planning studies for this expansion model consider the consequences of ideal operating circumstances. Through active management of these resources, the network's Distributed Energy Resources (DERs) are utilized in accordance with each operational situation. Investment in distribution network assets, such as feeders, substations, and DERs systems combining traditional gas turbines and renewable wind generators, is jointly considered at the planning level (Kabirifar et al., 2019). In Figure 1, the numbers of published relevant and significant literature from 2014 to 2022 emphasize the significance of research in this area. Research regarding expansion planning of distribution networks considering electric vehicle loads has been increasing, and the trend shows it will keep increasing due to market sentiments. Figure 2 shows the number of published relevant and significant literature in different countries to infer the global application of this study.

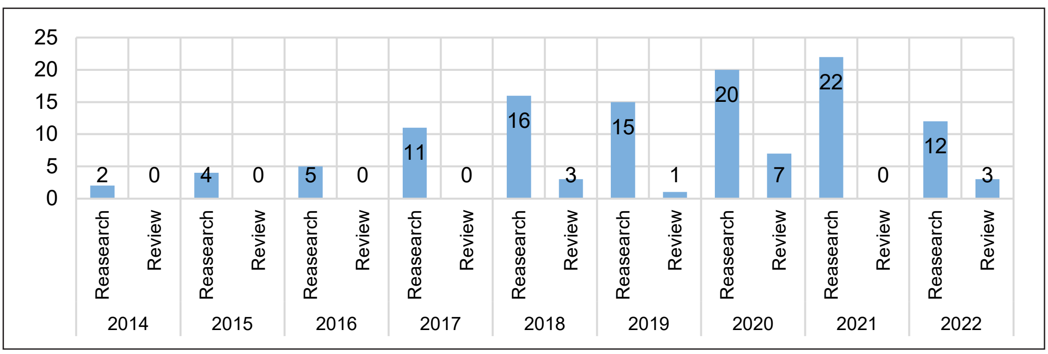

Figure 1. Number of relevant research published by years

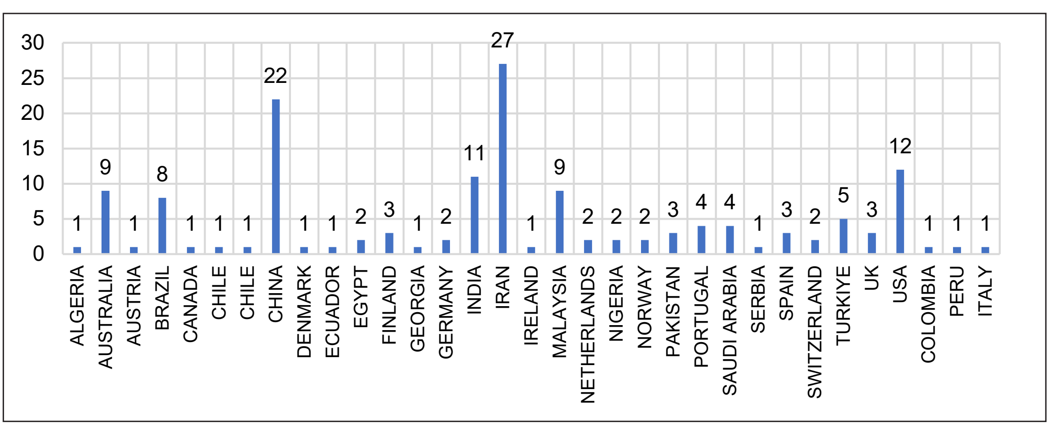

Figure 2. Number of relevant research published by country

DISTRIBUTION NETWORK EXPANSION PLANNING OVERVIEW

The primary objective of distribution planning is to provide a steady supply of energy to meet customer demand at the lowest cost feasible considering the load, in accordance with asset management best practices and in an ecologically conscious way. The main planning difficulties are determining the most economical expenditure in proportion to the expected risk of supply dependability or the frequency and impact of breakdowns. Planning methodology is evolving to align with the growth of active control in smart-grid applications. Through multi-objective, probabilistic and risk-oriented planning, the innovative approach to distribution network planning that integrates active distribution network capabilities offers more affordable solutions (Aghaei et al., 2014; Esmaeili et al., 2016; Hemmati et al., 2015).

Distribution Network Expansion Planning Objectives

An objective function is a mathematical expression that describes the current state of a multivariate system. Depending on the problem or intended value, changing these variables will result in the biggest or smallest optimal value. The goal functions can be maximized or minimized to get that value (Verma et al., 2019). Many objectives and functions need to be considered during the execution of the distribution network expansion planning, which can be categorized into financial, income-related, technical, optimal size and location, as well as social and economic. The objectives functions of design and planning criteria of DNEP shall take into consideration the following:

(i) Minimization of total emissions (Esmaeili et al., 2016; Ehsan & Yang, 2019a, 2019b).
(ii) Feeder, substation and Distributed Energy Resources investment cost (Esmaeili et al., 2016; Aghaei et al., 2014; Hemmati et al., 2015).
(iii) Volt-VAR optimization by Capacitor Banks (Ameli et al., 2017; Ayoubi et al., 2017).
(iv) Battery Energy Storage System (BESS) investment and operation cost (Masoumi-Amiri et al., 2021; Cossi et al., 2012; Ehsan & Yang, 2019a, 2019b).
(v) Energy loss minimization (Aghaei et al., 2014; Dumbrava et al., 2011).
(vi) Voltage Stability & Voltage Profile Improvement (Esmaeili et al., 2016; Lin et al., 2019; Poornazaryan et al., 2016).
(vii) Reliability Improvement (Aghaei et al., 2014; Dumbrara et al., 2011).
(viii) Minimize Line Loading (Gallano & Nerves 2014).
(ix) Optimal Power Flow (OPF) solution (Hemmati et al., 2015).
(x) Load variations and purchased energy (Bagheri et al., 2015).
(xi) Asset investment cost (Mazhari et al., 2015).

