RESILIENT DISTRIBUTION SYSTEM BY FORMING/COUPLING MICROGRIDS IN EXTREME CONTIGENCIES

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ABSTRACT

The ability of the distribution system to efficiently withstand low-probability, high-impact events; while enabling a quick recovery and restoration to the normal state is interpreted as resiliency. Microgrids with distributed generation (DG) provide a resilient solution in the case of major faults in a distribution system due to natural disasters. Microgrids could be formed to supply the maximum lost loads after losing the upstream network. Each microgrid is expected to supply its local load independently, however, it is probable that the formed microgrids experience power deficiency (overloading) due to the intermittency of wind and solar DGs as well as load uncertainty. In this paper, an operational approach is proposed by forming multiple microgrids using available DGs from the radial distribution system in real-time operations to maximize the critical loads to be picked up while satisfying the constraints for the microgrids formation problem by controlling the ON/OFF status of the remotely controlled switch devices and DGs. Power balance in each formed microgrid is monitored and it is maintained by interconnecting the adjacent microgrids whenever required; since a microgrid may have surplus supply while the other may have shortage. A 4-feeder 1069-node test system with DGs is simulated to demonstrate the feasibility of the proposed method.

INTRODUCTION

Outage of a large number of customers, losing the upstream supply, significant damage of transmission and distribution networks and difficulty in repairing and restoring the supply are expected in severe natural disasters. The ability of the power system to efficiently withstand low-probability, high-impact events while ensuring least possible interruption in power supply is considered as resiliency. As protecting the power distribution grids from catastrophic natural events is quite complicated and uneconomical, quick restoration ability after disasters is considered as the suitable solution. Resiliency issues could be tackled by deployment of microgrids with Distributed Generations (DGs) in extreme contingencies. Microgrids could be formed in natural disasters by using available emergency generators through expanding their supply coverage beyond their designed service areas; or renewable energy resources such as wind/PV supply units that are gaining popularity to the environmental concerns [1]-[2].

In [3] three important measures to enhance resiliency, i.e., utilization of microgrids, distribution automation, and vulnerability analysis are discussed. It is indicated that traditional distribution systems cannot become resilient in one step and the transition will take many years to achieve a certain level of resiliency. During this transitional period, protection and restoration schemes must be re-considered as the radial structure of distribution systems could no longer exists by integration of DGs and microgrids. In [4], Distribution System Resiliency is discussed as a process of modernizing the grid that needs considerable time, effort and innovation. It outlines a distribution resiliency roadmap, identifying critical pieces of such an effort. In [5], spanning tree search algorithm is used for reliability analysis of smart distribution systems with Distribution System Restoration technique and remote control capability. Switching sequence is decided by a set of rules. In [6], an optimization method is proposed to restore loads after a fault by changing the topological structure of the distribution network while meeting electrical and operational constraints. A strategy incorporating microgrids is used to maximize the restored load and to minimize the number of switching operations. Spanning tree search algorithms are applied to find the candidate restoration strategies by modeling microgrids as virtual feeders and representing the distribution system as a spanning tree. In [7] a multi-agent based distributed restoration system is proposed without significant changes to the existing Distribution Automation System to enhance the operational reliability.

In this paper, a new approach is proposed to form multiple microgrids using available DGs on radial distribution feeders in real-time to maximize the pick-up of critical loads while satisfying the constraints for the microgrids formation problem by controlling the ON/OFF status of the feeder/DG switches. Supply/demand balance in each formed microgrid is monitored and whenever required would be maintained by interconnecting the adjacent microgrids; as a microgrid may have surplus supply while the other may have shortage. A 4-feeder 1069-node test system with DGs is simulated to demonstrate the feasibility of the proposed method. Following benefits could be captured by the method:

- Overloading of the formed microgrids is alleviated by interconnecting the neighboring microgrids; load shedding is also reduced in extreme contingencies taking into account the intermittency of renewable energy resources.
- Reconfiguration is best exploited to mitigate the vulnerability of the formed microgrids upon occurrence of contingencies.
- The decisions to close/open the remotely controlled switches are not completely based on a healthy and intact communication system, but partial information gathered locally from equipment could be used to capture a semi-complete vision of the power system [2].

