RELIABILITY EVALUATION OF RADIAL DISTRIBUTION SYSTEMS INCLUDING DISTRIBUTED GENERATION BASED ON AN IMPROVED CLASSIFICATION ALGORITHM

Arman Amini BADR[1], Navid Taghizadegan KALANTARI[2]

This paper presents a reliability assessment algorithm for radial distribution systems including microgrids (MG). The effects of microgrids and system reconfiguration on distribution system reliability can be evaluated using the proposed algorithm. The impacts of location and capacity of the distributed energy resources and sectionalizing switches on reliability indices are determined. Moreover, proper location is determined by classification of load points in distribution system. An approach to identifying the out of service section after a fault event is presented based on the adjacency matrices. The classification of nodes is obtained by identifying different adjacency matrices based on protective devices.

Keywords: Reliability analysis, distribution system, distributed generation, microgrid

1. Introduction

Microgrid that contains distributed energy resources is a part of a distribution system and can be isolated from the rest of the network in the event of an upstream fault. Distributed generation and energy storage technology include variable energy sources.. For example, Wind Energy Conversion System, Micro Turbine, Diesel Generator, Gas Turbine, Fuel Cell, Biomass Systems, Photovoltaic Systems, and Super Conducting Energy Storages. These units have dispersed in all over power system. Also, these technologies have considerably affected on power system performance. Because dispersed generators have small capacity, usually they are located in distribution system. Nowadays, it has predicted that distributed energy resources of MG will be a significant percentage of all new generation. The DG impact on the distribution system reliability is the primary subject of various publications and is widely recognized as a means to increase reliability of systems [1]-[6]. Analysis of the customer failure statistics of most utilities shows that the distribution system makes the greatest individual contribution to the unavailability of supply to a customer and the electrical

[1] Department of Electrical Engineering, Azarbaijan Shahid Madani University, Islamic Republic of Iran, e-mail: arman.a58@gmail.com
[2] Department of Electrical Engineering, Azarbaijan Shahid Madani University, Islamic Republic of Iran, e-mail: ntaghizadegan@yahoo.com

distribution network failures account for approximately 80 % of the average customer interruptions [7]. Distribution system reliability enhancement is conducted by reducing the expected failure rate and outage time. There are a large number of publications in reliability assessment of distribution systems [8]-[11]. Both simulation and analytical methods have been used for evaluating the reliability indices of distribution systems. Distribution system reliability indices are still employed to assess microgrid reliability [12]–[16]. However, [17] introduces new metrics specially designed for microgrid reliability. Connection matrix is utilized in [12] to assess the reliability of customers in the microgrid and the reliability of the distribution system. To evaluate the active distribution systems, microgrids are modeled based on virtual power plant concept in [14]. Analytical techniques can be categorized into markov and network modeling. These techniques in large–scale distribution systems may be time-consuming and need too much memory. Reference [18] and [19] present an approach to search for the shortest paths between any two nodes of distribution system. The classification of nodes has been made by considering the sections controlled by protection devices based on the shortest path. [19] does not consider the distributed generation units in distribution network. In this paper, load points are classified by attenuation network topology and tree graph of network for reliability analysis of distribution systems including DGs, so the classification of [19] is improved. To consider the network constraints in sections with DGs, the optimum load shedding is used with the aim of minimization of customer interruption cost. When a failure occurs in the network, a section of feeder that is affected from this failure should be isolated. A feeder is divided to different areas with respect to sectionalizing, tie switches, and MGs location. Then, reliability indices are calculated. The structure of paper is as follows: in section 2, details of problem and basic assumptions are briefly described. The proposed algorithm is illustrated in section 3. In section 4 the method is applied to typical distribution systems to demonstrate the validity of algorithm.

2. Problem and assumptions

Distribution system reliability evaluation in the presence of MGs is an important issue in system planning and operating. Also, the utilities evaluate different approaches to provide competitive rates and acceptable reliability levels to customers. As load increases, the distribution system has to be expanded to satisfy the increased customer load requirements. For example, adding a distribution feeder, a distribution substation or dispersed generators to meet the growing customer loads are some of the alternatives to system improvement. Nowadays, smaller and environmentally friendlier distributed generation in microgrids can be built economically by independent generators. MG consists of small generators typically ranging in capacity from several kilowatts to 10 MW connected to distribution systems. Some distribution systems as radial systems have meshed configuration by using normally open point with the adjacent feeders. The amount of capacity transfer available from the neighboring distribution system will depend on the network operating arrangement and loading on the various interconnected networks. It is, therefore, not always feasible to transfer all disconnected loads on a distribution system to the neighboring feeders through the normally open points.

