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Research Interests

- Electric distribution systems
- Optimization
- Graph algorithms
- Reliability and resilience

Research Summary

The central theme of my research is *optimal design and operation of distribution systems*. I study the planning and operation of modern distribution grids with specific focus on resiliency and reliability. Specific contributions from this research can be categorized under three areas: a new modeling framework for incorporating reliability into distribution feeder reconfiguration problem, an optimal network augmentation scheme for improving the resiliency and reliability of distribution grids, and a modern planning and operating scheme for multiple microgrids by considering real-time supply-demand conditions.

When reliability is considered as an objective in addition to loss minimization, majority of the feeder reconfiguration approaches resort to heuristic algorithms for obtaining the optimal configurations. My research proposes a mixed-integer quadratic programming framework in which standard reliability indices can be included either as objectives or as constraints. To facilitate the inclusion of reliability indices, a path-based data structure is proposed for modeling load-point failure rates and topology constraints. The information about paths in the network can also be used for deriving upper bounds for the approximation errors in the load-point failure rates. Since the optimal topology is a function of loading conditions, time-series power flow using various load patterns is performed to study the sensitivity of annual active power losses to the loading conditions.

The work on optimal augmentation is inspired by the closely related *design of survivable networks* problem in communication networks. Optimal network augmentation seeks to improve the reliability of the distribution network by installing new tie-lines in a cost-effective manner. As per Menger's Theorem, a k-edge connected graph has at least k edge-disjoint paths between any two vertices. Therefore, 2-edge-connecting the graph of a distribution network makes it survivable against the failure of any single line—an alternative path to the substation will always exist for use in service restoration. Experiments performed on standard test systems using existing graph algorithms for minimum cost 2-edge-connectivity augmentation illustrates the capability of the proposed optimal augmentation scheme. The algorithms allow assigning weights to the candidate edges based on practical considerations like cost, geographical constraints, policy restrictions, etc. Completely 2-edge-connecting a network can be costly and impractical. It will be interesting if the reliability of certain parts of the network can be improved in a selective manner. Termed as *local edge-connectivity augmentation*, this problem does not have tractable graph algorithms which can be applied to distribution networks. An integer linear program has been developed to tackle local edge-connectivity augmentation by assigning higher connectivity requirements to special nodes catering to critical loads or distributed energy resources (*The work on local edge-connectivity augmentation is unpublished*).

Dynamic microgrids is a novel concept where multiple microgrids are identified within a distribution system, with their boundaries changing as the supply-demand conditions change in the network. This is different from the conventional fixed-microgrids, wherein their topology remains as designed regardless of network conditions. Since supply-adequacy is critical for successful islanded operation of the microgrids, a central controller identifies dynamic microgrids with minimum imbalance between their loads and internal generation. Under normal operation, the distribution system operates as a single grid, connected to the MV or HV grid. Islanding is initiated as a response to any event—external or internal—that affects the operation of the grid. The microgrids form islands based on the latest boundaries identified by the central controller. Dynamic microgrids are identified with the help of a k-way spectral graph partitioning algorithm, where k denotes the number of microgrids to be formed. An optimization version of the algorithm is also developed which can be used to model operational requirements like the presence of sufficient generating resources and reactive power capabilities in each microgrid.

Publications

Journal *Joel Jose and Anupama Kowli,* "Path-based Distribution Feeder Reconfiguration for Optimization of Losses and Reliability", IEEE Systems Journal, 2019. *Early Access.*
https://ieeexplore.ieee.org/document/8727910

Conference *Joel Jose and Anupama Kowli,* "Network Expansion for Improved Reliability in Distribution Networks", 2018 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC), Malaysia, 2018.
https://ieeexplore.ieee.org/abstract/document/8566464

Conference *Anupama Kowli, Joel Jose, V. S. Borkar, and T. P. Imthias Ahamed,* "A Dynamic Programming Framework for Optimal Home Scheduling", IEEE PES Innovative Smart Grid Technologies Asia Conference (ISGT Asia 2017), Auckland, 2017.
https://ieeexplore.ieee.org/abstract/document/8378433

Conference *Joel Jose, Anupama Kowli, Vaibhav Bhalekar, Krishna V. Prasad and Narayanan Rajagopal,* "Dynamic Microgrid-based Operations: A New Operational Paradigm for Distribution Networks", IEEE PES Innovative Smart Grid Technologies Asia Conference (ISGT Asia 2016), Melbourne, 2016.
https://ieeexplore.ieee.org/abstract/document/7796446

Conference *Joel Jose and Anupama Kowli,* "Reliability Constrained Distribution Feeder Reconfiguration for Power Loss Minimization", National Power System Conference (NPSC 2016), Bhubaneswar, 2016.
https://ieeexplore.ieee.org/abstract/document/7858938