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Editorial

Optimization Principles Applied in Planning and Operation of Active Distribution Networks

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1. Introduction

Optimization principles play an important role in the planning and operation of active distribution networks (ADNs), which are designed to handle the inrush of distributed generation (DG) resources like renewables and, nowadays, battery energy storage systems (BESSs) and electric vehicles (EVs). These principles help to optimize power flows, enhance reliability, and minimize operational costs while accommodating the intermittent nature of energy generation and variable patterns of consumption. Advanced techniques such as mixed-integer linear programming, genetic algorithms, particle swarm optimization, and machine learning are commonly used to tackle challenges like voltage regulation, loss minimization, demand response, cost minimization for DG investments and grid operation, network expansion, and even dual planning of electric and heating/transportation networks [1–7]. The application of these principles is essential for developing an efficient, flexible, and sustainable network that is transitioning towards a smart grid.

2. Review of Optimization Principles for Planning and Operation of ADNs

Focusing on specific objective functions that address both technical and economic challenges plays a crucial role in improving the planning and operation of ADNs. One common objective is the minimization of power losses, which were otherwise substantial in passive DNs. This can be solved through the proper installation of DGs, capacitors, BESSs, or distribution static compensators (D-STATCOMs) [8]. In the case of looped or interconnected networks, reconfiguration is also a viable option and must be handled considering the daily profiles of production facilities and consumers [9]. However, although installing DGs may alleviate losses in some parts of the network, it can also increase them in other parts. ADNs often experience increased losses due to the suboptimal installation of DGs and due to long-distance power transfers. Another important objective is the minimization of operational costs, which includes generation, energy purchasing, and maintenance costs [10]. Improving voltage stability is also a key objective, as maintaining voltage within permissible limits and away from the voltage-collapse point is vital for grid reliability [11]. In addition, demand-side management (DSM) is often optimized to align energy consumption with generation, thus reducing peak demand and flattening load profiles [12]. However, this must be included as an ancillary service to properly incentivize the included consumers. This can involve real-time pricing mechanisms or incentive schemes that encourage users to shift their consumption to off-peak hours. Another important objective is the maximization of renewable energy integration and grid hosting capacity, as ADNs must accommodate fluctuating power from solar and wind. The optimization model may incorporate variable generation profiles, forecasting, and storage solutions to enhance resilience and flexibility [13]. Optimization also focuses on minimizing emissions, where techniques are used to prioritize cleaner energy sources, aligning with environmental goals. Moreover, enhancing grid resilience and service restoration is crucial in ensuring minimal service disruption and quick recovery after outages [14]. Some techniques also target the reduction in power imbalance caused by DGs, with objective functions ensuring a balance between supply and demand through flexible grid operation, all the while avoiding congestion and enhancing

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overall efficiency [15]. A critical objective function in distribution network operation is maximizing reliability and minimizing outages. This includes assessing the impact of network configuration, equipment reliability, and maintenance strategies on the overall reliability indices. Enhanced reliability often translates to reduced operational costs and improved customer satisfaction. Network expansion is another objective which has a goal to determine the optimal expansion strategy to accommodate future load growth [16]. This involves minimizing the total investment cost while ensuring adequate capacity to meet future demand [17]. The planning process incorporates factors such as the installation of new substations, transformers, and distribution lines, considering both capital and operational expenses. The integration of EVs into the existing distribution network includes optimizing the location and capacity of charging stations to minimize network congestion and losses. Objective functions often focus on load management strategies that can smoothen the additional demand created by EV charging, thereby avoiding peak load issues [18]. Dual planning of electric and heating networks adopts a holistic approach, where the objective is to optimize the operation of both systems simultaneously to achieve cost savings and enhanced efficiency [19]. This involves developing joint objective functions that consider the synergy between electricity and heating loads, allowing for the sharing of resources and infrastructure.

This Special Issue focuses on the following points, raising interesting questions while expanding the current state of knowledge:

- The study in [20] reviewed advancements in technologies aimed at ensuring the sustainability of electricity production, transmission, and consumption, particularly highlighting solar photovoltaic (PV) systems for their low maintenance costs and ability to reduce power losses through local generation. It emphasized the importance of optimal location and sizing for PV projects to maximize financial, technical, and environmental benefits in electrical systems. Additionally, this study noted that while various mathematical methods have been used to model the operation of these systems, most do not adequately evaluate the quality and repeatability of their solutions within short processing times.
- The article in [21] discussed the role of microgrids as a bridge between reliance on bulk power grids and the shift toward renewable energy sources, particularly in islanded modes where local controllers must uphold power quality standards. It presented a tool focused on tuning the parameters for secondary consensus-based control in inverter-based islanded microgrids, addressing the challenge of managing many parameters even in simple structures. This study utilized the design of experiments to optimize parameter settings efficiently, demonstrating that this methodology can achieve optimal outcomes with fewer experiments compared to traditional trial-and-error approaches.
- The work in [22] explored the integration of renewable distributed generation into electrical distribution networks as a viable solution for balancing energy production and consumption. Various metaheuristic algorithms were employed to optimize the allocation of photovoltaic and wind turbine distributed generation while accounting for uncertainties in energy output and seasonal load variations. The results indicated that the marine predator algorithm outperformed other algorithms in terms of speed and efficiency, achieving significant reductions in seasonal active losses for the IEEE 33-bus and 69-bus networks, through a multi-objective function that minimized multiple technical indices associated with power loss and system performance.
- Paper [23] addressed the challenge of achieving total power network observability in smart grids through the optimal placement of Phasor Measurement Units (PMUs), which enhanced real-time monitoring and control while offering high accuracy due to their increased sampling rates. To tackle the high installation costs associated with PMUs, the authors proposed a novel Binary Firefly Algorithm (BFA) that utilizes node degree centrality scores to minimize the number of PMUs required for complete observability, considering the effects of Zero Injection Buses (ZIBs) and single PMU

outages. The results demonstrated that the BFA not only matched but improved upon the optimal PMU placements achieved by existing meta-heuristic techniques in IEEE test systems, highlighting its effectiveness in enhancing system robustness and measurement availability.

- Finally, article [24] highlighted the importance of managing flexibility in distribution networks, driven by the increasing integration of renewable energy sources and the electrification of transport and heating. It emphasized challenges regarding the commonly used sensitivity-based approach for regulating voltage profiles with reactive power from distributed energy resources (DERs), noting its inaccuracy under significant voltage deviations and the absence of a systematic implementation strategy in real-world applications. The authors proposed a new algorithm that calculates the necessary consumer flexibility in near real time to maintain operational criteria, assessing network states and sensitivities to optimize resource allocation, thereby enhancing network flexibility and improving overall resource utilization through simulations of actual distribution network data.

3. Conclusions

Given the diverse objectives involved in distribution network planning and operation, multi-objective optimization approaches are increasingly used. These methods allow for trade-offs between conflicting objectives, such as cost versus reliability, enabling planners to arrive at balanced solutions that cater to multiple criteria. In summary, the objective functions for distribution network planning and operation have evolved to accommodate a wide range of factors, including network expansion, electric vehicle integration, demand response, and the dual planning of electric and heating networks. The emphasis on optimizing costs, reliability, and sustainability while integrating advanced technologies positions these functions as essential tools for modern energy distribution systems.

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