Skeleton Network Reconfiguration for System Restoration in Restructured Power Industry

Hamireza Jafarian*, Mostafa Rajabi Mashhadi**, and Mohammad Hossein Javidi***

*Graduate student in Ferdowsi University of Mashhad, hajafaria@asu.edu
** Deputy of research and planning of Khorasan Regional Electric Co., m.rajabimashhadi@krec.ir
*** Professor Ferdowsi University of Mashhad, h-javidi@ferdowsi.um.ac.ir

Abstract-- *Power system restoration is an important task for system operators. Due to the importance of the problem, the ways which will be used for solving it are significant as well. One of the best methods for restoring a power system is recognition and access to the network reconfiguration. If the main skeleton-network is recognized appropriately, other parts of the network can be restored at the shortest possible time. Restructuring in power industry add new complicated constraints to the problem of power system restoration. While this issue has been investigated by many researchers, little attention has been paid to this task in a market based environment. In most solving methods an index is defined to rank the network nodes. But none of the suggested indices have the comprehensiveness and also none of them considered the issues which have been dictated by the power market. This article represents a new combined index and market based method for ranking the network buses, which by applying it to different power systems; the best reconfigured network can be distinguished. Restoring other parts of the network from this skeleton network will lessen the restoration time. By using this index we can also decrease the cost of blackout and the cost of the power system restoration. This index in compare to similar indices has a better function and performs a better bus ranking for complicated power networks in market environment. Genetic algorithm is used to solve this problem. The suggested method is used to rank the buses of the IEEE 30-bus network. Results show that this method in compare with similar methods has a better performance*

Index Terms-- Restructured power industry, Genetic algorithm, Power system restoration, Skeleton-network reconfiguration

1. Introduction

Modern societies are dependent on the electrical energy. The demand for a reliable energy increases daily which makes the power systems operation more complicated and increases the probability of occurring errors in the network [1]. Generally after the restructuring of electrical power industry the probability of blackouts has been increased. Because in this new environment the power systems do not run integrated anymore and each market participant is looking for his own benefits [2].

Therefore, some huge blackouts have occurred all over the world in this decade, for example the two blackouts in 1999 in Taiwan [2], 2002 in brazil [3], 2003 in Sweden and Denmark [4], 2003 a blackout in a big part of America and Canada's electric network, 2005 in java-bali Indonesia and in 2006 in a big part of the Europe connected network which caused lots of economical, political and social damages [5].

The negative effects of long time blackouts on society, economy and the power system itself, made the fast restoration after the blackout more important. Since a fast and suitable restoration plan will result less amount of damages on electric devices that are caused by blackouts for subscribers [6].

The power system restoration problem after a partial or complete blackout is as old as the power industry. Because of the unusual operation of network after a complete blackout, the power system restoration needs an exact programming [7].

Until now two strategies have been suggested for power system restoration after a complete blackout: restoration by path and restoration by zone [8].

In restoration by zone, after a blackout occurs network will be divided in two separated islands. In this method the main idea is to create some stable islands rapidly so that the blackout time increases to the less possible amount for subscribers. The next step which usually causes some problems is to synchronize these islands and restore the network to its former integrated state. It should be note that in this method lots of blackstart plants are needed.

In restoration by path, the main part of the network should be energized at first and after that other loads and power stations should be energized parallel. This method, because of the stability of the premier network and step by step energizing of the power network is more reliable in compare to restoration by zone. The main problem with this strategy is the time needed for energizing the whole network [8].

Because the time is the most important factor in the restoration process, most of the researches have been limited on the island restoration method. In this method because of the parallel restoration of several islands, it is possible to energize more subscribers at premier steps of restoration. However, in this method synchronizing the islands is a complicated matter, if operators don’t do it carefully it can cause the network to collapse and bring more damages to electrical devices. Therefore, if it's possible to reduce the time needed for energizing the subscribers in restoration by path, this method, according to its high quality power and less need of blackstart units is better and more reliable than restoration by zone method.