The high cost associated with power interruptions and considering that the costs of transmission and distribution systems are taking an increasingly large portion of the utility capital investment, use of DG and MG in power industry could be a cost effective solution to enhance system reliability. When system outage happens, the DG owned by a microgrid will supply emergency energy preferentially to the contracted customers prior to other customers. Instead of isolating DGs from the system, when a fault occurs in distribution system, by opening switches in the upstream and downstream side of DGs, an isolated area can be supplied. Based on the above issues, MGs can improve reliability through islanding operation. If DGs operate as back up, only indices related to duration of interruption will be improved. But in parallel operation both indices related to duration and frequency of interruption are improved.

The following information is met by the results:

1. Where to install DGs;
2. Each of the load points locates which section on different failures of system;
3. Which load points should be fed by MG;
4. When MG is a choice to improve system reliability.

2.1. Reliability indices

The reliability of an individual customer load point is very dependent on the topology, design and operation of local distribution system. Radial networks in distribution systems are the most simple and general model. A simple distribution system is usually represented by a general feeder which consists of main sections, and a series component. A radial distribution system consists of transformers, transmission lines, breakers, fuses, and disconnected switches. Consequently the principle of series systems can be applied directly to these systems.

The primary reliability indices expressed in (1) to (3) are the expected failure rate λ, the average duration of failure r, and the annual unavailability U at the customer load points.

$$\lambda_s = \sum_i \lambda_i \tag{1}$$

$$r_s = \frac{U_s}{\lambda_s} = \frac{\sum_i \lambda_i r_i}{\sum_i \lambda_i} \tag{2}$$

$$U = \sum_i \lambda_i r_i \tag{3}$$

Other reliability indices such as SAIDI, SAIFI, AENS and ASAI can be determined. In addition, the reliability cost/worth indices of EENS, ECOST, and IEAR can be also calculated.

2.2. Basic assumption

The following assumptions have been made in the proposed algorithm:

1. Elements of network have only up/down state.
2. The outages of distribution system are independent.
3. The location of switches and MGs on distribution system is known.
4. A fault in radial distribution system is interrupted by the nearest (breaker/fuse) on its upstream side and is isolated by its nearest protective devices.
5. Spare capacity for feeders is sufficient to supply the adjacent feeders.
6. Protection devices and DGs of microgrids are 100% reliable.

3. Solution algorithm

In general, the strategy of method is declared: During system failure, the network is first divided into different areas by protective devices; then interrupted area is identified and load points that are fed with distributed generators, are recognized with power flow and load shedding techniques. An optimum load-shedding technique is used to improve the reliability of a local distribution system. The load shedding priority among sections of distribution system is determined to minimize the total system interruption cost. Finally, reliability indices of radial distribution system are calculated. The proposed algorithm is based on the following assumptions.

1- The system has radial structure

2- Fault and MG locations are known.

There are two kinds of switching operations: One is isolating the failure point so that a load point of interest which has lost power may be re-supplied from the original source. Second, if an alternate source is available, after isolation of the failure point, some load points will be fed by an alternate source. Therefore, it is possible to restore some of the lost loads by reconfiguration the network. The location of protection or isolation components on the network and their response to failures can have an important impact on the reliability indices. The distribution system is divided to sections by these protection and isolation components. A section is a group of components whose entry component is a switch or a protection device. Each section has one and only one switch or protection device.

3.1. Classification

When a failure occurs in the network, a section of feeder that is affected by this failure should be isolated. When faults are on the lines with switches, they are isolated by those switches and faults on lines without switches are isolated by opening proper downstream and upstream switches. A feeder is divided into different areas with respect to the sectionalizers, tie switches, and DG location. Load points are classified by attenuation network topology and tree graph of network. Nodes are classified in terms of the impacts of failures on them. In [18], nodes have been classified into four types. In this paper, nodes are classified into five types based on the duration of interruption time for each node.

A) Healthy nodes with zero interruption time

B) Nodes with interruption time equal to switching time

C) Nodes with interruption time equal to sectionalizing time plus the recloser time of a tie switch

D) Nodes with interruption time equal to repair time

E) Nodes with interruption time equal to switching time plus the starting time of DG

When a component fails, first circuit breaker/fuse on upstream line must be identified using the tree traverse algorithm. The nodes locating the upstream side of circuit breaker/fuse and the nodes of other feeders are identified as nodes of class A. The other nodes belong to classes B, C, D and E.

Based on the definition of various classes, the proposed algorithm for classification of load points of radial distribution system consists of the following steps:

1. The adjacency and path matrix is made to determine paths between any two nodes of networks. The rows and columns of matrix consist of nodes of network.

2. Then the adjacency matrices are made on three different states:

2.1. Without the branches including breakers.

2.2. Without the branches including fuse.

2.3. Without the branches including sectionalizing switches.

Using these matrices, the connected components of network for protection devices are determined.