Thirty-five (35) relevant and significant review papers have been summarized to map out the current trends of the research and important criteria of Distribution Network

Expansion Planning, Distributed Energy Resources (DERs), Capacitor Banks, and Electric Vehicle Loads worldwide. Table 1 shows a comparison of the review papers based on the potential areas by types of network systems that previous research has covered in each paper. Table 2 shows a summary of research areas related to electric vehicles. Table 3 summarizes research areas related to integration with distribution systems. Meanwhile, Table 4 shows a summary of research areas related to objective functions and constraints that have been taken into consideration related to DNEP research. Objective function selection clearly shows increasing penetration of DERs, adoption of capacitor banks and expansion cost optimization. However, the research regarding the adoption of the integration of EVs load as the objective is still limited. Hence, this creates the motivation to execute research toward integrating EV load into DNEP. Furthermore, Table 5 summarizes the optimization methods researchers in previous research have adopted. Several scholars suggested using heuristics to directly optimize complicated optimization problems. It is difficult to ensure that the solution is globally optimum despite its simplicity of implementation. Many heuristic evolutionary algorithms, such as Tabu Search, Ant Colony, Particle Swarm Optimization, Genetic Algorithm, and Monte Carlo, have been introduced.

Distribution Network Expansion Planning Constraints

Any technological problem's effectiveness and applicability rely on the precise definition of an objective function, and the selection of constraints constricts the available options. DNEP challenges have a similar characteristic. To find the best solution for every site, the proper technological, social and economic factors must constrain the objective functions of DNEP issues. Constraints are the requirements on various objective functions in DNEP to arrive at the most optimal, consistent, and economical solution. Therefore, efficiently solving DNEP issues depends greatly on the selection of suitable constraints. The current study tries to compile the restrictions considered in more than eighty original publications published throughout ten years. The limitations taken into consideration by several distinguished scholars have been explored by grouping them into technical, non-technical, time and financial and other limitations. Concerning the assimilation of DERs and BESS, special considerations necessary for choosing limitations for DNEP have also been highlighted.

According to Figure 3, most researchers consider uncertainties, reliability, load growth, and asset investment minimization their objective functions and constraints.

The EV load is yet to be considered in most research regarding DNEP. Hence, this situation leads to the motivation to further study the impact of the EV load on the existing distribution networks. Many constraints need to be considered during the execution of the distribution network expansion plan. The constraints of design and planning criteria of the distribution network shall take into consideration the following:

Table 1
Research areas by types of network system

Reference paper	Expansion Planning	Generation System	Transmission System	Distribution Network System
Arasteh et al., 2016	✓		✓	✓
Muñoz-Delgado et al., 2015	✓	✓	✓	✓
Cossi et al., 2012	✓		✓	✓
Ramirez & Bernal, 2001	✓		✓	
Dumbrava et al., 2011	✓		✓	✓
Nejadfard-Jahromi et al., 2015	✓		✓	
Mazhari et al., 2015	✓		✓	✓
Georgilakis & Hatziargyriou., 2015	✓		✓	
Jeddi et al., 2019				
Moradijoz et al., 2017	✓			✓
Ehsan & Yang, 2019b	✓			✓
Ehsan & Yang, 2019a	✓			✓
Melgar-Dominguez et al., 2021	✓			✓
El-Ela et al., 2019				✓
Lopez et al., 2021				✓
KC & Regmi, 2019				✓
Sirjani, 2017				✓
Eid et al., 2022				✓
Rangarajan et al., 2017				✓
Ayalew et al., 2022	✓			✓
Moazzami et al., 2019	✓			✓
Amjady et al., 2017	✓			✓
Srinivasan & Visalakshi, 2017				✓
Hoog et al., 2015				✓
Bagheri et al., 2015	✓			✓
Lin et al., 2019	✓			✓
Poornazaryan et al., 2016				✓
Masoumi-Amiri et al., 2021)	✓			✓
Ayoubi et al., 2017				✓
Hemmati et al., 2015	✓			✓
Aghaei et al., 2014	✓			✓
Esmaeili et al., 2016				✓
Kabirifar et al., 2019	✓			✓
Manríquez et al., 2020	✓	✓	✓	
Pinto et al., 2021	✓			✓

Table 2
Research areas related to electric vehicles

Reference paper	Electric Vehicles	EV Smart Charging	EV Optimal Charging
Arasteh et al., 2016)			
Muñoz-Delgado et al., 2015			
Cossi et al., 2012			
Ramirez & Bernal, 2001			
Dumbrava et al., 2011			
Nejadfard-Jahromi et al., 2015			
Mazhari et al., 2015			
Georgilakis & Hatziargyriou., 2015			
Jeddi et al., 2019			
Moradijoz et al., 2017	✓		
Ehsan & Yang, 2019b	✓		
Ehsan & Yang, 2019a	✓		
Melgar-Dominguez et al., 2021			
El-Ela et al., 2019			
Lopez et al., 2021			
KC & Regmi, 2019			
Sirjani, 2017			
Eid et al., 2022			
Rangarajan et al., 2017			
Ayalew et al., 2022			
Moazzami et al., 2019			
Amjady et al., 2017			
Srinivasan & Visalakshi, 2017			
Hoog et al., 2015	✓		✓
Bagheri et al., 2015			
Lin et al., 2019			
Poornazaryan et al., 2016			
Masoumi-Amiri et al., 2021			
Ayoubi et al., 2017			
Hemmati et al., 2015			
Aghaei et al., 2014			
Esmaeili et al., 2016			
Kabirifar et al., 2019			
Manríquez et al., 2020	✓	✓	
Pinto et al., 2021			

Table 3
Research areas related to integration with distribution network system

Reference paper	Distributed Energy Resources (DER) / DG	Capacitor Banks	Micro Grid
Arasteh et al., 2016	✓	✓	
Muñoz-Delgado et al., 2015	✓	✓	
Cossi et al., 2012		✓	
Ramirez & Bernal, 2001		✓	
Dumbrava et al., 2011		✓	
Nejadfard-Jahromi et al., 2015	✓	✓	
Mazhari et al., 2015		✓	
Georgilakis & Hatziargyriou., 2015	✓	✓	
Jeddi et al., 2019			
Moradijoz et al., 2017			
Ehsan & Yang, 2019b	✓		
Ehsan & Yang, 2019a	✓		
Melgar-Dominguez et al., 2021	✓	✓	
El-Ela et al., 2019	✓	✓	
Lopez et al., 2021		✓	
KC & Regmi, 2019		✓	
Sirjani, 2017	✓	✓	
Eid et al., 2022	✓		
Rangarajan et al., 2017	✓		
Ayalew et al., 2022	✓		
Moazzami et al., 2019	✓		
Amjady et al., 2017	✓		
Srinivasan & Visalakshi, 2017	✓	✓	
Hoog et al., 2015			
Bagheri et al., 2015	✓		
Lin et al., 2019			
Poornazaryan et al., 2016	✓		
Masoumi-Amiri et al., 2021			✓
Ayoubi et al., 2017		✓	
Hemmati et al., 2015	✓		
Aghaei et al., 2014	✓	✓	
Esmaeili et al., 2016	✓		
Kabirifar et al., 2019	✓		
Manríquez et al., 2020	✓		
Pinto et al., 2021	✓	✓	

