ENHANCEMENT OF MICROGRID RESILIENCY BY MITIGATING CASCADING FAILURES THROUGH RECONFIGURATION

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ABSTRACT

Although modelling and mitigating cascading failures in large power systems especially at transmission level is well studied in both academia and power industry, its investigation in microgrids, especially when operating in autonomous mode, is at its early stages. The reason is the inherent properties of microgrids in comparison to the conventional power systems, like the availability of distributed resources as limited and intermittent power supplies or the flexibility of establishing loop structures. Moreover, the communication infrastructure and power-electronic devices are specific to the microgrids that could be well exploited in strengthen the system resiliency. In this paper, the resiliency of the autonomous microgrid is enhanced by reconfiguration, defined as a constrained nonlinear optimal problem with discrete, boolean and continuous variables. Structure reformation, load shedding and generation regulation are applied in reconfiguration problem of the autonomous microgrid. The proposed method is tested on the IEEE 33 bus sample network to demonstrate its efficiency.

INTRODUCTION

The ability to supply the customers in severe contingencies caused by hazards such as hurricanes or earthquakes is considered as resiliency. Normally, distribution grids are designed to tolerate normal contingencies such as tripping of a feeder or loss of a substation. Generally, tie-switches are anticipated to restore a de-energized feeder in a distribution system, as multiple routes would be present to supply the loads that are de-energized by disconnecting from the upstream grid due to a fault. However, it is different in the case of a microgrid, as it has limited paths for supply the loads, and limited sources to feed the loads. So, a normal contingency in a distribution system would be interpreted as an extreme contingency in a microgrid. Hence, special methods are required to enhance resiliency of a microgrid [1]-[3].

In [4], restoration of the distribution system is performed by a sequence of switching operations and a new strategy for evaluation of the system reliability is proposed. Optimal restoration schemes are obtained by an algorithm called spanning tree search to maximize the re-energizing of the tripped loads with a minimal number of switching operations. In [5], restoration is done by changing the topological structure of the distribution network while meeting electrical and operational constraints. It is shown that the microgrids embedded in distribution systems could improve the restoration capability of the distribution systems. It presents a restoration strategy by using microgrids based on spanning tree search algorithms. The proposed method searches for the candidate restoration strategies by modeling microgrids as virtual feeders and representing the distribution system as a spanning tree.

In this paper, the resiliency of an autonomous microgrid is improved by mitigating the overloading of the feeders. Reconfiguration would be used to maintain the loading of the lines less than a specified threshold, so the likelihood of the outage of the feeders due to the overloading is minimized. Since outage of a line could severely impact the path to supply the loads, two approaches are applied to enhance the resiliency of the microgrid:

1) Isolated areas without any supply upon disconnection of the microgrid from the upstream utility-grid are avoided by studying the topology of the distribution system in advance.
2) The lines with loadings more than a specified threshold is identified in the microgrid after transferring to autonomous mode. Reconfiguration is applied as remedial actions to alleviate the the loadings, so minimizing the possibility of the line outages.

IEEE 33 bus is used as the test system to show the performance of the proposed method.

PROBLEM FORMULATION

The overloading of the lines is alleviated in the formed autonomous microgrid after disconnection from the upstream grid. The embedded generation of the autonomous microgrid is considered as a combination of fixed and intermittent energy resources which requires to be re-dispatched at each time period and update the supply pattern accordingly. A random outage is simulated to check its impact on the power flow of the other lines. Optimal power flow (OPF) is used to determine the new operating point. Upon convergence of the optimal power flow, the algorithm checks another line, until it does not converge anymore, and then reconfiguration is applied by using the tie switches to solve the convergence. Load shedding is used as the last resort to converge the optimal power flow. The lines with loading more than 70% are considered as candidates for the next outage. For selecting the next line for outage, a random number is generated for each line. It may be possible that the microgrid be divided into different islands after outage of the candidate lines. In this case, the power balance of the formed islands needs to be maintained by different methods. When the microgrid operates in an autonomous mode, the radial structure is not preferable, as the path between any unique DG and the loads may be lost, degrading the resiliency [6].