PROBLEM FORMULATION

Microgrids are formed by assuming the upstream grid is unavailable; a suitable optimization is formulated to maximize the critical loads to be supplied using the available resources and controllable switches. DGs with intermittent supply along with conventional ones are considered, the formed microgrids would be connected together whenever required. So, N microgrids, each with one DG, are formed to maximize the total critical loads to be restored after disconnection from the main utility-grid. As the DGs with intermittent supply cannot guarantee a stable supply, so the formed microgrids could be interconnected to exchange surplus power. Mixed-integer linear program (MILP) is used to maximize the prioritized loads within a microgrid [2].

TRADITIONAL RESTORATION

Figure 1 shows a traditional underground distribution system structure. Each substation has 4 output feeders and each feeder has the potential of being connected to any of the 2 substations at its ends. The coupling switch is normally open, but it could be closed whenever the feeder is disconnected from one of its dead-end substations. The feeders are radial.

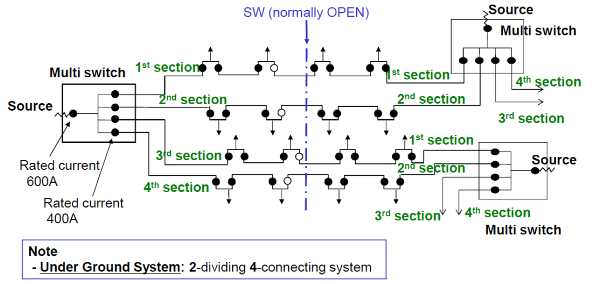


Figure 1: Traditional distribution system

As each feeder has a limited ampacity, it could not transmit the whole amount of the load of the other feeders. It is required to share the load of the disconnected feeder among the remaining ones. Figure 2 shows the case with the fault on the interconnecting cable between the source and the multi-switch box. Four feeders with 100A each is tripped and restored by closing the coupling switches.

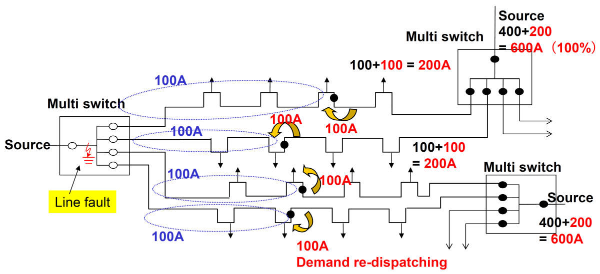
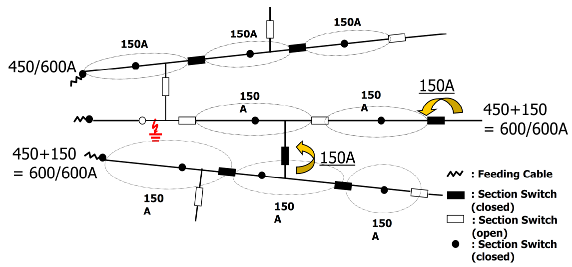


Figure 2: Restoration of the lost loads by closing coupling switches and disconnecting from the faulty section.

Figure 3 shows 3 feeders with 600A overload rating and 450A continuous rating. Each feeder has 3 sections, each with 150A load. During a fault on one of the 150A sections as specified in the Figure, the other two 150A sections could be energized by the adjacent feeders.