Table 4
Potential research areas related to objective functions and constraints

Reference paper	Multi- Period	Multi-Objective	Reliability	AC power flow	Uncertainties
Arasteh et al., 2016	✓	✓		✓	✓
Muñoz-Delgado et al., 2015	✓	✓		✓	✓
Cossi et al., 2012	✓			✓	
Ramirez & Bernal, 2001	✓	✓		✓	
Dumbrava et al., 2011	✓			✓	
Nejadfard-Jahromi et al., 2015	✓	✓	✓	✓	
Mazhari et al., 2015	✓	✓	✓	✓	
Georgilakis & Hatziargyriou., 2015	✓	✓	✓	✓	
Jeddi et al., 2019					
Moradijoz et al., 2017			✓		
Ehsan & Yang, 2019b	✓			✓	
Ehsan & Yang, 2019a	✓			✓	✓
Melgar-Dominguez et al., 2021	✓	✓		✓	✓
El-Ela et al., 2019		✓		✓	✓
Lopez et al., 2021		✓		✓	✓
KC & Regmi, 2019				✓	✓
Sirjani, 2017		✓		✓	✓
Eid et al., 2022		✓	✓	✓	✓
Rangarajan et al., 2017				✓	✓
Ayalew et al., 2022	✓		✓	✓	✓
Moazzami et al., 2019	✓		✓	✓	✓
Amjady et al., 2017	✓		✓	✓	✓
Srinivasan & Visalakshi, 2017		✓		✓	✓
Hoog et al., 2015		✓	✓	✓	✓
Bagheri et al., 2015	✓	✓		✓	✓
Lin et al., 2019	✓	✓	✓	✓	
Poornazaryan et al., 2016		✓	✓	✓	
Masoumi-Amiri et al., 2021	✓	✓		✓	
Ayoubi et al., 2017		✓		✓	
Hemmati et al., 2015	✓	✓		✓	✓
Aghaei et al., 2014	✓	✓	✓	✓	
Esmaeili et al., 2016		✓		✓	✓
Kabirifar et al., 2019	✓	✓	✓	✓	
Manríquez et al., 2020	✓		✓	✓	
Pinto et al., 2021	✓	✓	✓	✓	

Table 4 *(continue)*

Reference paper	Demand & Transmission Capacity	Energy Balance Constraint	Generation Constraint	switch placement	Load Growth	Network Reconfiguration	Optimal operating condition	Asset Investment Minimization	Voltage Stability	Power Losses	Operational Cost	Thermal Limit of Feeder & Substation	Demand Response	Harmonic / Power Quality	Cost of Energy Purchase	Carbon Emission Taxes
Arasteh et al., 2016				√												
Muñoz-Delgado et al., 2015																
Cossi et al., 2012																
Ramirez & Bernal, 2001																
Dumbrava et al., 2011																
Nejadfard-Jahromi et al., 2015																
Mazhari et al., 2015				√												
Georgilakis & Hatziargyriou., 2015				√												
Jeddi et al., 2019																
Moradijoz et al., 2017								√								
Ehsan & Yang, 2019b							√	√								
Ehsan & Yang, 2019a							√	√								
Melgar-Dominguez et al., 2021					√		√	√			√				√	√
El-Ela et al., 2019								√	√				√			
Lopez et al., 2021									√							
KC & Regmi, 2019								√	√							
Sirjani, 2017														√		
Eid et al., 2022									√	√						
Rangarajan et al., 2017					√									√		
Ayalew et al., 2022					√				√	√						
Moazzami et al., 2019					√			√	√							
Amjady et al., 2017					√			√								
Srinivasan & Visalakshi, 2017						√				√						
Hoog et al., 2015									√			√				
Bagheri et al., 2015					√				√							
Lin et al., 2019					√			√			√					
Poornazaryan et al., 2016					√				√	√						
Masoumi-Amiri et al., 2021					√			√			√					
Ayoubi et al., 2017									√	√						
Hemmati et al., 2015					√			√			√					
Aghaei et al., 2014					√			√	√	√						
Esmaeili et al., 2016						√			√	√	√					
Kabirifar et al., 2019					√		√	√								
Manríquez et al., 2020	√	√	√		√											
Pinto et al., 2021				√												

Table 4 *(continue)*

Reference paper	Allocation of Voltage Regulators	pollutant Gas Emission	Power injection capability of grindable parking lots	Economic Risk
Arasteh et al., 2016				
Muñoz-Delgado et al., 2015				
Cossi et al., 2012				
Ramirez & Bernal, 2001				
Dumbrava et al., 2011				
Nejadfard-Jahromi et al., 2015				
Mazhari et al., 2015				
Georgilakis & Hatziargyriou., 2015				
Jeddi et al., 2019				
Moradijoz et al., 2017			✓	✓
Ehsan & Yang, 2019b				
Ehsan & Yang, 2019a				
Melgar-Dominguez et al., 2021	✓			
El-Ela et al., 2019				
Lopez et al., 2021				
KC & Regmi, 2019				
Sirjani, 2017				
Eid et al., 2022				
Rangarajan et al., 2017				
Ayalew et al., 2022				
Moazzami et al., 2019				
Amjady et al., 2017				
Srinivasan & Visalakshi, 2017				
Hoog et al., 2015				
Bagheri et al., 2015				
Lin et al., 2019				
Poornazaryan et al., 2016				
Masoumi-Amiri et al., 2021				
Ayoubi et al., 2017				
Hemmati et al., 2015				
Aghaei et al., 2014				
Esmaeili et al., 2016		✓		
Kabirifar et al., 2019				
Manríquez et al., 2020				
Pinto et al., 2021				