3. Considering the definition of various classes, the nodes of network or the load points for each component failure belong to suitable classes. Flowchart of the load point classification is shown in Fig. 1.

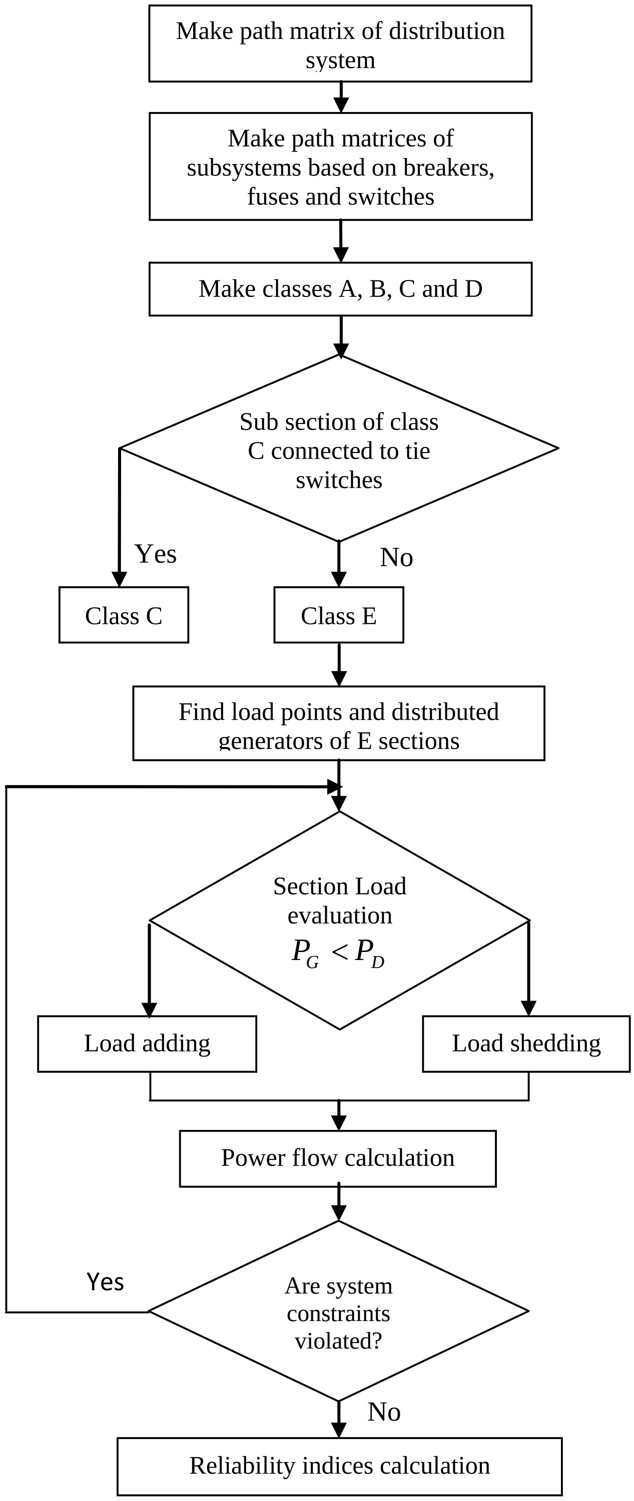

Fig. 1. Flowchart of the classification of load points

4. Run power flow to check whether there is a constraint violation in the resulting area which has made of nodes on classes E and C. If there is no violation, go to step 6. Power flow equations are represented in (4) and (5).

$$I_j = \sum_m I_m + \frac{S^*_{load}}{V^*_j} \tag{4}$$

$$V_j = V_i - I_j Z_j \tag{5}$$

Where:
I_j=current through branch j
I_m=current through directly connected downstream busbar fed by branch j
S_{load} = load attached to busbar j
V_j =voltage at downstream busbar of branch j
V_i =voltage at upstream busbar of branch j
Z_j=the impedance of branch j

Constraints are:

$V_j^{min} < |V_j| < V_j^{max}$

$P_{Gj}^{min} \le |P_{Gj}| \le P_{Gj}^{max}$

$Q_{Gj}^{min} \le |Q_{Gj}| \le Q_{Gj}^{max}$

$|I_j| \le I_j^{max}$

Where:
P_{Gj}= generated active power through busbar j
Q_{Gj}= generated reactive power through busbar j

5. If there is a voltage constraint violation at the nodes and line capacities, start the constraint handling process (load shedding) and then go to step 4. The load points with load shed are located in class D.

6. Compute a set of reliability indices.

In the isolated area which has microgrid, if there are several generators, DG unit with biggest capacity will be modeled as a voltage source and the others will be treated as negative loads. But capacity of DGs must not be out of the determined limits.