SAMPLE NETWORK

A test system with 4 feeders and 1069 nodes including microgrids is developed in [6] and used in [3] and [5]. It is composed of four "R3–12.47–2" feeders, and seven tie switches and four microgrids. It has 156 normally closed sectionalizing switches. The Taxonomy "R3–12.47–2" sample distribution network is a prototypical unbalanced distribution feeder model for moderate urban areas. It is developed by the Pacific Northwest National Laboratory (PNNL) [5] with nominal voltage equal to 12.47 kV and load, including losses equal to 4.652 MVA [8]. It contains single family homes, light commercial loads, and a small amount of light industrial loads. R3-12.47-2 has approximately 33% overhead and 67% underground lines. The feeder loading is limited to 60% to ensure the ability to transfer load to other feeders, and vice versa. Climate region 3 is the non-coastal South West of the United States and is characterized by a hot and arid climate.



- Continuous Current Rating; 450A, Loading Level ; 75% (450/600)
- Over Load Current Rating; 600A
- Single Step Switching to Neighbor Distribution Line

Figure 3: Restoration of the lost section load by closing coupling switches.

Figure 4 shows the sample test system with Distributed Generators (DGs) with intermittent generation. The transformer capacity at each feeder is 7.5 MVA. The active and reactive power limits of the DGs are shown in Table 1. Power flows are calculated by GridLAB-D, which is a new power distribution system simulation and analysis tool with an advanced algorithm at its core designed for determining the simultaneous state of millions of independent devices [9]. It is worth noting that the R3-12.47-2 test system is composed of single-phase, double-phase and three-phase loads. GridLAB-D performs unbalance load flow, so it is possible to use single-phase DERs.

Table 1: Maximum Capacity of DGs

DG #	P (MW)	Q (MVar)	S (MVA)
DG1	5.15	2.25	5.62
DG2	1.65	0.95	1.90
DG3	2.50	1.75	3.05
DG4	1.00	0.55	1.14

SIMULATION RESULTS

Different scenarios could be simulated on the sample system, but the worst one is the lack of supply from the upstream grid. Figure 5 shows a severe case with the fault on the main substation node. It is clear that all the feeder breakers should be opened to isolate the fault.