SAMPLE SYSTEM SET-UP

Figure 1 shows the IEEE 33-bus network single-line diagram that is used as the test system for simulations. The parameters of the test system such as loads and lines are found in [7]. Figure 1 is considered as the base case. In order to simulate the proposed method, Distributed Generators (DGs) are considered and installed on buses 9 and 30. Bus 9 is equipped with fixed-generation supply and Bus 30 is equipped with intermittent generation such as wind power [6]. Critical loads are assumed at Bus 7, Bus 9, Bus 18 and Bus 33, so they should be kept in service with high priority. Upstream utility-grid is connected at Bus 1.

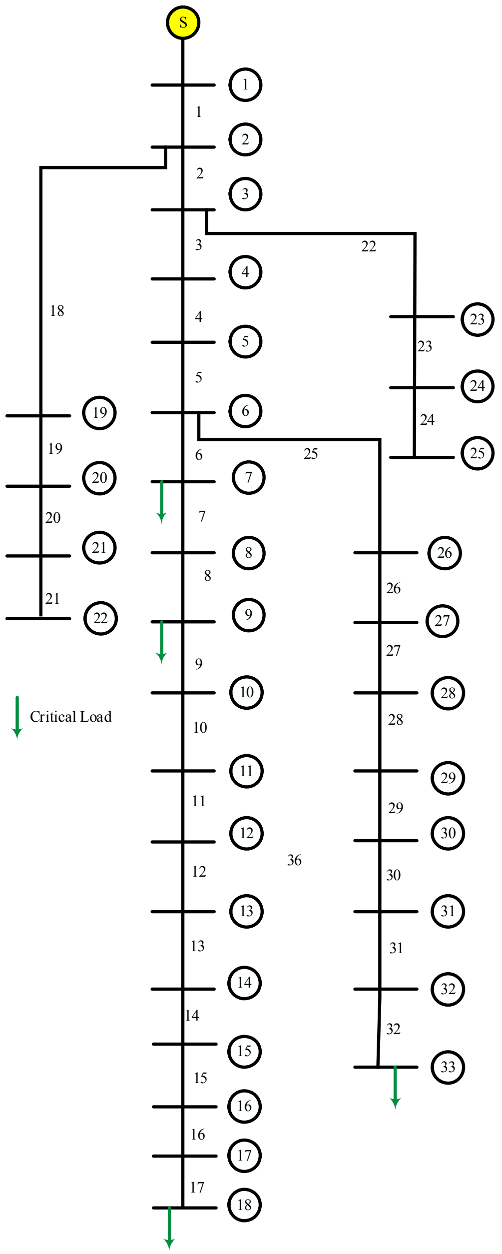

Figure 1: Single-line diagram of the test system as the base case

It is assumed that a severe fault at the upstream grid occurs and forces the test system to transfer to the autonomous mode. A microgrid is formed with the supply resources at Bus 9 and Bus 30. The formed microgrid with radial feeders is not desired from the resiliency point of view. If the formed autonomous microgrid has only radial feeders, it is likely that the outage of a unique line may lead to the loss of a large portion of the loads energized by any of the DGs. Hence, it is preferable to establish different loops in the formed microgrid by closing tie-switches in the test system so that the DGs could be interconnected with each other [6]. Figure 2 shows the possible interconnecting sectionalizing sections that could provide closed loops. They are marked by dashed lines in Figure 2; namely Buses 25-29, 18-33, 9-15 and 12-22. Among different available choices to form a loop, closing the tie-switch between Bus 18 and Bus 33; also the tie-switch between Bus 25 and Bus 29 is selected, as it provides the *N-1* contingency criterion, i.e., losing one line in this microgrid does not de-energize any connected load.