3.2. Optimum Load shedding technique

The optimum load shedding is used in this paper with the aim of minimization of customer interruption cost. If isolated area has M section, the total state to evaluate load shedding process will be (2M-1). M is the number of protection devices in determined area.

Reference [20] introduces a priority weight factor (PWF) which has been defined based on the Sector customer damage functions (SCDF) and feeder load. In addition, customers have been divided into large user, industrial, commercial, agriculture, residential, government and institution and office and buildings categories. This factor with a simple change can be used to determine priority of each section. The load shedding procedure for determining which sections of load points should not be restored consists of the following steps:

Step 1. The priority weighting factor and total load for each section in the determined area is calculated.

Step 2. The total load for each state of 2M-1 state of sections is determined. If the total load is smaller than the generator capacity deficiency, this state is omitted.

Step 3. The optimum state with the minimum PWF is selected. The load points of sections of the selected state must belong to class D.

PWF for section j is determined using (6):

$$PWF_{ij} = \sum_{k=1}^{N} L_k c_k (r_i) \tag{6}$$

where, k and N are respectively load point and number of loads connected to section j. L_k is the peak load of load point k, and $c_k (r_i)$ is the per unit customer cost for duration r_i .

4. Case studies and results

Tow distribution test systems are used in this paper. An urban distribution system connected to bus 2 of the RBTS is shown in Fig. 2. Next, a rural /urban test system connected to bus 6 of the RBTS is shown in Fig. 3. The RBTS is a basic reliability test system which developed by the power system research group at the University of Saskatchewan [8]. First system consists of residential, small industrial, commercial and government customers and the second system consists of agricultural, residential, commercial and small industrial customers. The peak load of both systems is 20 MW. The basic reliability data for the test systems are presented in [8], [21].

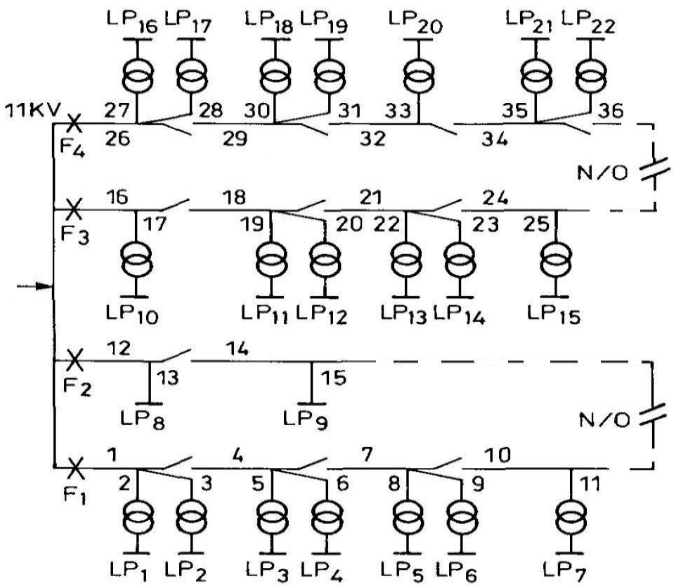

Fig. 2. Distribution system for RBTS-BUS2

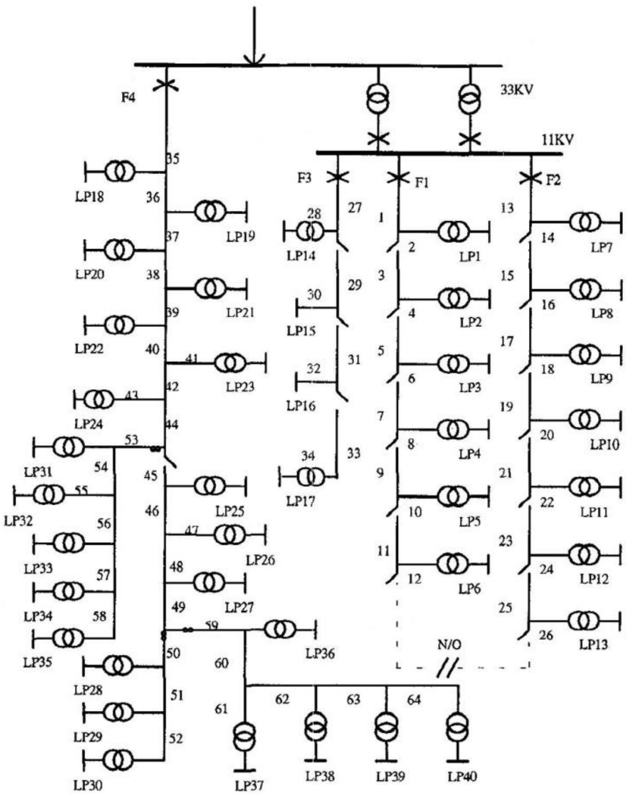

Fig. 3. Distribution system for RBTS-BUS6

4.1. Load point Reliability indices without MG

The proposed algorithm is used to evaluate the reliability of the two distribution systems while there are no MGs. The basic reliability indices of load points in the RBTS-BUS2 and BUS6 are shown in Tables 1 and 2, respectively. It is assumed that the impacts of all outages at each distribution system supply point have been ignored. Moreover, in distribution network of BUS6, sectionalizing switches are installed on lines 50, 53 and 59 instead of fuses. The results shown in Tables 1 and 2 have been verified and compared with those presented in [8], and [21].