Table 5
Potential research areas related to optimization method

Reference paper	Heuristic	Monte Carlo Simulation (MCS)	Mix Integer Linear Programming (MILP)
Arasteh et al., 2016	✓	✓	
Muñoz-Delgado et al., 2015	✓	✓	
Cossi et al., 2012	✓		
Ramirez & Bernal, 2001	✓	✓	
Dumbrava et al., 2011		✓	
Nejadfard-Jahromi et al., 2015	✓	✓	
Mazhari et al., 2015	✓		
Georgilakis & Hatziargyriou., 2015	✓	✓	
Jeddi et al., 2019			
Moradijoz et al., 2017		✓	
Ehsan & Yang, 2019b			
Ehsan & Yang, 2019a			
Melgar-Dominguez et al., 2021			
El-Ela et al., 2019	✓		
Lopez et al., 2021	✓		
KC & Regmi, 2019			
Sirjani, 2017	✓		
Eid et al., 2022			
Rangarajan et al., 2017			
Ayalew et al., 2022			
Moazzami et al., 2019	✓		
Amjady et al., 2017			✓
Srinivasan & Visalakshi, 2017	✓		
Hoog et al., 2015	✓		
Bagheri et al., 2015	✓		
Lin et al., 2019			
Poornazaryan et al., 2016	✓		
Masoumi-Amiri et al., 2021			
Ayoubi et al., 2017	✓		
Hemmati et al., 2015	✓	✓	
Aghaei et al., 2014	✓		
Esmaeili et al., 2016	✓		
Kabirifar et al., 2019			✓
Manríquez et al., 2020			✓
Pinto et al., 2021	✓	✓	

Table 5 *(continue)*

Reference paper	Genetic Algorithm (GA)	Particle Swarm Optimization (PSO)	Tabu Search (TS)	Bilevel Optimization Approach	Numerical Experiment	Linear Optimization	Lion Pride Optimization (LPO)	Multi-Objective Hybrid Big-Bang Crunch (MOHBB-BC)	Triangular Fuzzy Number (TFN)	Fuzzy	Imperialistic Competitive Algorithm (ICA)	Bald Eagle Search (BES)	Discrete Lightning Search Algorithm (DLSA)	Ant Colony Algorithm (ACA)	Analytical Method
Arasteh et al., 2016		✓													
Muñoz-Delgado et al., 2015	✓														
Cossi et al., 2012	✓		✓												
Ramirez & Bernal, 2001															
Dumbrava et al., 2011															
Nejadfard-Jahromi et al., 2015	✓														
Mazhari et al., 2015	✓														
Georgilakis & Hatziargyriou., 2015	✓	✓													
Jeddi et al., 2019															
Moradijoz et al., 2017															
Ehsan & Yang, 2019b															
Ehsan & Yang, 2019a															
Melgar-Dominguez et al., 2021															
El-Ela et al., 2019		✓													
Lopez et al., 2021														✓	
KC & Regmi, 2019															✓
Sirjani, 2017													✓		
Eid et al., 2022															
Rangarajan et al., 2017															
Ayalew et al., 2022															
Moazzami et al., 2019							✓								
Amjady et al., 2017															
Srinivasan & Visalakshi, 2017		✓										✓			
Hoog et al., 2015						✓									
Bagheri et al., 2015	✓														
Lin et al., 2019					✓										
Poornazaryan et al., 2016											✓				
Masoumi-Amiri et al., 2021				✓											
Ayoubi et al., 2017		✓								✓					
Hemmati et al., 2015															
Aghaei et al., 2014		✓													
Esmaeili et al., 2016								✓	✓						
Kabirifar et al., 2019															
Manríquez et al., 2020															
Pinto et al., 2021	✓														

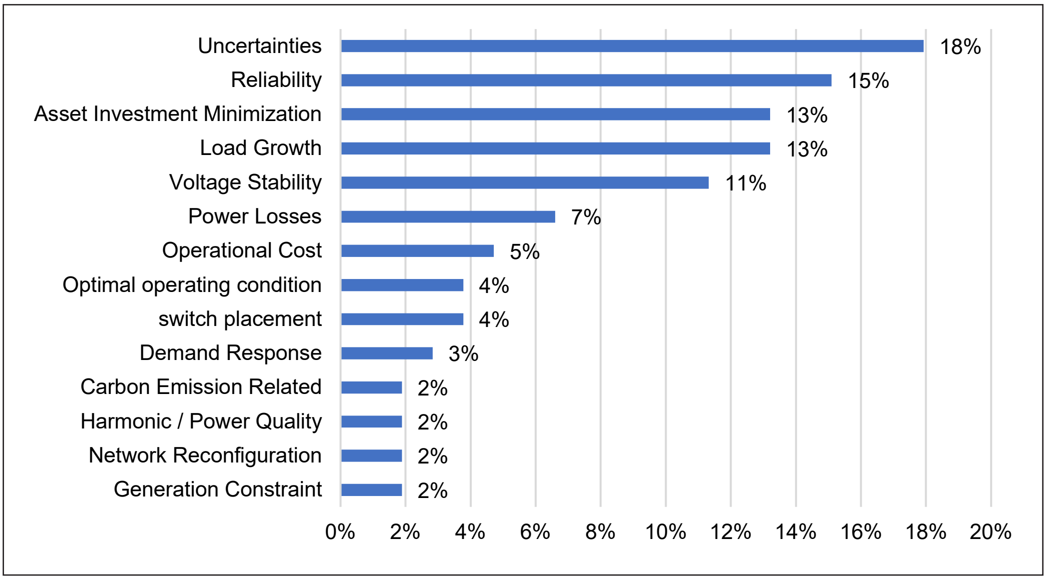

Figure 3. A Summary of objective functions and constraints in DNEP

1. Voltage drops (Bagheri et al., 2015; Hoog et al., 2015).
2. Substation loading and branch current limit (Bagheri et al., 2015; Liu et al., 2017; Ehsan & Yang, 2019a, 2019b).
3. Network radiality constraint (Ameli et al., 2017; Pathak & Prakash, 2018).
4. Demand response (Pinto et al., 2021; Muñoz-Delgado et al., 2015).
5. Microgrid (Masoumi-Amiri et al., 2021; Pinto et al., 2019; Twaisan & Barisci, 2022).
6. DGs reactive power capacity, DGs active power capacity and DGs penetration (Arasteh et al., 2016; Esmaeili et., 2016; Kumar & Kumar, 2020; Pinto et al., 2019; Srinivasan & Visalakshi, 2017).
7. Network loss (Srinivasan & Visalakshi, 2017).
8. Nominal power rating of transformers (Hoog et al., 2015).
9. Nominal current ratings of lines (Pinto et al., 2019).
10. Phase unbalance (Hoog et al., 2015).