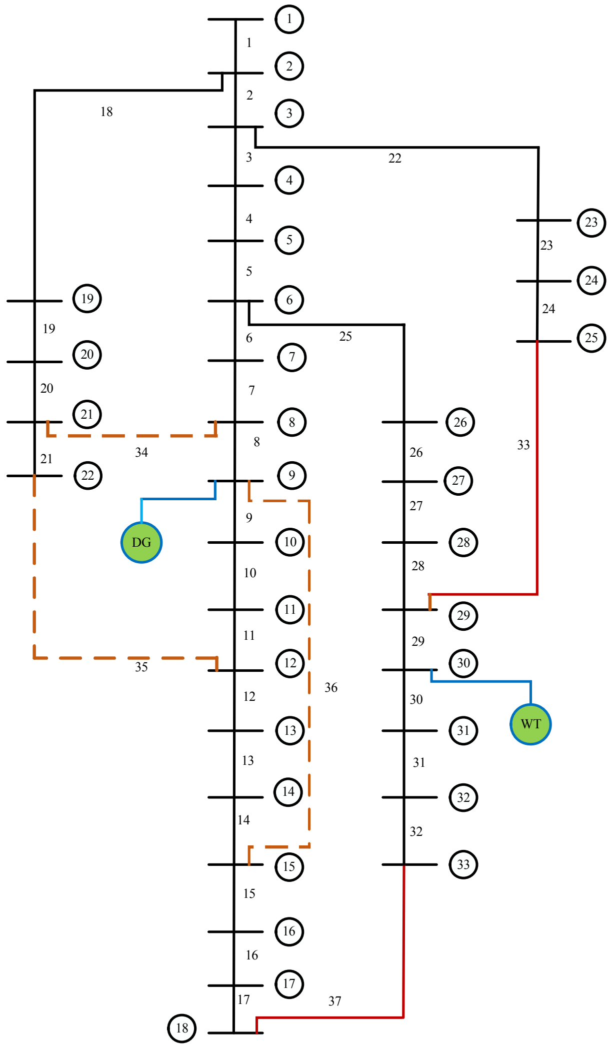

Figure 2: Modified single-line diagram of the test system

SIMULATION RESULTS

As Bus 9 is equipped with fixed-generation supply and Bus 30 is equipped with intermittent wind generation, the proposed method is applied at the time of maximum production of wind power plant. Lines 7, 8, 29 and 33 would be loaded over 50%; therefore, they have more likelihood to be tripped, among these candidates line 29 is selected and tripped. Optimal power flow does not converge after disconnection of Line 29, hence, just only after shedding 0.83 MW of the loads, it would converge. After the outage of line 29, there would be 11 lines that are candidates for tripping due to overload. Lines 16, 32 and 37 are selected at this stage. Upon their outage, Bus 17, Bus 18 and Bus 33 would be de-energized; i.e., the microgrid loses 0.342 MW of the loads, leading to splitting the microgrid into two islanded individual sub-microgrids.

This is clearly shown in Figure 3. Line 29 is highlighted showing its outage. After its disconnection, two microgrids are established. Microgrid 1 is in red color and microgrid 2 is in blue. Lines 16, 17, 37 and 32 are de-energized and Buses 17, 18 and 33 are also de-energized, as shown in gray color in Figure 3.

It is necessary to maintain each sub-microgrid, treating each of them as a separate microgrid. In this regard, the first step is balancing the generation and the demand. Fortunately, microgrid 1 has the power balance and the optimal power flow would be converged; needless to say that DG1 is a conventional power plant, so it could maintain the power balance by using its governor system.

In microgrid 1, lines 6, 7 and 8 have higher loadings than the other lines. So, they are candidates for an outage. Line 8 is randomly selected and disconnected. Upon disconnection of Line 8 in microgrid 1, all the loads connected to Bus 2 to Bus 8 (i.e., Bus 2, Bus 3, Bus 4, Bus 5, Bus 6, Bus 7 and Bus 8) and also Bus 19 to Bus 29 would be lost. The lost load in microgrid 1 is nearly 1.68 MW. Meanwhile, the cascading failures would stop and the remaining parts of microgrid 1 continue to operate; DG1 on Bus 9 delivers 0.85MW+j0.41Mvar.

Optimal power flow for sub-microgrid 2 is converged and luckily no line with loading over 70% is seen. There is no necessity to perform any remedial actions for this sub-microgrid. DG2 on Bus 30 delivers 0.54MW+0.26Mvar.

It is worth noting that finally the two sub-microgrids remain in-service, but at the expense of 2.708 MW loads that are shed to keep the remaining parts of the system. This amount is remarkable and is nearly 72.8% of the total load. This scenario is well shown in Figure 4. The cascading failures that occur on the test system at base case as Figure 1, lead to the final structure of Figure 4 are summarized as follows:

1) line 29 is a candidate, randomly selected and tripped;
2) OPF converges after shedding 0.83 MW;
3) Lines 16, 32 and 37 are tripped sequentially;
4) Upon tripping of Lines 16, 32 and 37, Buses 17, 18 and 33 would be de-energized;
5) The microgrid loses 0.342 MW of the loads, splitting into two individual sub-microgrids;
6) Line 8 is randomly selected and disconnected.
7) Outage of Line 8 leads to de-energizing of Busses 2 to 8 and Busses 19 to 29 with 1.68 MW loss load;
8) Microgrid 1 continues to operate and DG1 on Bus 9 delivers 0.85MW+j0.41Mvar;
9) DG2 on Bus 30 delivers 0.54MW+0.26Mvar.
10) Finally, 2.708 MW (72.8% total load) is lost.