Current solving ways are based on the definition of an index, to rank the network nodes. But none of the suggested indices have the comprehensiveness and they don't have the appropriate function for some networks. And also none of them considered the issues which have been dictated by electricity market. Therefore in this article a combined index is given to recognize and reconfigure the network. By its use it's possible to reduce the blackout time for the network. By using this index we could also decrease the cost of blackout and the cost of the power system restoration. This article has been presented to show the efficiency of this index. The suggested method has been applied on IEEE 30-bus network and the problem has solved by genetic algorithm and the results show that this method has preference over the former method.

Coming up, in part 2, the full description of the new method for solving network reconfiguration is given. In part I flowchart of the main program is described. The results of simulation and comparison with former method are mentioned in part 4. And finally conclusion is given in part 5.

2. Description of New Network Reconfiguration Method

Generally the power system restoration process contains two separated stages: assigning the skeleton network and performing practical actions in order to energizing the whole network from skeleton network [9]. This article is focused on the first stage, recognizing the skeleton network. In this article the aim of network reconfiguration is to assign a subsystem for restoration of the network in the first step of restoration that most of the important buses are in it.

In order to reach the reconfiguration network, an index must be defined to determine the importance of the network buses which by its use; the network buses can be ranked. Traditionally, the index that was used to determine the importance of buses was the degree of each node. This means that according to network topology, the nodes that have more connected lines are more important. Although this index is valid for most of the networks, there are also some exceptions which in that an important node in compare to other network nodes doesn't have the higher degree. A sample of these exceptions is shown in the fig. 1 [10].

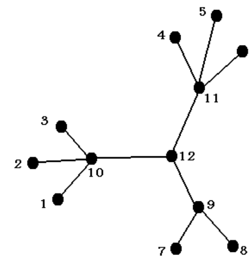

Fig. 1. Improper performance of node degree

As shown in this figure, although node 12 has a lower degree than nodes 10 and 11, it is the most important one. In 2007 an index was presented in which for ranking the buses instead of node degree, a parameter called node importance degree (α) was used. In defining this index beside the connected lines to the node, degree of those nodes which are next to the main node were also concerned [10].

But this index also doesn’t have appropriate performance for some networks. For example in fallowing figure, nodes 11 and 12 have the same node importance degree (α=0.0625), but node 12 in compare to node 11 is much more important. In this article a combined and flexible index is going to be presented. Further description will be given also.

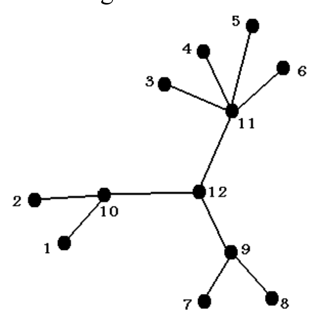

Fig. 2. Improper performance of node importance degree

Until now several indices has been presented to measure the importance of the complicated network nodes. Such as, betweenness index [11], closeness index [12], eigenvector index, subgraph index [13] and many other indices. But none of them can show the difference between various nodes in complicated power networks by themselves. Therefore, combinational node ranking index (η) is presented in this article which is a weighted combination of some indices. So we will be able to rank the network nodes in the best way by its use.

This index is defined as follow.

$$\eta(i) = w_1 \times \alpha(i) + w_2 \times \beta(i) + w_3 \times \gamma(i) + w_4 \times \delta(i) \qquad (1)$$

In which

i	Node number
$\alpha(i)$	Node importance degree of *i*th node
$\beta(i)$	Betweenness of *i*th node
$\gamma(i)$	Closeness of *i*th node
$\delta(i)$	Inverse of interruption cost of *i*th node

w_1, w_2, w_3 and w_4 are weighted coefficients for each index, and $w_1 + w_2 + w_3 + w_4 = 1$

In order to calculate α for each node, it is necessary to combine that node with its adjacent nodes and create a combined node. After making a new network, this index for the wanted node will measure as follow [10]:

$$\alpha(i) = \frac{1}{n_i \times l_i} \tag{2}$$

$$l_i = \frac{\sum_{i,j \in V_i} d_{\min_{i,j}}}{n_i(n_i - 1)} \tag{3}$$

Where

n_i Number of network's nodes after combining the ith node with its adjacent nodes

l_i The average of minimum distance in the network after the combination of ith node with adjacent nodes