Distribution Network Expansion Planning Integration with Electric Vehicle Loads, Distributed Energy Resources and Capacitor Banks

Due to several key factors, research related to Distribution Network Expansion Planning and integration with EV load, DERs, and CBs is gaining more prominence than previous research. With the increasing adoption of electric vehicles, there is a rising demand for efficient integration of these loads into the existing distribution network. This necessitates the need for advanced planning strategies to accommodate the charging infrastructure and

Table 6
Summary of research related to Distribution Network Expansion Planning and integration with EVs load, DERs and CBs

References	Year	Contribution	EVs Load	DERs	CBs
Aghaei et al., 2014	2014	The objective functions of Multi-Stage Distribution Expansion Planning include cost reduction, voltage stability index, active power losses, and Energy Not Distributed.	No	Yes	No
Hemmati et al., 2015	2015	The results revealed that using DG increased system performance, improved the voltage profile, decreased planning expenses, and reduced losses.	No	Yes	No
Bagheri et al., 2015	2015	DERs have been considered as the expansion planning options that verified the efficiency of the proposed method in decreasing the total cost of environmental pollution	No	Yes	No
Esmaeili et al.2016	2016	A multi-objective framework is suggested for simultaneous network reconfiguration and DER power allocation in distribution networks.	No	Yes	No
Poornazaryan et al., 2016	2016	A new index has been developed to evaluate the ideal size and position of DG units, taking into consideration load fluctuation, to reduce active power losses and improve the voltage stability margin.	No	Yes	No
Rangarajan, et al., 2017	2017	The proposal of a unique notion of leveraging smart PV inverters as virtual detuners for removing network resonances sets the basis for further study.	No	Yes	No
Ameli et al., 2017	2017	This framework may accept various cooperative behaviors among decision-makers. The stochastic behavior of a gridable parking lot is being examined as an alternative supply resource to improve the dependability of the distribution network.	Yes	No	No
Srinivasan & Visalakshi, 2017	2017	An application to reduce power loss in distribution networks by allocating and sizing DGs units and capacitors as efficiently as possible, both with and without reconfiguring the network	No	Yes	Yes
Sirjani, 2017	2017	The best position and size of capacitors were chosen based on system equivalent circuits, predicted wind speed, and harmonics to minimize energy losses, optimize reactive power, and lower management costs.	No	No	Yes
Ameli et al. 2017	2017	A unique technique for concurrent dynamic scheduling of feeder reconfiguration and CB switching is presented in DG units with unknown and variable generations over time.	No	Yes	Yes
Ayoubi, et al. 2017	2017	A novel method for placing capacitors in the presence of harmonic distortion is described, along with a suggested resonance index.	No	No	Yes

Table 6 *(continue)*

References	Year	Contribution	EVs Load	DERs	CBs
Quevedo et al., 2017	2017	BESS can contribute to the coordinated DNEP by integrating renewable energy and EV charging demand, minimizing investment and operating expenses, and eliminating the need to extend existing substations.	Yes	Yes	No
Kabirifar et al., 2019	2019	The investment, maintenance, operation, and unsupplied energy expenses' net present value (NPV) is reduced.	No	Yes	No
Moazzami et al. 2019	2019	Deploy DERs as candidate equipment for distribution system growth to meet operational and economic needs while avoiding feeder extension and substation concerns.	No	Yes	No
Jeddi et al., 2019	2019	The suggested optimization model calculates the size, placement, and power factor of DERs. Other selection criteria include the transformer or line improvements requirement and the ideal year for DER installation.	No	Yes	No
Yu et al., 2019	2019	In conjunction with the various incremental distribution service pricing supervision mechanisms, incremental power distribution planning models that suit the appropriate demands are proposed.	No	No	No
KC & Regmi, 2019	2019	This study employs an analytical technique. The distribution system's load flow is performed using a backward/forward sweep algorithm.	No	No	Yes
El-Ela et al., 2019	2019	Various goal functions are used in the allocation issue under consideration to optimize the voltage profile, maximize operational loss savings, reduce overall investment costs, and increase loading capacity.	No	Yes	Yes
Pinto et al., 2019	2019	Coordinated operation and expansion planning reduce the problem's total cost, and demand response and DERs coordination results are more consistent.	No	Yes	Yes
Kumar & Kumar, 2020	2020	A novel multi-objective function model is devised to tackle the Multistage Distribution System Planning problem with planning and operational limitations.	No	No	No
He et al., 2022	2021	The expansion site selection and capacity plan of EVCSs are obtained to lower the total yearly societal cost of charging stations.	Yes	No	No
Lopez et al., 2021	2021	The goal function uses three-phase capacitor banks dispersed across the distribution network and sized to produce minimum power loss values.	No	No	Yes
Pinto et al., 2021	2021	The suggested computational model is described as a mixed integer nonlinear optimization problem, which is addressed using a combination of Monte-Carlo simulation and optimum power flow.	No	Yes	No