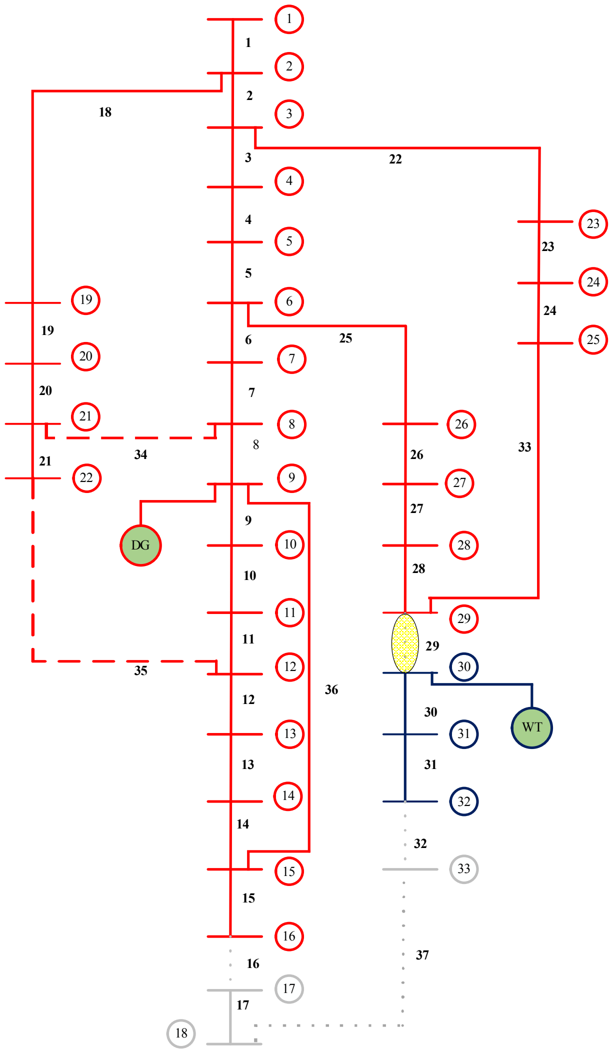

Figure 3: Single-line diagram of the sample system after outage of Line 29

REMEDIAL ACTIONS

As the outage of Line 29 is very critical which may lead to cascading failures with the result of the outage of more than 70% of the system load, remedial action is required. It is required to prevent the outage of Line 29, i.e., alleviating its overload is required. For example, if Line 8 is tripped due to a fault, then 1.09 MW load shedding is required for the OPF to be converged. However, the loading of Line 29 is 87.1%, i.e., it is at the risk of tripping due to the overload. The remedial action to find the optimum structure with the line loadings less than 70% is executed and the optimal topology would be as follows:

1) Close the tie switch interconnecting Bus 12 to Bus 22 (Line 35).
2) Open the Line 13(connecting Bus 13 to Bus 14).