$d_{\min i,j}$ The shortest distance between *i* and *j* after combination of node *i*

Betweenness index for each node is calculated as follow [12].

$$\beta(i) = \sum_{j,k \in N, j \neq k} \frac{n_{jk}(i)}{n_{jk}} \tag{4}$$

Where

n_{jk} The number of shortest path between *j* and *k*

$n_{jk}(i)$ The number of shortest path between *j* and *k* which pass through *i*

Closeness index (γ) for each node will be calculated by dividing 1 by sum of distances between that node and other network nodes. It is obvious that the lesser the sum of distances to other nodes is the bigger the index is and that node is more important [12].

$$\gamma(i) = \frac{1}{\sum_{j \in N} d(i,j)} \tag{5}$$

Where

$d(i,j)$ Distance between i and j

Following table shows the amounts of different indices for nodes 11 and 12 in fig.2. As it can be seen, although the amount of node importance degree is the same for both nodes, the amounts of betweenness and closeness indices for node 12 is more than node 11 and that shows node 12 is more important than node 11.

TABLE I
COMPARISON OF NODE IMPORTANCE DEGREE, BETWEENNESS AND CLOSENESS

γ	β	α	Node no.
0.0476	0.4242	0.0625	11
0.0526	0.5909	0.0625	12

Fitness function is defined as fallow.

$$f = \frac{N_s}{\sum_{i \in N} \eta(i)} \tag{6}$$

Where

N The set consisting of all nodes in skeleton network

N_s Total number of nodes in skeleton network

And constraints of the problem are:

$$\Delta U < \Delta U_{\max} \tag{7}$$

$$\Delta P < \Delta P_{\max} \tag{8}$$

Where

$$\Delta U = \frac{n_{\Delta U}}{n_c} \tag{9}$$

$$\Delta P = \frac{\sum_{i \in L} (MP_i - CP_i)}{L_c} \tag{10}$$

In which:

n_c The number of existed nodes in reconfigured network

$n_{\Delta U}$ The number of nodes that their voltage is over the limited area

L Set of existed lines in reconfigured network

L_c The number of existed lines in reconfigured network

MP_i The maximum capacity of ith transmission line

CP_i The current capacity of ith transmission line

For solving the restoration problem which is multi-objective, multi-constraints, complicated and nonlinear, using the traditional optimization algorithms can't be beneficial. Therefore to solve this optimization problem, in this article, genetic algorithm is used. Genetic algorithm is an algorithm based on repetition that its premier principles are adopted from genetic science. This algorithm uses the natural selection principle to find an optimal answer or path [14].

3. METHODOLOGY

Fig.3. shows a general structure of the algorithm that is used in this paper. In the first step, values of node importance degree, betweenness and closeness indices and inverse of interruption cost of each node should be calculated. Values of each index should be normalized in terms of maximum of that

index. After that, a random set of GA solutions should be created. A solution is defined with the state sequence denoting which lines are selected to take part in reconfiguration network. When a certain transmission line is selected, corresponding position in state sequence takes 1 value. Otherwise, 0 value is taken. The next step is checking the connection of the solution. If a solution isn't integrated it will change to an integrated one. After this step, fitness function should be calculated and after running power flow and checking constraints the best solutions will be recorded. This process will continue until it reaches the stop criteria.