Table 6 *(continue)*

References	Year	Contribution	EVs Load	DERs	CBs
Masoumi-Amiri et al., 2021	2021	The inclusion of a microgrid structure in distribution network development plans improves operational conditions and encourages investor engagement in the electricity system.	No	Yes	No
Zhang et al., 2021	2021	A multi-objective planning model for the sizing and placement of EVSEs and the extension of a power distribution network with significant wind power penetration.	Yes	No	No
Melgar-Dominguez et al., 2021	2021	The goal function of this optimization model is to reduce the predicted cost of energy acquired from the market, as well as charges related to carbon emission levies while maximizing energy purchased from DG developers.	No	Yes	Yes
Ayalew et al., 2022	2022	The performance of the existing and improved networks is evaluated using current and expected load demand for the year 2030.	No	Yes	No
Borozan et al., 2022	2022	For large-scale and long-term, DNEP suggests Grid-to-Vehicle (G2V), Vehicle-to-Grid (V2G), and Vehicle-to-Building (V2B) investment and operation models under multi-dimensional uncertainty.	Yes	No	No
Gholami et al., 2022	2022	This article aims to arrange EV charging stations and smart PV inverters in distribution networks simultaneously to minimize power loss, voltage deviation, and voltage imbalance.	Yes	Yes	No

manage the additional load effectively. The proliferation of DERs, such as solar PV systems and energy storage, adds complexity to the distribution network. Research focusing on the optimal integration of DERs along with EV loads can help enhance system reliability, flexibility, and efficiency. Meanwhile, CBs are crucial in improving power factors, reducing losses, and enhancing voltage stability in distribution networks. By incorporating CBs into expansion planning alongside EVs and DERs, researchers can explore holistic approaches to enhance grid resilience and stability. The focus on integrating EVs load, DERs, and CBs into DNEP research reflects a shift towards addressing the evolving challenges and opportunities in modern power systems, aiming to facilitate a more sustainable, efficient, and reliable energy infrastructure. Table 6 summarizes relevant research articles on Distribution Network Expansion Planning and integration with EV load, DERs and CBs. According to Table 6, the comparison of reviewed research has been focused on EV load, DERs and CBs and shows that no previous research considered EV load, DERs and CBs in the DNEP research.

The primary issue with DNEP is the intricacy of the distribution networks. Power balance, voltage profiles, branch capacity, DG restrictions, radiality constraints, network loss and pollutant emissions are just a few requirements that must be met. As a result, the researchers broke the DNEP challenges into smaller components and offered a range of methods to address different issues. In any event, to arrive at a workable solution, we need sufficient information on the DNEP models. As the trend indicates, future optimization challenges should consider power supply. Volt-VAR optimization by CBs, the integration of RERs, and the load of EVs can all lead to more optimum solutions.

IMPACT OF ELECTRIC VEHICLES (EVS) LOAD TOWARD DISTRIBUTION NETWORK

It is widely acknowledged that the most effective way to address pollution, global warming and energy sustainability issues is to electrify the transportation industry. The EV adoption and distribution level is expected to see a range of growth rates worldwide, depending on the accessibility of charging infrastructure, user desire, and income. With a low number of EVs and charging stations, the distribution network is not expected to encounter any technological problems. However, as the penetration of EVs increases, several technological problems surface. Violations of voltage limits, harmonic distortion, and higher losses might result from these problems. To enable demand response and provide different operating reserves using the energy stored in EVs, vehicle-to-grid operation (V2G) may also be taken into consideration.

As one of the possible energy solutions to lower system peak demand, the V2G operates on Smart Grid infrastructures that provide effective network and EV communication. EVs require a connection to the electrical grid to obtain charging for propulsion. EVs are dynamic loads that might disperse throughout the power grid. The reliability and quality of the power supply will be put at risk by the connectivity of a sizable fleet of EVs to the power grid. As a result, the technical effects of EV charging will be discussed and considered when all Electric Vehicles Supply Equipment is planned, installed and operated (Fan et al., 2021; Francisco et al., 2020; Zhou et al., 2014). Some of the impacts of electric vehicles (EVs) load on distribution network systems are as follows:

1. Increase in peak demand (Gallo, 2016).
2. Increase in power losses (Veldman & Verzijlbergh, 2014).
3. Voltage drop/Voltage profiles (Energy Commission, 2017).
4. Overloading of system components (Francisco et al., 2020).
5. Phase unbalanced (Veldman & Verzijlbergh, 2014).
6. Harmonics (Lucas et al., 2015).
7. Electric Vehicles (EVs) load massive penetration (Francisco et al., 2020; Taljegard et al., 2019).

When modeling a DNEP problem, the interaction between transportation and distribution networks, as well as various charging facilities like parking spaces, private charging locations at houses and quick charging stations, may be considered. If the Distribution

Network Operator is authorized to invest in RERs, the illiquidity of these resources must be considered. Because Grid Parking Lot storage capacity is an excellent tool for encouraging RER integration, the cooperative interaction between Distribution Network Operator and Grid Parking Lot Operator should be reflected in the operational phase as well as the planning level (Moradijoz et al., 2017). Researchers can also incorporate further, more thorough modeling of the interactions between park visitors and the effect of renewable energy on incremental planning (Yu et al., 2019). The operational problem's accuracy might be improved by modeling short-term uncertainty in EV availability and the effects of smart charging on battery deterioration but at the price of the problem's scale and tractability.

Future research will examine the effects of including smart charging investment options in distribution expansion planning under uncertainty, as well as the influence of various EV fleets on their option values (Borozan et al., 2022). Real-world transportation and distribution network data might be included in the optimization to produce more practical planning outcomes. One may also examine EVCS real-time functioning concerns, such as missing data, data delay, and sensor failure. In certain circumstances, data processing techniques such as deep learning may be able to ease these concerns (Zhang et al., 2021).

For distribution systems with realistic load models, the following are possible combinations of variables for DGs with EV planning: (a) Size, location, and types of DGs with EVs and (b) The types, placement, and synchronization of DGs and EVs. The location, size, and management of various types of DGs with EVs in distribution networks with varied load situations may be improved using realistic approaches. Future distribution systems with diverse, dynamic loads may utilize hybrid optimization methods to improve placement, scalability, and coordinated control over different types of DGs with EVs (Singh & Dubey, 2022). There are several unresolved concerns, such as how to mitigate power quality problems caused by electric vehicles and imbalanced networks, simultaneously reconfiguring the network and allocating renewable energy to increase the capacity of EVCSs (Gholami et al., 2022). The EV charging station extension planning study can take into account the foreign mature ancillary services market, traffic light location, quantity, and the real driving patterns of electric car users influence on forecasting charging demand, and the EV charging and discharging power adjustable to its participation in the influence of peak regulation, among other factors (He et al., 2022).