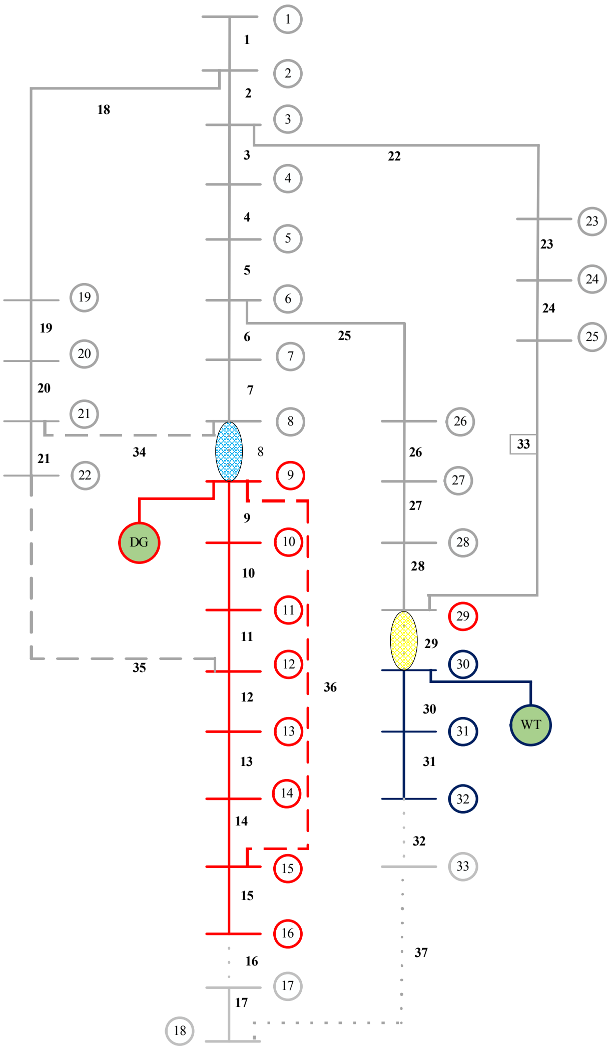

Figure 4: Final stage of the test system after cascading failures started by the outage of Line 29.

CONCLUSIONS

In this paper, a new algorithm to mitigate the vulnerability of a microgrid due to the cascading failures caused by overloading of the feeders is proposed. Resiliency of an autonomous microgrid is enhanced by reconfiguration provided that the overloading of the lines is alleviated; thereby the likelihood of the outage of the feeders is minimized. The proposed approach, firstly checks the topology of the microgrid to avoid isolated areas with no supply upon disconnection of the microgrid from the upstream grid.

Secondly, the algorithm searches for the lines with higher loading (more than a threshold). If there are any overloaded lines, remedial actions are performed by reconfiguration to alleviate the overloading to mitigate the possibility of their outage. The optimum structure is obtained by evaluating the outage of each line, considering the consequences, i.e., the extent of loads that remains unsupplied. So an optimal configuration is extracted with the maximum robustness whenever the lines with the higher loadings are tripped. Needless to say that upon disconnection of a microgrid from the upstream grid, the supply-demand balance is maintained by using the reserve capacity of the storage devices. After stabilizing the microgrid in the autonomous mode, the proposed algorithm is performed to extract the optimum configuration for maximum resiliency due to outage of line. The proposed methodology is simulated on IEEE 33-bus network as the test system to show the merits. It is shown that the resiliency of the network is improved by implementation of the proposed method.

REFERENCES

[1] M. Khederzadeh and A. Beiranvand, 2015, "Identification and Prevention of Cascading Failures in Autonomous Microgrid," *IEEE Systems Journal*, Early Access.

[2] C. Chen, J. Wang, F. Qiu, D. Zhao, 2015, "Resilient Distribution System by Microgrids Formation after Natural Disasters," *IEEE Trans. Smart Grid,* vol. 7, pp. 958-966.

[3] Y. Xu, K. P. Schneider, D. T. Ton, 2015, "Toward a Resilient Distribution System," *Proceedings IEEE Power & Energy Society General Meeting,* pp. 1-5.

[4] Y. Xu, C. C. Liu, and H. Gao, 2015, "Reliability Analysis of Distribution Systems Considering Service Restoration," *Proceedings IEEE PES Conference Innovative Smart Grid Technologies*, pp. 1-5.

[5] J. Li, X. Y. Ma, C. C. Liu, and K. P. Schneider, "Distribution System Restoration With Microgrids Using Spanning Tree Search," *IEEE Trans. Power Syst.*, vol. 29, no. 6, pp. 3021-3029.

[6] E. Sortomme, S. S. Venkata and J. Mitra, "Microgrid Protection Using Communication-Assisted Digital Relays", *IEEE Transaction on Power Delivery*, vol. 25, no.4, Oct. 2010.

[7] E. Afzalan, M. A. Taghikhani, M. Sedighizadeh, 2012, "Optimal Placement and Sizing of DG in Radial Distribution Networks Using SFLA", *International Journal of Energy Engineering*, 2012, 2(3): 73-77.