다중고장에 대한 전기 네트워크 구심성 척도

로델 도사노[a], **송화창**[b], 이병준[c]
군산대[a], 서울산업대[b], 고려대[c]

A Measure of Electric Network Centrality Due to Multiple Contingencies

Rodel D. Dosano[a], Hwachang Song[b], Byongjun Lee[c]
Kunsan Nat'l University[a], Seoul Nat'l Univ. of Technology[b], Korea University[c]

Abstract - This paper proposes a power system blackout model and devises a method of identification and selection of higher-order contingencies that may threaten power system security. To study how failures spread in power grids, network observability based on topological concept is utilized which provide a means of monitoring network evolutions due to multiple contingencies. The simulations and results are presented using the IEEE 118-bus test system.

1. Introduction

Recent large blackouts on power transmission systems left uncertainties to operate power system with security and reliability. Existing power system operational methodologies and planning which previously works well fail to operate. Even modern and large power networks are vulnerable to these uncertainties on daily task which needed an urgent response. Awareness on the impacts of these large blackouts on economic, social and physical aspects pushes to create an efficient and smart solution to reduced the damage to the system if cannot be prevented or mitigated.
This paper deals with power system blackout model with multiple contingencies and in combine with graph network theory to obtain measures in critical network components. These measures are used to find the importance of each node related to the response of the network when one of its components is deactivated. Vulnerability of power system can be viewed through system topology, by observing how these important nodes are close to each other and how responsive they are in an event of disturbance. In addition, location of system components for upgrading can easily be found without a brute-force enumerations of all components. The simulation is conducted using the IEEE 118-bus test system which shows its effectiveness.

2. Centrality Measure

2.1 Blackout Simulation Model

In the references related to graph theory, electric power network can be represented as a valued undirected graph G, with N nodes (buses) and K arcs (transmission lines and transformers). The graph G is described by the N x N adjacent matrix $\{E_{ij}\}$. If a transmission line exist between bus i and bus j, e_{ij} which is the element of $\{E_{ij}\}$ has a value between (0,1], otherwise e_{ij} =0. The diagonal elements of the adjacency matrix are zero.
By combining the simulation model and the delta centrality measures by [2] in the graph theory, we proposed a multiple contingencies identification using blackout model based on OPF. The proposed method captures the dynamic evolution of the electric network process as a result of component outage. The evolutions of criticalities on transmission lines and the continuation growth of power system conditions are captured. The vulnerability of power system to blackouts can be viewed by examining the coherency of important nodes using centrality measures.

The basic methodology of the algorithm is as follows:
1. Running OPF using a base case of the system and calculate the AC power flow, then deactivate the line when a certain criteria holds like; lines whose active power flow are beyond their limits or lines which carries a largest flow. Major generating units are not included in the outage but in severe cases, load shedding is perform if non-convergence is found in OPF solution in order to continue the simulations.
2. Compute index for critical lines. Initially at time t =0, value of e_{ij} =1, it means all active lines are perfectly working and there's no overloading. Then updates the index of line criticality using the method in [3],

$$e_{ij}(t+1) = \begin{cases} e_{ij}(0)\dfrac{C_i}{L_i(t)} & \text{if} \quad L_i(t) \ > \ C_i \\ e_{ij}(0) & \text{if} \quad L_i(t) \ \le \ C_i \end{cases}$$

where e_{ij} is the index of line criticality, $L_i(t)$ is the actual line power flow and C_i is the rated capacity of transmission line at time t.
3. Calculate centrality measures on each active buses and cluster nodes belong to group of highest score. Evaluate the coherency of these high score clustered nodes. Lines that isolate or loosen the links between important nodes are only considered as candidates of multiple contingency sets. Calculate the decrease of network efficiency. Identify the critical line outages that have high impact in decreasing the efficiency of the network.
4. Continue the simulation for the next contingency until certain condition is met.

2.2 Concept of Delta Centrality

The idea of centrality was first introduced in [1] to study social behavior in small group of people. Standard centrality can be divided into two classes based on the idea, (i) relevance to the distance between individuals and, (ii) on how the node acts as intermediary among others. Recently, [2] introduced a concept of delta centrality which is a generic measures of the classical centralities. Its main concept is based on the idea on how important is the node (an individual) when the network (social network) response to the deactivation of one of its components. Given a graph $G(V,E)$ representing an electric network, the delta centrality (Δ centrality) measure of node i can be define as;

$$C_i^{\Delta} = \frac{P[G] - P[G']}{P[G]} = \frac{(\Delta P)_i}{P}$$

where P is a generic quantity measuring the relationship of the graph and ΔP is the variation of P under the deactivation of a component in the graph. The delta centrality can be a measure of any of the classical centrality measures and its effectiveness depend on the choice of parameter used. For example, taking P as a measure of efficiency E of the network, the efficiency E of the network can be define as;

$$E[G] = \frac{1}{n(n-1)} \sum_{i \neq j \in G} \frac{1}{d_{ij}}$$

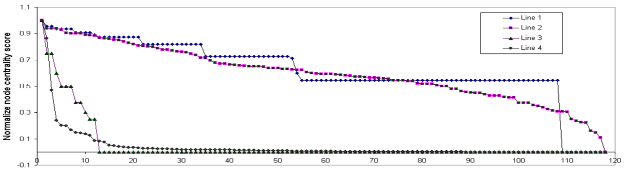
where d_{ij} is the efficiency of transmission lines and n is total number of branches. The delta centrality measure as a measure of efficiency of each line can be calculated as:

$$C_i^E = \frac{E[G] - E[G']}{E[G]} = \frac{(\Delta E)_i}{E}$$

3. Simulation and Results

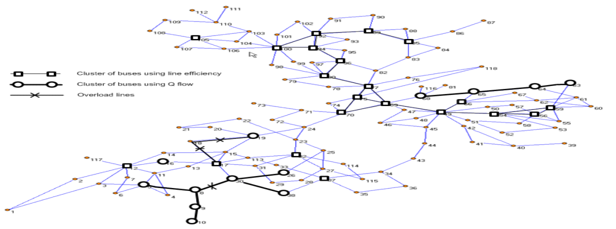
The proposed algorithm is carried out in the simulation using the IEEE 118-bus test system. After running the OPF using base case data, individual AC line flows are calculated. No overloadings are identified during the first OPF run, so to create contingency, line which carry biggest amount of active power with respect to its rating is chosen be a candidate for tripping. The values of the elements in adjacency matrix e_{ij} are all one since no overloading in any line occurs. Tripping the line carrying the highest loading causes active power to be directed in other path which created increases of active flows to other lines. Overloaded lines can be identify by those with e_{ij} value less than 1 and the line with lowest value is the next candidate to be deactivated. As the number of line outage increases while the simulation process continues, the number of elements in E_{ij} which has a value less than 1 increases also. At the end of the fifth line outage, non-convergence in the solution of OPF was found. In order to continue the simulation, load shedding are perform in some load buses until an operational solution is found.

In a way to identify sets of critical line outages or multiple contingencies, we first track severe changes in each nodes as results of line outages using delta centrality measure. Four parameters were used to evaluate the importance of components in the network by measure of the centrality.



<Fig. 1> Normalized node centrality scores

Figure 1 represents the normalized node centrality score of each buses based on their computed delta centrality measure. The higher value represents those nodes which responses to the deactivation of a component while the least values are those which are not so sensitive to the outage. Line 1, 3 and 4 show node clustering capability using active power flow, reactive power flow and number of directly connected lines respectively. Line 2 which uses the magnitude of line impedance shows no significant behavior in clustering the nodes.



<Fig. 2> Node-branch configuration of 118-bus system

Figure 2 shows the generated node-branch network of the test system with clustered nodes based on the centrality measures. Clusters of nodes which have high scores using the efficiency of line active power flow are marked with heavy circle while nodes with high scores using changes of reactive power flow into the node are marked in heavy circle in Figure 2. Lines that carry current above their capacity rating are marked "x". Directly link or well-clustered important nodes are connected by heavy lines. The main idea in selecting sets of critical line is based on considering only the lines which loosen the cohesiveness of important nodes to the other members.

Note: *****-infeasibility or system collapse

Line tripped using centrality measure	Decrease in Network Eff'y	Line tripped using line overloads	Decrease in Network Eff'y
12-16	0.0072	4-5	0.0000
12-14	0.0145	64-65	0.0290
12-13	0.0145	23-32	0.0145
12-11	*****	38-65	0.0500

(a)

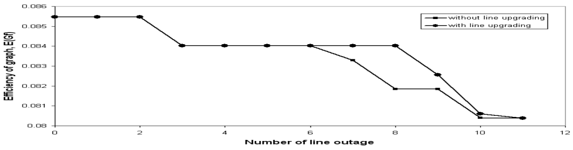
Line tripped using centrality measure	Decrease in Network Eff'y	Line tripped using line overloads	Decrease in Network Eff'y
15-13	0.0145	25-27	0.0145
32-113	0.0145	23-25	0.0145
89-92	*****	26-30	*****
49-66	*****	30-38	*****

(b)

<Table 1(a-b)> Study results

The damage on the network by deactivating these critical lines is compared with that of other failure simulation process like tripping line that carry highest loading. After the second line outage, Table 1a shows the comparison in the decrease of network efficiency with the selected critical lines outage using both algorithms. The proposed algorithm has distinguished a critical line (11-12) that could lead the system to blackout or infeasibility. It should be noted here that line (11-12) carries a active power below its line rating. After the fifth line outage, Table 1b shows that line (89-92) and (49-66), and (26-30) and (30-38) are critical lines that can cause system infeasibility. Interestingly, lines (26-30) and (30-38) which is identified by the other method can also be identified by the proposed approach.

In economic perspective, not all lines can be considered for upgrading. Enumerating all line as candidate for upgrading is an exhaustive work in planning especially for large power system. Upgrading of power system infrastructure to improve its reliability can be simplified by reinforcing additional ties or enhancing tolerance factor of lines between important nodes. This results to allow enough active power to flow, thus improving cohesiveness. The upgrading of the lines between two loosely pilot nodes shows improvements on the efficiency of the network shown in Figure 3. Furthermore, overloadings on some lines are eliminated as well as enhanced in network reliability.



<Fig. 3> Comparison results of network efficiency

4. Conclusion

This paper deals with a power system blackout model due to multiple contingencies and introduce a way to identify initiating higher-order contingencies that may cause high risk to power system. The algorithm considers only selected important nodes to determine sets of critical contingencies in multiple contingencies screening problem.

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