Researchers can consider the potential that when EVs are not in use, they may pump power into the network. Additionally, the model will incorporate additional generational technology (Quevedo et al., 2017). The analysis of electric vehicle charging and discharging methods should pay attention to the percentage of various electric vehicle users (operating and non-operating cars) willing to engage in aggregation regulation under various compensation price incentives (Zou et al., 2022). In addition to enhancing network stability, BESS may be utilized to mitigate the stochastic nature of renewable generating and EV charging demand. The optimization model could consider BESS's position and size in later rounds. To provide planning outcomes that are more realistically applicable, the optimization process might make use of data from actual distribution and transportation networks. Charging station real-time operating problems, including missing data, delays, and sensor failure, could also be taken into account. Sometimes, data processing methods like deep learning can help to solve these problems (Zhang et al., 2021). Figure 4 shows a tree diagram for DNEP, together with the impact of EV load penetration and integration with DERs and CBs.

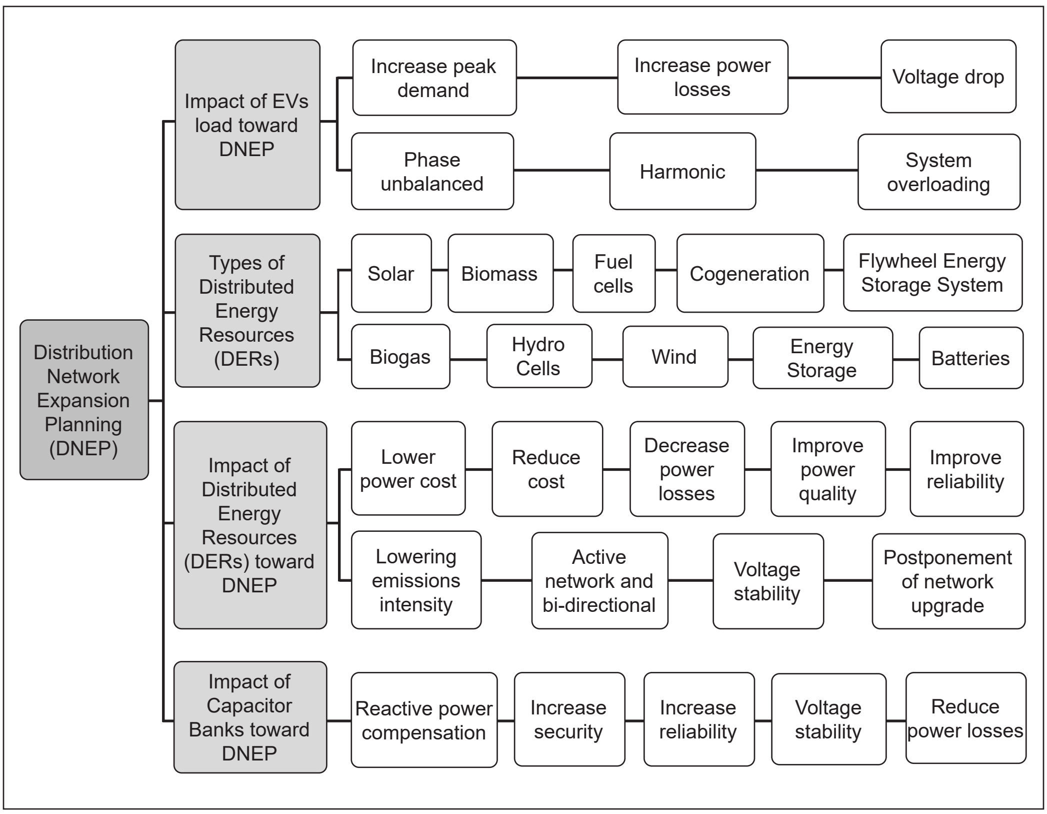

Figure 4. Tree diagram for DNEP

INTEGRATED DISTRIBUTION NETWORK EXPANSION PLANNING WITH DERS

The planning problem for the ADN differs from standard DNEP problems in how DERs are integrated. The distribution system known as the ADN can manage a variety of DERs, including loads, storage, and generators. It is important to note that ADN enhances network performance at the planning and operation levels by reducing the influence of renewable resources' unpredictability. A paradigm for ADN planning that considers active resource management was put out. Reference (Al-Kaabi et al., 2013) put out a multi-configuration, multi-period optimum power flow approach to assess the effect of various DG configurations. A long-term dynamic planning of DGs taking active management into account has been given (Abapour et al., 2015). These studies have produced separate DNEPs. To manage the output power of DGs, Karagiannopoulos et al. (2017) initially increased the network's assets before introducing a real-time tractable iterative AC OPF.

The utility planning approach for the DNEP was proposed (Mansor & Levi, 2017). The two-step strategy that has been presented extends network assets in the first stage and takes network operation into account in the second. These two articles examine planning and operation levels separately, but an integrated framework is necessary. ADN planning models for multiple-stage, multiple-load scenarios have been proposed (Shen et al., 2016). While network reconfiguration and DGs dispatch are dealt with in the operating problem, the network assets are enlarged in planning. The ambiguity of resources is not addressed, however. The planning of a cooperative multistage distribution network that takes into account active resource management is presented (Kabirifar et al., 2019). The distribution system operator (DSO) seeks to reduce investment and operational expenses related to the proposed planning and operation levels.

When electricity is produced from sources, frequently renewable energy sources, close to the point of consumption rather than centralized generating sources from power plants, the process is referred to as distributed generation (Ayalew et al., 2022). Several types of DGs can be integrated into distribution network expansion planning as follows:

1. Solar (Rangarajan et al., 2017)
2. Biogas (Freitas et al., 2019)
3. Biomass (Ferreira et al., 2018)
4. Hydro Power (Raza et al., 2013)
5. Fuel Cells (Pinto et al., 2021; Veldman & Verzijlbergh, 2014)
6. Wind (Amjady et al., 2017)
7. Cogeneration (Cogeneration Technologies, 2022)
8. Energy storage (Comodi et al., 2017)
9. Flywheel Energy Storage Systems (Technologies of Energy Storage, 2022)
10. Batteries (Technologies of Energy Storage, 2022)
11. Superconducting Magnetic Storage Systems (SMES) (Carnegie et al., 2013).