Table 1.

Load point reliability indices for RBTS-BUS2

Load Point	$\lambda(f\ /yr)$	r(h)	$U(h/yr)$
1	0.2442	14.711	3.5933
2	0.2572	14.221	3.6583
3	0.2572	14.174	3.6463
4	0.2442	14.662	3.5813
5	0.2572	14.174	3.6463
6	0.254	14.291	3.63
7	0.2572	14.022	3.6073
8	0.1447	3.8739	0.5097
9	0.1447	3.5216	0.5097
10	0.2475	14.531	3.5965
11	0.2572	14.174	3.6463
12	0.2605	14.06	3.6625
13	0.2572	13.972	3.5943
14	0.2605	13.86	3.6105
15	0.2475	14.483	3.5854
16	0.2572	14.221	3.6583
17	0.2475	14.584	3.6095
18	0.2475	14.483	3.5854
19	0.2605	14.01	3.6495
20	0.2605	14.01	3.6495
21	0.2572	13.972	3.5943
22	0.2605	13.86	3.6105

Table 2.

Load point reliability indices for RBTS-BUS6

Load Point	$\lambda(f\ /yr)$	r(h)	$U(h/yr)$
1	0.3382	10.92	3.69
2	0.3513	10.54	3.72
3	0.348	10.70	3.72
4	0.3382	10.87	3.68
5	0.348	10.59	3.69

6	0.3382	10.9	3.69
7	0.3772	9.7	3.73
8	0.3805	9.91	3.77
9	0.3805	9.81	3.73
10	0.3675	9.98	3.67
11	0.3772	9.99	3.77
12	0.3675	10.1	3.70
13	0.3772	9.85	3.71
14	0.2505	14.4	3.6
15	0.2452	3.52	0.86
16	0.2485	4.17	1.03
17	0.2505	16.63	4.16
18	1.191	5.5	6.55
19	1.191	5.5	6.55
20	1.191	5.5	6.55
21	1.191	5.5	6.55
22	1.191	5.5	6.55
23	1.2186	5.56	6.78
24	1.2255	5.57	6.83
25	1.191	8.08	9.62
26	1.2186	8.07	9.84
27	1.191	8.07	9.62
28	1.582	8.06	12.75
29	1.582	8.06	12.75
30	1.582	8.06	12.75
31	1.8028	6.51	11.74
32	1.8396	6.38	11.74
33	1.8028	6.51	11.74
34	1.8028	6.51	11.74
35	1.8028	6.51	11.74
36	1.7844	8.2	14.64
37	1.8189	8.05	14.64
38	1.7844	8.2	14.64
39	1.7844	8.2	14.64
40	1.7844	8.2	14.64

4.2. Classification of load points

Classification of load points for failure branches of distribution systems is shown in Tables 3 and 4. For example, at load point 8 of the RBTS-BUS2 about 93.33% of system failures belongs to class A, and never belongs to classes C and E. This case can therefore be used to determine the suitable location of DGs and MGs. In other words, the load points which have high possibility to be in classes C and E are suitable load points that can be supplied by DGs and MGs. Moreover, it is not always feasible to transfer all disconnected loads of class C at a distribution network to the neighboring feeders through the normally open circuits. The problem can be overcome by installing DG on either the faulted feeder or the adjacent feeder and serve customers when a utility supply interruption occurs.

Table 3.

Classification of distribution system RBTS-BUS2

Load Point	A(%)	B(%)	C, E(%)	D(%)
2	88.33	5.00	0	6.66
4	88.33	3.33	3.33	5.00
6	88.33	1.67	5.00	5.00
8	93.33	1.67	0	5.00
10	88.33	5.00	0	6.66
12	88.33	3.33	3.33	5.00
14	88.33	1.67	5.00	5.00
16	88.33	5.00	0	6.66
18	88.33	3.33	3.33	5.00
20	88.33	1.67	5.00	5.00
22	88.33	0	6.66	5.00

Table 4.