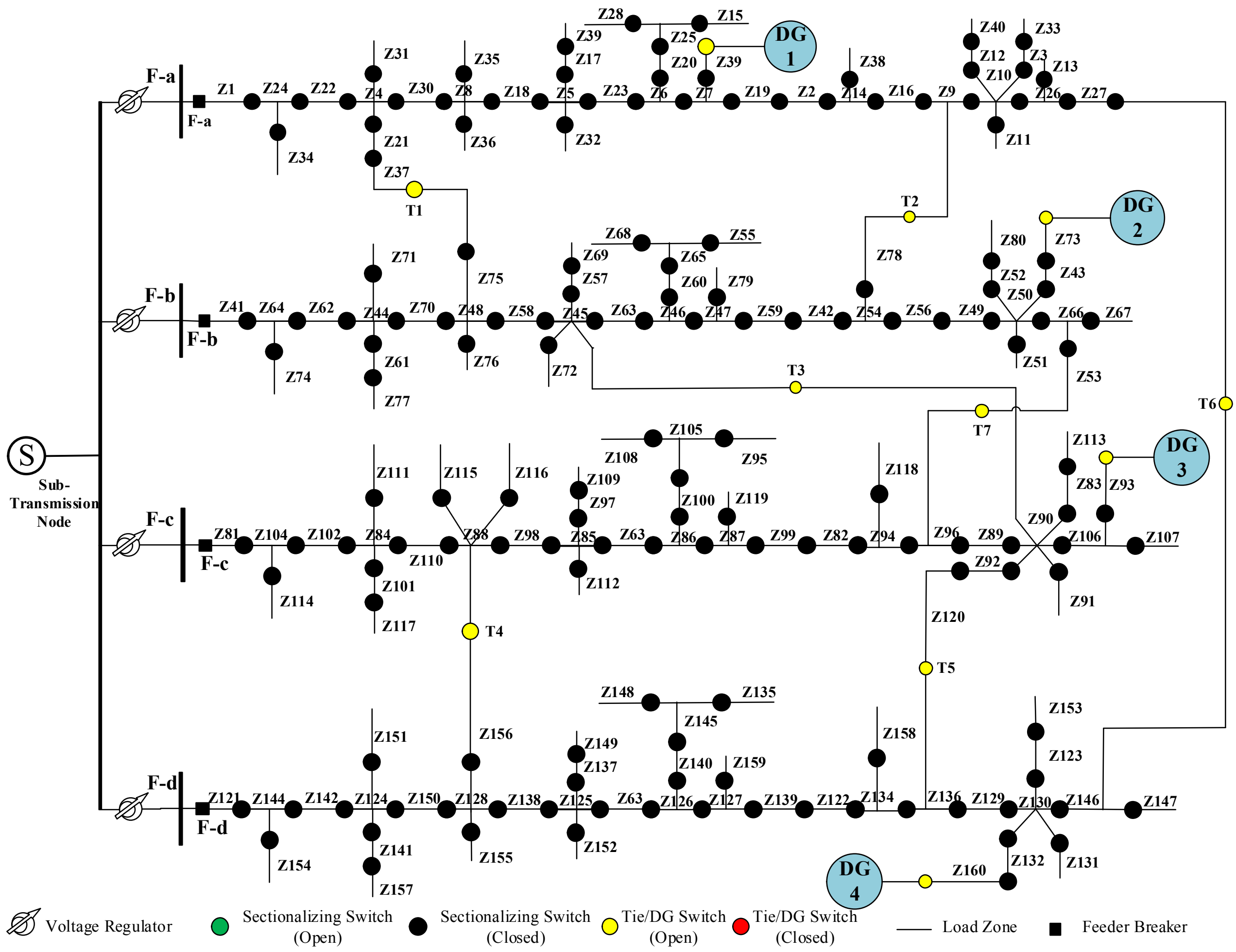


Figure 4: One-line diagram of the 4-feeder 1069-node test system

As already explained it is required to form individual microgrids with separate DGs. Feeder-a is energized completely by using DG1, so an individual microgrid is formed, but DG2 has a limited supply and could not feed all the loads. The optimization method is used to supply the maximum prioritized loads up to 1.90 MVA fulfilling the operational constrains including the voltage permissible ranges. Similarly, Feeders 3 and 4 are also partially energized by forming individual microgrids. However, interconnection of formed microgrids 1 and 2 could be performed by closing Tie switch T2. This could help to supply more loads. The maximum load of Feeder-a is 4.42MW+j1.41Mvar or 4.64 MVA, so DG1 has nearly 1 MVS surplus supply to help microgrid 2. The same is done by closing T5 to interconnect micrograms 3 and 4. It is worth noting that once the two microgrids are interconnected, the optimization process could be performed again to optimize the priority of both microgrids. As the DGs could be a mix of fixed and intermittent generation, so it is required to run the optimization program whenever there is a significant change in the generation amount. Tie switches T1 to T7 could be well exploited to optimize the operation of the microgrid, individually or interconnected. It is worth mentioning that the proposed method is also applicable for faults on the radial feeders, whenever disconnected from the upstream network due to a fault. In this case, the DGs could be used to energize the loads by proper closing the tie-switches.

CONCLUSIONS

This paper presented an operational approach to set up multiple microgrids using available DGs from the radial distribution system to maximally energize the critical loads by controlling the ON/OFF status of the remotely controlled switch devices and DGs. Supply/demand is monitored in each formed microgrid and whenever required the adjacent microgrids would be interconnected by remotely-controlled tie switches. A 4-feeder 1069-node test system with DGs is simulated to demonstrate the feasibility of the proposed method.