Many benefits of distributed energy resources, such as installing DER units, may enable them to lower their power costs or achieve higher levels of dependability. Additionally, DERs may lower the price of enhancing the power system, lowering the overall cost of supply that customers must pay. By replacing other, more emissions-intensive generations, increased DER penetration may also aid in lowering the total emissions intensity (Twaisan & Barisci, 2022). Over the last ten years, the liberalization of energy markets, rising fuel prices, environmental concerns, and the high cost of constructing a new big power plant have all contributed to the drive for small-scale distributed generation (DG) units to be installed in the distribution network (DN) to fulfill the increasing demand for electricity. However, the network becomes active and bi-directional when DG units are connected to the DN. The role of DGs in modern DN is progressively growing. Predictions state that about 20% of the next generations will be implanted. It is widely established from earlier research that distributing DG units inside the DN optimally leads to a decrease in power loss, an increase in voltage and dependability, an improvement in power quality, and the postponement of network upgrades (Amjady et al., 2017; Energy Commission, 2017; Moazzami et al., 2019; Srinivasan & Visalakshi, 2017).

Rapid load growth rates cause the distribution equipment to become overloaded, and because replacing overloaded power system components is expensive, it is not a simple task. To lower peak demand, novel incentive schemes, including permanent demand reduction, load curtailment/shifting, distributed generation (DGs), and others, have been created in response to growing economic pressure to fully utilize the capacity of present power equipment. The electrical utilities must plan appropriately if they want to see an improvement in consumer satisfaction with electric energy. This development has been noticed by utilities, who have taken DGs into account while building and running distribution networks. When placed in the best possible position, distributed generation (DG) may reduce power losses, improve supply quality and reliability, and save construction costs associated with transmission and distribution (Ahmed et al., 2022; Ayalew et al., 2022). DG units have been distributed into distribution networks using hybrid Harmony Search and Particle Artificial Bee Colony methods to lower power loss and improve the voltage profile (Muthukumar & Jayalalitha, 2016; Jeddi et al., 2019).

INTEGRATED DISTRIBUTION NETWORK EXPANSION PLANNING WITH CAPACITOR BANKS

To provide reactive power compensation, maintain security and reliability, and raise bus voltage, capacitors are positioned along the Radial Distribution Network (RDN). To improve voltage control and boost power factors at the sub-station bus, capacitors of the proper size should be installed along the feeders. A review of the literature revealed many artificial intelligence strategies that may be used to address the problem of the ideal placement of capacitors. A differential search method Eid et al. (2022) has been used to optimize the DGs unit in the presence of the static VARs compensator to minimize power loss in distribution systems.

Capacitors are positioned along the RDN to provide reactive power compensation, preserve security and dependability, and increase bus voltage. However, installing capacitors of the right size along the feeders will enhance voltage control and increase power factors at the substation bus. According to a literature survey, several artificial intelligence approaches might be used to tackle the optimum capacitor placement problem. Reactive power assistance is necessary for distribution networks. Shunt capacitor banks that are able to provide power factor correction and voltage control can offer this support or appropriate compensation. The inductive characteristics of distribution lines, including line charging capacitances and other inductive elements, like transformer impedances and loads, cause network resonances (Rangarajan et al., 2017).

Capacitors are frequently placed in distribution systems for reactive power compensation to reduce power and energy loss. Size and placement are important considerations when using a capacitor to minimize loss. Additionally, the proper positioning of capacitors is crucial to minimizing system power losses and overall capacitor costs. This paper compared the voltage dips and power losses before and after the capacitor installation. The results indicated that the suggested solution may enhance the distribution system's voltage performance and power losses, which would be advantageous for the distribution networks (KC & Regmi, 2019). A heuristic-based optimization technique is investigated Lopez et al. (2021) to improve the voltage profile and reduce power loss in a medium voltage distribution network. The goal function uses three-phase capacitor banks dispersed across the distribution network and sized to produce minimum values for the losses. Ant colony and genetic optimization algorithms were used as two heuristic techniques for this localization and dimensioning. An Improved Grey Wolf Optimizer has been put out in this study to address the coordinated allocation of DGs and CBs in distribution systems.

CONCLUSION

DNEP is very complex and involves improving the system to meet the increasing demand using the most cost-effective strategy. Among the planned choices are the extension of substations, upgrade of distribution feeders, the installation of additional DERs facilities, installation of CBs and many other methods. Distribution planners in contemporary networks must have faith in the reversibility of investments where Renewable Energy Resources (RERs) inject clean and cost-effective for DNEP to meet growing demand and environmental requirements. In addition, the increasing adoption of EVs poses challenges for DNEP. EV loads have the potential to strain existing infrastructure due to increased demand for electricity, especially during peak charging times. It could require utilities to invest in upgrading and expanding distribution networks to accommodate the additional load from EV charging. Hence, careful planning and integration of EVs into distribution network expansion plans are essential to ensure grid reliability and cost-effectiveness. A comprehensive review of DNEP has been carried out in this paper, which covered all possible objective functions, problem constraints, various horizon times as well as problem variables, the optimization model (single/multi-objective), utilization of DERs, utilization of CBs, and problem uncertainties. The examined literature demonstrates that several notable researchers have taken distinct objective functions into consideration to accomplish comparable DNEP goals.

In summary, a holistic approach to DNEP that considers EV loads, DERs integration, and Capacitor Banks installation is essential for designing sustainable power systems that are resilient, efficient, and capable of supporting the transition to a cleaner energy future. When it comes to EV loads, a holistic approach would involve forecasting future demand from EV charging stations and strategically planning network upgrades to accommodate this load without compromising grid stability. Combining this with integrating DERs can help balance supply and demand, maximize renewable energy utilization, and enhance grid resilience. Moreover, installing Capacitor Banks strategically along the distribution network can help improve power factor correction, reduce losses, and enhance voltage regulation. By considering all these components together, utilities can optimize their investments, minimize system inefficiencies, and create a more sustainable power system capable of effectively meeting future needs.

There are several key areas for further research in DNEP to address emerging challenges and optimize the integration of renewable resources. First, advanced modeling and simulation can accurately capture the dynamic behavior of distribution networks with high penetrations of renewable energy sources, energy storage systems, and electric vehicles. Second, researching and developing optimization algorithms that effectively manage distributed energy resources, demand response programs, and other grid-edge technologies to improve grid reliability, efficiency, and cost-effectiveness. Next, investigate strategies to enhance grid resilience and flexibility by integrating microgrids, smart grid technologies, and automated control systems. By focusing on these research areas, stakeholders can improve DNEP practices, accelerate the transition to sustainable energy systems, and contribute to a more resilient and efficient grid infrastructure for the future.

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