Classification of distribution system RBTS-BUS6

Load Point	A(%)	B(%)	C, E(%)	D(%)
1	89.28	4.46	2.68	3.57
3	89.28	2.68	5.36	2.68
5	89.28	0.89	7.14	2.68
7	88.39	5.36	2.68	3.57
9	88.39	3.57	5.36	2.68
11	88.39	1.78	7.14	2.68
13	88.39	0	8.93	2.68
15	91.07	1.78	4.46	1.78
17	91.07	0	6.25	2.68
19	86.61	3.57	0.89	8.93
21	86.61	3.57	0.89	8.93
23	85.71	3.57	0.89	9.82
25	86.61	0	8.93	4.46
27	86.61	0	8.93	4.46
29	83.03	0	8.93	8.03
31	81.25	3.57	0.89	14.28
33	81.25	3.57	0.89	14.28
35	81.25	3.57	0.89	14.28
37	80.36	0	8.93	10.71
39	81.25	0	8.93	9.82

4.3. System reliability indices

If DG units of microgrids are coordinated properly, they can have a positive impact on distribution system reliability. A simple example is a back up generation, which starts up and serves customers when a utility supply interruption occurs. Online DG units can also reduce equipment loading and enable load transfers from adjacent feeders experiencing outages. In this section, the application of the proposed method to analyze the DG impact is investigated. The system reliability indices for typical distribution systems were computed for the different cases. In order to show the effectiveness of the proposed algorithm, the DGs location remained fixed while the capacity of DGs will be varied. DG capacity is determined considering the load of each feeder. Tables 5 and 6 illustrate the impacts of DG on reliability of typical systems.

Details of case studies:

1) First system

1- Without MG.

2- 4 MGs whose generation capacity is equal to 1MW are installed at the load points 7, 9 15 and 22.

3- Case 2, but capacity of generation of MGs is 3 MW.

4- Case 2, but MGs is equipped with uninterruptible power supply (UPS).

5- Case 3, but MGs is equipped with UPS.

2) Second system

1- Without MG.

2- 2 MGs whose generation capacity is equal to 1300 kW are installed at the load points 6 and 13; also, 2 DGs whose capacity is equal to 2300 kW and 3500 kW are installed at the load points 27 and 17 respectively.

3- Case 2, but capacity of generation of MGs is 2.3, 5.1 and 5 MW.

4- Case 2, but MGs is equipped with UPS.

5- Case 3, but MGs is equipped with UPS.

Comparing the results shown in Tables 5 and 6, it is clear that the reliability effect of DGs of microgrids in distribution system BUS6 is more than BUS2. It indicates that this effect differs from one system of another greatly. Besides, DGs along with UPS as back up units can improve indices that related to frequency of interruption.

Table 5.

System reliability indices for RBTS-BUS2

Case	SAIFI [int./cus.yr]	SAIDI [hr./cus.yr]	AENS [kWhr/cus.yr]	ASAI
1	0.3074	3.6761	18.2975	0.9996
2	0.3074	3.6761	18.2942	0.9996
3	0.3074	3.6741	18.285	0.9996
4	0.3065	3.6752	18.2124	0.9996
5	0.2569	3.6237	17.9725	0.9996

Table 6.

System reliability indices for RBTS-BUS6

Case	SAIFI [int./cus.yr]	SAIDI [hr./cus.yr]	AENS [kWhr/cus.yr]	ASAI
1	0.8318	6.1236	22.7144	0.9993
2	0.8318	5.4835	19.3133	0.9994
3	0.8318	5.4831	19.3115	0.9994
4	0.6911	5.2369	18.1022	0.9994
5	0.6732	5.2186	18.0192	0.9994

4.4. Impact of the unavailability of DGs

In this section, the unavailability of DGs is assumed between 0 to 10 percent and the variation of SAIDI, EENS, and ECOST depend on this index is shown in the Figs. 4-9 for RBTS-bus2 and bus 6 respectively. Impact of the unavailability of DGs in bus 6 is more than bus 2 because of the construction of bus 6.