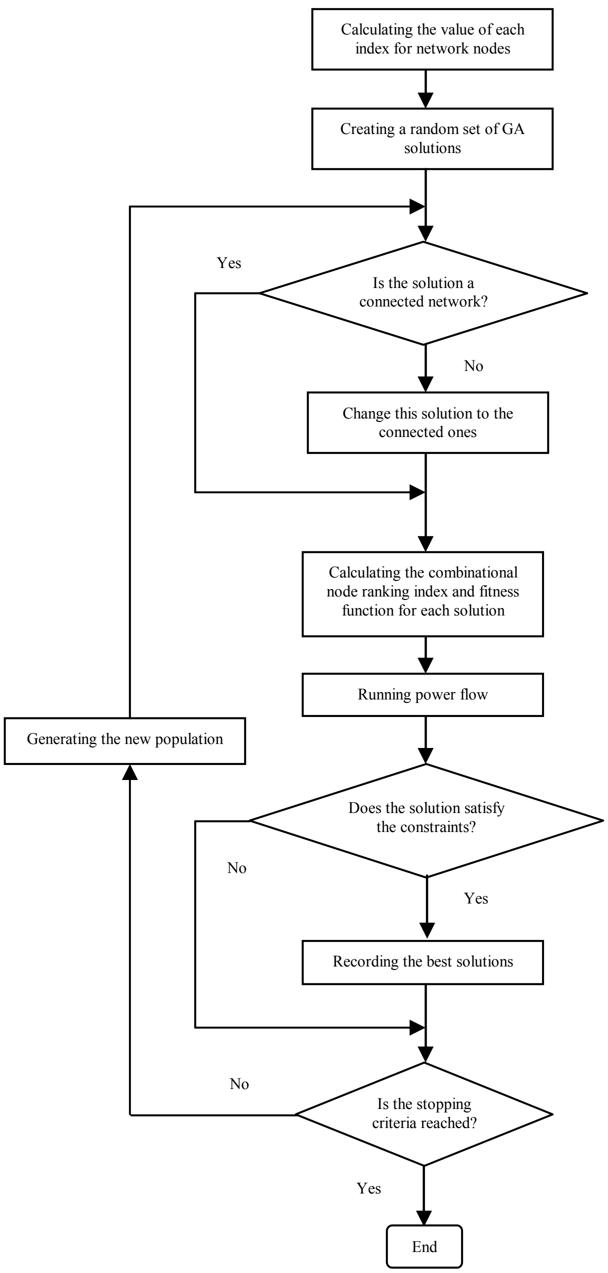

Fig. 3. Flow of the main program

4. CASE STUDY AND RESULTS OF SIMULATION

In order to analyze the performance of combinational node ranking index that was suggested in this paper and compare it to former suggested indices, this method was applied on modified IEEE 30-bus network which is showed in fig. 4. Values of indices for this network's nodes are calculated. To show the relative importance of nodes, value of each index for each node should be normalized in terms of maximum of that index. Normalized values of all indices for this network's nodes are shown in the Table IV. Based on load's importance and load of each node, an interruption cost assign to load nodes of network. Table III shows the interruption costs of load nodes of this network. Weighted coefficients w_1, w_2, w_3 and w_4 take value of 0.25, 0.5, 0.2 and 0.05, respectively. Betweenness, because of its priority takes the maximum coefficient. The second and third priorities are node importance degree and closeness. Finally, inverse of interruption cost takes 0.05 because economical issues are not so important in first stage of restoration.

TABLE III
VALUE OF INTERRUPTION COST FOR LOAD NODES

Node no.	Interruption cost \$/h	Node no.	Interruption cost \$/h	Node no.	Interruption cost \$/h
1	---	11	50	21	60
2	80	12	70	22	---
3	55	13	---	23	70
4	65	14	60	24	70
5	50	15	70	25	55
6	60	16	55	26	60
7	65	17	60	27	---
8	65	18	55	28	50
9	55	19	60	29	55
10	70	20	55	30	55

Power system restoration problem is multi-objective, combinatorial, non-linear and a constrained optimization problem. Because of good performance of genetic algorithm in solving problems like this, GA is used in this paper. In this algorithm every chromosome has 41 genes because there are 41 transmission lines in this network. Tournament selection method is used to select the solution that contributes in the production of new generation and crossover, mutation and selection rates are 0.5, 0.3 and 0.2 respectively.

