This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/TSG.2017.2709699, IEEE Transactions on Smart Grid

Microgrid Topology Planning for Enhancing the Reliability of Active Distribution Networks

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***Abstract*—Loop-based microgrids are signified by their high reliability in islanded and grid-connected operations. This paper proposes an iterative procedure for the optimal design of a microgrid topology in active distribution networks, which applies graph partitioning, integer programming, and performance index for the optimal design. The proposed approach avoids infeasible and non-optimal designs of microgrid structures and provides remedial solutions for enhancing our previous topology design method. The numerical results for a microgrid test system show that the proposed designated steps can optimize a loop-based microgrid structure in an active distribution network.**

***Index Terms*—Loop-based microgrids, optimal topology planning, graph partitioning, integer programming.**

I. Nomenclature

Symbol	Definition
B_s	Total number of radial branches of the solution s
C_{ij}	Length of lines (edges)
D	Peak load
D_s	Total length of lines of the solution s
E	Set of edges or interconnection lines
EC	Energy storage capacity
es	Ratio of energy storage capacity to peak load
G	Graph $G = \{V, E\}$
GC	Distributed generation capacity
$mis(\mathbf{V_m})$	Power mismatch of vertex set $\mathbf{V_m}$
P_s	Total active power losses of the solutions s
P_n^k	The k-partition of a graph G_n
Q_s	Total reactive power losses of the solutions s
S_s	Total apparent power losses of the solutions s
t_i	Integer variable to eliminate sup-loops in ILP
V	Set of vertices or nodes
X_{ij}	Binary variable of ILP
$\lambda_{m,n}$	Power balance and storage facility sharing index

II. Introduction

Microgrids are active distribution systems that include distributed energy resources (DER), such as distributed generation (DG) and distributed storage (DS), and can operate in either grid-connected or island autonomous mode [1],[2]. The main goals of microgrids are to improve the distribution grid reliability, to support the high penetration of renewable energy, to offer islanding operability, and to improve the generation efficiency in a sustainable power grid [3].

The microgrid research, development, and implementation have been further accelerated in recent years and certain topics related to control, protection, operation, and planning strategies have been studied more extensively. Such provisions enhance the economics of power systems at steady state and its resilient operation during extreme conditions. Much of recent studies pertain to emerging technologies for deploying DERs in AC power systems [4]–[7]. However, DC microgrids have attracted additional attention because of the DC attributes of DER technologies [8]. Detailed reviews on the control and operation of DC microgrids were presented in [9],[10].

The optimal topology design of microgrids has been a recurring research topic and novel control and communication strategies have emerged on AC/DC hybrid architectures [11],[12]. These research studies are based on new control and operation strategies for coordinating individual grids in networked microgrids. In [13],[14], a hierarchical control strategy for multiple microgrids is proposed and an optimal planning methodology of networked microgrids is presented. Specifically, the authors in [14] propose a clustering-based method for the optimal planning of networked microgrids. The authors apply a probabilistic minimal cut-set iterative method for an optimal planning of interconnection system which is based on the enhanced network reliability. The authors demonstrate numerically that the methodology can offer accurate and efficient interconnection alternatives for microgrid cluster-based topologies. Furthermore, technical and economical relevance to community microgrids is demonstrated in [14].

With the evolution of conventional distribution system to active distribution networks, earlier planning strategies are mostly revisited for exploring distributed microgrids. An optimal design of active distribution network in a cost effective, reliable and secure manner is essential for satisfying the proliferation of DERs and customer participation in demand response. Reference [15] presents a review of new models and methods for the power distribution planning (PDP) problem. The PDP solution for the expansion or reconfiguration of an existing power system can incorporate an active distribution network and new control and protection scenarios in such networks [16]–[20].

Reference [21] focuses on the design of an overlay topology which uses resource sharing for increasing the active distribution network reliability in microgrids. The topology planning with a high penetration of microgrids in medium voltage distribution networks is investigated in [22] where the design of radial microgrids consider the reliability and security of distribution systems. In [23], a multi-objective strategy is proposed to convert normally closed-loop system to an optimal mesh-based primary feeder arrangement. The DER planning in grid-connected microgrids is studied in [24] as a nonlinear programming problem which is solved by a

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