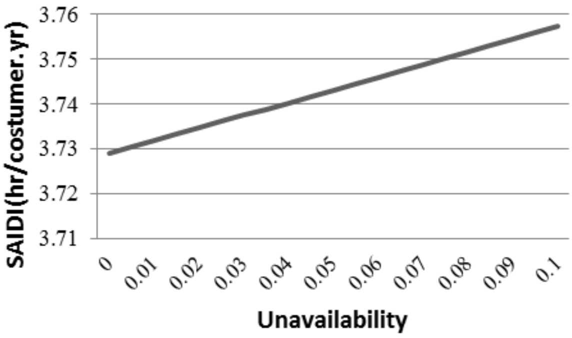

Fig. 4. SAIDI variation versus unavailability of DG for RBTS-BUS2

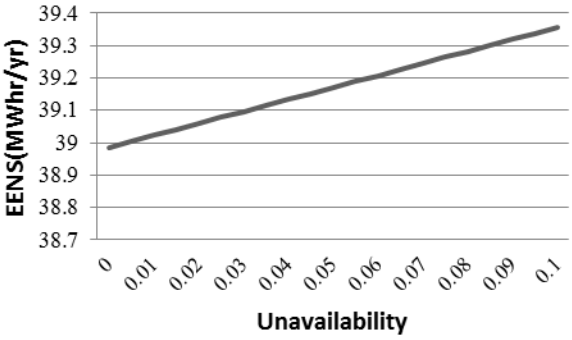

Fig. 5. EENS variation versus unavailability of DG for RBTS-BUS2

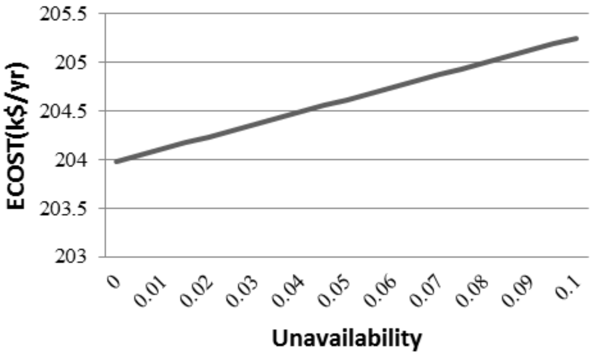

Fig. 6. ECOST variation versus unavailability of DG for RBTS-BUS2

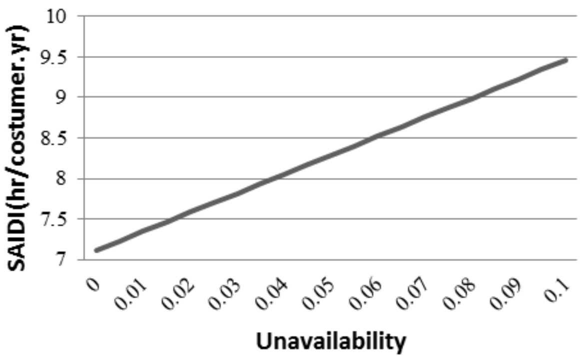

Fig. 7. SAIDI variation versus unavailability of DG for RBTS-BUS6

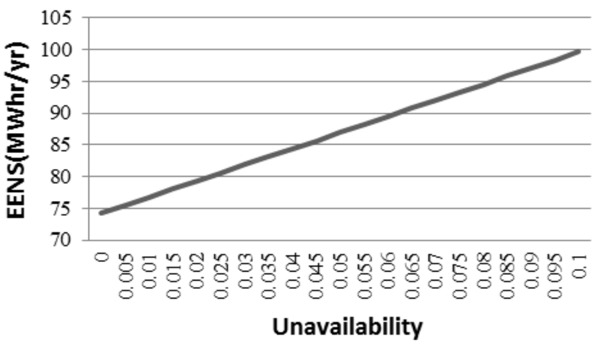

Fig. 8. EENS variation versus unavailability of DG for RBTS-BUS6

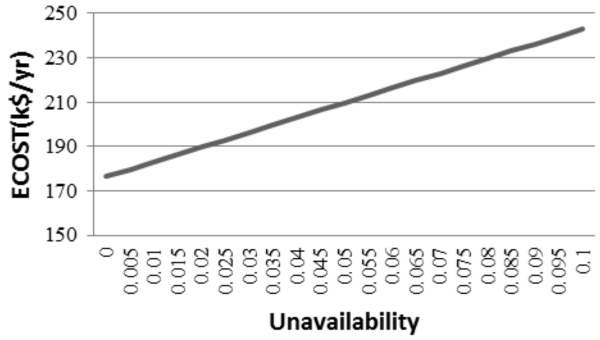

Fig. 9. ECOST variation versus unavailability of DG for RBTS-BUS6

5. Conclusions

An algorithm is proposed in this paper to investigate the MG impacts on radial distribution system reliability. The algorithm is efficient for large-scale radial distribution systems, and can accommodate the effects of fault isolation and load restoration. The classification of nodes of network is based on identification of sections which are controlled by protection devices. Therefore, the graph-based algorithm results from adjacency matrices based on protective devices. The validity and effectiveness of the proposed algorithm was demonstrated by applying a computer program to two RBTS test systems. The impacts of location and capacity of these generators and sectionalizing switches on reliability indices were determined. Suitable locations of MGs were determined using the proposed method. The presented results indicate that although system reliability indices of distribution network are improved in the presence of DGs, the topology of system and the type of customers can considerably contribute at this field.

R E F E R E N C E S

[1] *R. E. Brown, L. A. A. Freeman*, "Analyzing the Reliability Impact of Distributed Generation," IEEE Power Eng. Society Summer Meeting **vol**. 2, pp. 1013-1018, 2001.