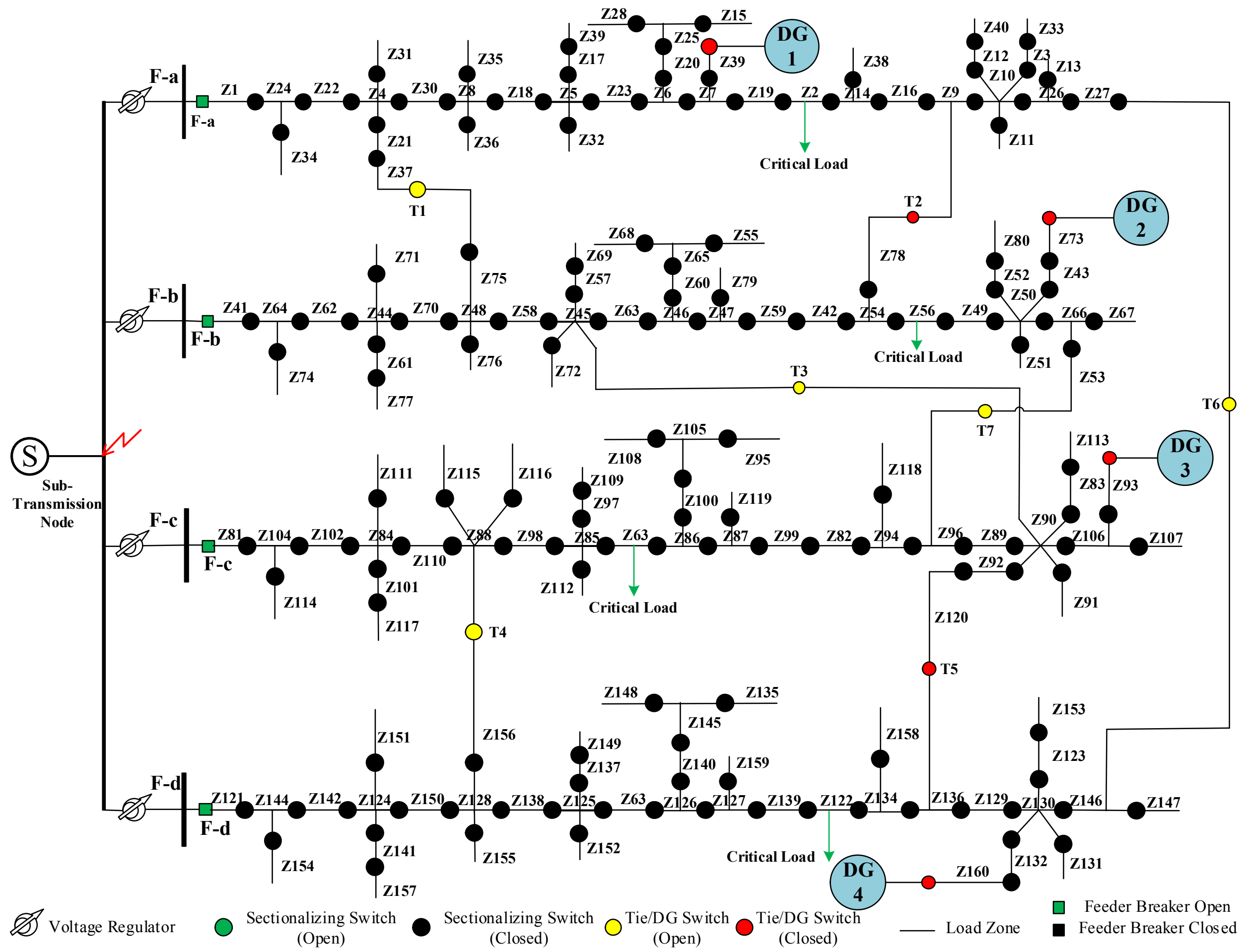


Figure 5: One-line diagram of the 4-feeder 1069-node test system

As in catastrophic events, the communication requirement is a challenging issue; it is required to consider this point in the proposed methodology. A novel approach based on distributed multi-agent coordination is presented in [2] which could be well exploited here. The work is in progress to adapt the method to the sample network.

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