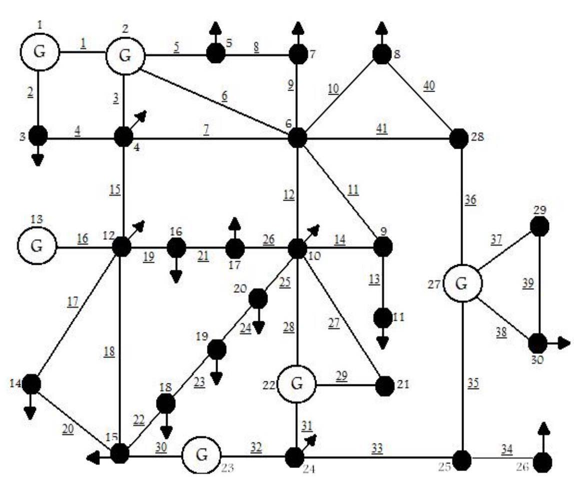

Fig. 4. IEEE 30-bus network

TABLE IV
VALUE OF INDICES FOR NETWORK NODES

γ	β	α	Node no.	γ	β	α	Node no.
0.6667	0.0590	0.6898	16	0.6168	0.0057	0.6823	1
0.7333	0.0902	0.6898	17	0.8148	0.2296	0.7764	2
0.6055	0.0652	0.6972	18	0.6535	0.0227	0.6819	3
0.6055	0.0666	0.6972	19	0.8800	0.5087	0.8286	4
0.7079	0.1488	0.6972	20	0.6168	0.0057	0.6770	5
0.7021	0	0.6870	21	1	1	1	6
0.7765	0.1989	0.7391	22	0.7174	0.0482	0.6770	7
0.6804	0.1776	0.7205	23	0.7500	0	0.7007	8
0.7333	0.3207	0.8910	24	0.8049	0.1587	0.7403	9
0.6667	0.2768	0.7736	25	0.9167	0.6509	0.8872	10
0.5197	0	0.7626	26	0.6000	0	0.6555	11
0.7021	0.4355	0.8075	27	0.7952	0.4941	0.8319	12
0.8148	0.4138	0.7764	28	0.5946	0	0.6584	13
0.5455	0	0.7019	29	0.6471	0	0.6984	14
0.5455	0	0.7019	30	0.7333	0.3080	0.7939	15

Optimal skeleton-network obtained from GA is shown in Fig. 5. 12 branches labeled in bold lines are identified to participate in reconfiguration network. Fig. 6. shows the skeleton network that is suggested in [10]. Fitness functions of these networks are 0.6462 and 0.7209 respectively.

In order to compare these two networks, number of switching that required for energizing other nodes of network should be calculated. It is obvious that the lesser the sum of switching is the lesser are the cost and the time of restoration process are because each switching consumes time and money. In TABLE IV number of switching that is needed for energizing the other nodes of these two networks are compared. Two shortest paths for each node are mentioned in this table. For nodes that there is only one way for energizing them, that way is also mentioned for second path. This table shows that average of switching for energizing other nodes via both paths in the network that suggested in this paper is lesser. This means that energizing whole network from this skeleton-network is faster and cheaper. Average of normalized interruption cost for networks that are shown in fig. 5 and fig. 6 are 0.6346 and 0.5848, respectively. This shows that by using combinational node ranking index cost of blackout is decreased.