[2] *I.S.Bae, J.O. Kim, J.C. Kim, C. Singh,* "Optimal Operating Strategy for Distributed Generation Considering Hourly Reliability Worth," IEEE Trans. Power Syst., **vol**. 19, No.1, pp. 287-292, February 2004.

[3] M. *Fotuhi, A. Rajabi*, "An analytical method to consider DG impacts on Distribution system reliability," IEEE Transm. and Distrib. Conf., pp. 1-6, 2005.

[4] *Manisa Pipattanasomporn, Michael Willingham, Saifur Rahman*, "Implications of on-Site Distributed Generation for Commercial/Industrial Facilities," IEEE Trans. Power Syst., **vol**. 20, No. 1, pp. 206-212, Feb. 2005.

[5] *G. Carpinelli, G Celli, F. Pilo, and A. Russo*, "Distributed generation siting and sizing under uncertainty," in Proc. IEEE Porto Power Tech. Conf., vol. 4, 2001.

[6] *R.C. Dugan and S. K. Price*, "Issues for distributed generation in the U.S.," in Proc. IEEE Power Engineering Society Winter Meeting, **vol**. 1, pp. 121-126, 2002.

[7] *R. Billinton, R.N. Allan*, "Probabilistic Assessment of Power Systems," in Proc. IEEE, vol. 88, No. 2, pp. 140- 162, Feb. 2000.

[8] *R.N. Allan, R. Billinton, I. Sjarief, L. Goel, K.S. So*, "A reliability test system for education purposes, basic distribution system data and results," IEEE Trans. Power Syst., **vol**. 6, No. 2, pp. 813-820, May 1991.

[9] *G. Kjolle, and K. sand*, "RELRAD–An analytical approach for distribution system reliability assessment," IEEE Trans. Power Delivery, **vol**. 7, pp. 806-814, Apr. 1992.

[10] R*.E. Brown, S. Gupta, R.D. Christie, S.S. Venkata, and R. Fletcher*, "Distribution system Reliability assessment using hierarchical Markov modeling," IEEE Trans. Power Delivery, **vol**. 11, pp. 1929-2934, Oct. 1996.

[11] *Z. Wang, F. Shokooh, and J. Qiu*, "an Efficient algorithm for assessing reliability Indices of general Distribution systems," IEEE Trans. Power Syst., **vol**. 17, No. 3, pp. 608-614, August 2002.

[12] I.*S.Bae, J.O. Kim*, "Reliability Evaluation of Customers in a Microgrid" IEEE Trans. Power Sys., **vol**. 23, No. 3, pp. 1416-1422, Aug. 2008.

[13] *M. E. Khodayar and M. Barati*, "Integration of high reliability distribution system in microgrid operation," IEEE Trans. Smart Grid, **vol**. 3, no. 4, pp. 1997–2006, Dec. 2012.

[14] *Z. Bie, P. Zhang, G. Li, B. Hua,M.Meehan, and X.Wang*, "Reliability evaluation of active distribution systems including microgrids," IEEE Trans. Power Syst., **vol**. 27, no. 4, pp. 2342–2350, Nov. 2012.

[15] *P. M. Costa and M. A. Matos*, "Assessing the contribution of microgrids to the reliability of distribution networks," Elect. Power Syst. Res., **vol**. 79, no. 2, pp. 382–389, 2009.

[16] *C.L.T. Borges and E. Cantarino*, "Microgrids Reliability Evaluation with Renewable Distributed Generation and Storage Systems," 18th IFAC World Congress (IFAC'11), Milano (Italy) Aug. 28 – Sep. 2, 2011.

[17] *S. Wang, Z. Li, L. Wu,M. Shahidehpour, and Z. Li*, "New metrics for assessing the reliability and economics of microgrids in distribution system," IEEE Trans. Power Syst., **vol**. 28, no. 3, pp. 2852–2861, Aug. 2013.

[18] *K. Xie, J. Zhou, and R. Billinton*, "Reliability evaluation algorithm for complex medium voltage electrical distribution networks based on the shortest path," IEE Proc.-Gener. Transm. Distrib., **vol**. 150, No. 6, pp. 686- 690, November 2003.

[19] *K. Xie, J. Zhou, R. Billinton*. "Fast Algorithm for The Reliability Evaluation of Large-scale Electrical Distribution Networks Using The Section Technique," IET Gen., Transm., Distrib., **vol**. 2, No. 5, pp. 701–707, Sep. 2008.

[20] *P. Wnag, R. Billinton*, "Optimum load-shedding technique to reduce the total customer interruption cost in a distribution system," IEE Proc.-Gener. Transm. Distrib., **vol**. 147, No. 1, pp. 51-56, Jan. 2000.

[21] *R. Billinton, S. Jonnavithula*, "A test System For Teaching Overall Power System reliability Assessment," IEEE Trans. Power Syst., **vol**. 11, No. 4, pp. 1670-1676, November 1996.