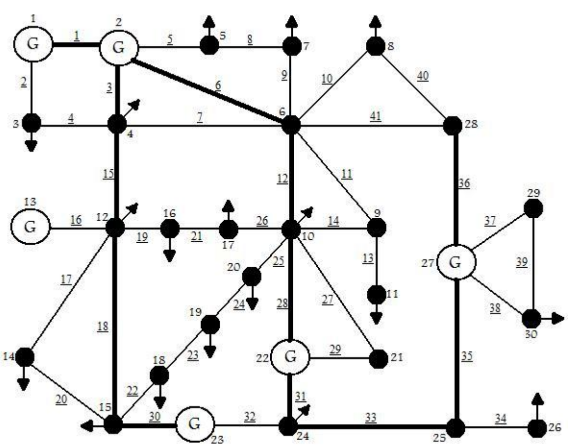

Fig. 5. Optimal skeleton-network

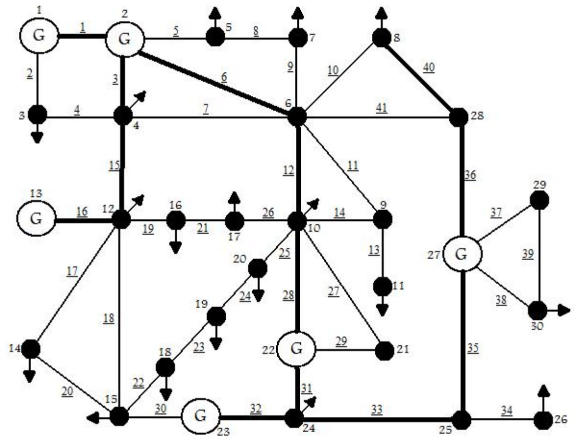

Fig. 6. skeleton-network suggested in past

TABLE IV
COMPARISON BETWEEN TWO SUGGESTED NETWORKS

Suggested network in this paper			Suggested network in 2007		
Node number	Shortest path	Second path	Node number	Shortest path	Second path
3	1	1	3	1	1
5	1	2	5	1	2
7	1	2	7	1	2
8	1	1	9	1	1
9	1	1	11	2	2
11	2	2	14	1	2
13	1	---	15	1	1
14	1	1	16	1	2
16	1	2	17	1	2
17	1	2	18	2	2
18	1	3	19	2	3
19	2	2	20	1	4
20	1	3	21	1	1
21	1	1	26	1	---
26	1	---	29	1	---
29	1	---	30	1	---
30	1	---	---	---	---
average	1.117	1.588	average	1.187	1.750

5. CONCLUSION

Restructuring of electrical power industry have increased the probability of blackouts in power networks. Network restoration after a blackout is a complicated matter that needs an appropriate programming. Generally this article focused on the first stage of power system restoration process which is identifying the skeleton-network.

In this article a combined index was presented for analyzing complicated networks that by its use it is possible to rank network busses and reduce the time needed for restoration. The issues which have been dictated by the power market to power system restoration problem such as interruption cost were considered in defining suggested index. Using this index could decrease the cost of blackout and the cost of the power system restoration.

This index in compare to former indices has more creditability and in networks that former indices were not practical has a better performance. This index was used for identifying the skeleton network of modified IEEE 30-bus network. This problem was solved by using genetic algorithm. By comparing results were obtained from this method with results were obtained from former methods efficiency of this new method was seen.

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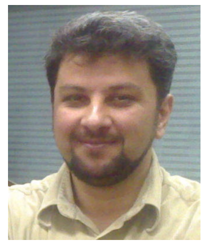
7. Biographies

Jafarian Hamidreza was born in Mashhad, Iran, on November 21, 1983. He received the B.Sc. degrees in Electrical Power Engineering in 2007 from Amirkabir University of Tehran, Iran. He is currently pursuing the M.Sc. degree in Ferdowsi University of Mashhad.
Her areas of interest include Electricity Market, Power System Restoration and Power System Operation, Planning and Optimization.



Mostafa Rajabi Mashhadi was born in Mashhad Iran, on June 2, 1971. He received his B.Sc and M.Sc Ph.D. degrees in electrical engineering from Ferdowsi university of Mashhad, Mashhad, Iran, in 1995 and 2001, 2010 respectively.
Since 2003, he has been employed in Khorasan Regional Electric Company (KREC) and has been engaged in electric and control department of khorasan gas turbine power plants, as the manager of Khorasan power market department and the manger of Dispatching Center of North East Area of Iran. His special fields of interest include power system control and operation and planning, restructuring, and artificial intelligence.
He is a member of power system studies and restructuring laboratory.

M. Hossein Javidi received his B.Sc. degree from Tehran University, Tehran, Iran in 1980, M.Sc. degree from Nagoya University, Nagoya, Japan in 1985 and Ph.D. degree from McGill University, Montreal, Canada in 1994, all in electrical engineering.

He is currently a professor in the Department of Electrical Engineering, Ferdowsi University of Mashhad, Mashhad, Iran. He was a board member, as well as the secretary of the electricity regulatory body in Iran (2003-2010). His research interests include power system operation and planning, restructuring and market design, and artificial intelligence.