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Reliability Assessment of Distribution Systems in Presence of Microgrids Considering Uncertainty in Generation and Load Demand

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ABSTRACT
The microgrid concept provides attractive solutions for reliability enhancement of power distribution systems. Normally, microgrids contain renewable-energy-based Distributed Generation (DG) units, which their output power varies with different environmental conditions. In addition, load demand usually changes with factors such as hourly and seasonal customer activities. Hence, these issues have to be considered in evaluating the reliability of such a power distribution system. This paper evaluates the reliability performance of distribution systems with considering uncertainties in both generation and load demands. The results of applying the proposed approach on a case study system verify its advantages compared to the previous studies.

KEYWORDS: Distribution system, Distributed generation, Microgrids, Reliability assessment, Smart grid.

1. INTRODUCTION

Power system reliability is one of the most important aspects in the power system operation. The distribution system as the final stage in the delivery of electricity to the end users has an undeniable role in this regard. For improving the supply reliability in distribution systems, various techniques are proposed. Among these methods are tree trimming, installing animal guards, replacing overhead bare conductors by covered conductors or underground cables, advanced protection and automation schemes. Furthermore, microgrid concept contributes a significant role in the enhancement of the electricity service reliability.

Generally, microgrid refers to a small-scale power system that can operate independently (as a stand-alone) with respect to the bulk power system [1-4]. It can prepare useful ways to integration micro generation and DG to LV networks. They may operate in parallel with the bulk power system during normal operating conditions and transit to islanded operation during abnormal conditions [5-10].

The effect of microgrids on distribution system reliability have been analysed and reported in some researches. Considering the importance of reliability studies relatd to DGs in the conventional distribution systems, a reliability model for identifying the DG equivalence for use in distribution system planning studies has been presented in detail by Chowdhury *et. al* [11]. The model is extended based on the Distribution Reliability (DISREL) program in order to calculate: System Average Interruption Frequency Index (SAIFI); System Average Interruption Duration Index (SAIDI); Customer Average Interruption Frequency Index (CAIFI); Average Service Availability Index (ASAI); Average Service Unavailability Index (ASUI); Energy not supplied (END), and expected outage cost in dollars ($). All of the studies reported in this reference have been done by different sizes of DGs from 1 to 6 MW.

Katiraei *et. al* in [12] have stated that micro-grids have a noticeable effect on reliability indices in

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distribution systems, without any case-study-specific data.

Probabilistic reliability evaluation in electrical distribution systems considering Distributed Energy Resources (DERs) and microgrids is emphasized in [13]. The authors considered the detailed impact of intentional islanding of the DER units on the reliability as well as the impact of different switching devices using Monte Carlo Simulation (MCS). The main feature of the work is to verify the large influence of the circuit breakers on the reliability indices along with the reduction in interruption costs.

In [14], Costa *et. al* have proposed a comprehensive technique for distribution system reliability assessment in the presence of microgrids based on its ability to isolated operation in emergency states. Their main contribution is to reduce the interruption rate and duration of the system, and thus improving the reliability indices of the distribution network.

In [15] MCS is applied to assess the impact of the integrated DERs on the reliability indices of distribution systems. The proposed method in this reference assumes that the loads are fix and DG outputs have no changes under islanding situations. Furthermore, the intermittent feature of DGs is neglected.

The major drawback observed in the previously described methods is certainly in generations and load demands. Whereas the main characteristic of the complicated power system considering smart grids is, uncertain generation and load profiles. The main contribution of this work is extending the technique developed in [14] through considering the uncertainties involved in generation and load demand in the reliability evaluation procedure. Actually, these uncertainties can be represented by suitable probability distribution functions. In this paper, the normal distribution function is used for representing uncertainties involved in both power generated by renewable-based DG units and load demand within a microgrid. A new probability distribution function representing the margin between generated power and load demand in the procedure of reliability evaluation is deduced and manipulated. The case study results indicate that involving uncertainties in calculations has led to the change of reliability indices.

The remainder of this paper is organized as follows; Sec. 2 reviews the reliability evaluation based on fundamental presented in [14]. Sec. 3 presents the proposed technique in this work with all details. Case study results are shown in section 4, and finally section 5 lists the main conclusion of this work.

2. REVIEW OF RELIABILITY EVALUATION

The characteristics of the microgrids can improve the reliability indices of its consumers. Also, the reliability indices of some Low Voltage (LV) and Medium Voltage (MV) consumers, which don't belong to any microgrid, can be improved. This is due to ability of the microgrid to feed their consumers while a fault is occurred in the upstream section of the network. To evaluate the microgrids impacts on reliability, the frequency and duration technique are employed. The analyses are conducted in two sections: the microgrids impacts on LV networks reliability and their impacts on MV networks reliability.

2.1. Impacts on LV Network

A typical LV distribution network without any isolating device is shown in Fig. 1.

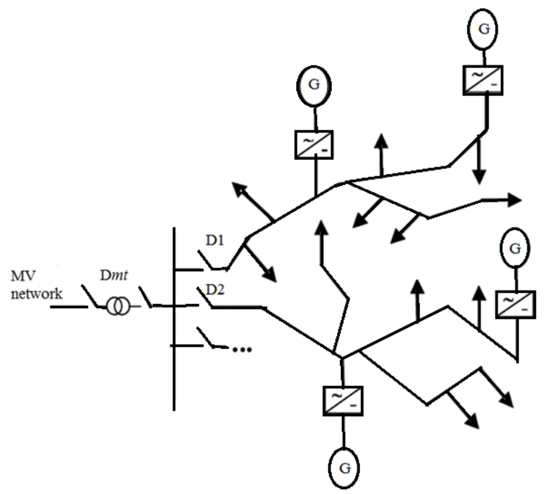

Fig.1. Sample LV network [8]

The failure rate (λ_c), unavailability (UC) and non-delivered energy (ENDC), for any consumer *C* connected to any feeder (*f*) of the LV network are given as follows:

$$\lambda_c = \sum_{i \in f} \lambda_i + \lambda_{up} \quad (1)$$

$$U_c = \sum_{i \in f} \lambda_i r_i + U_{up} \quad (2)$$

$$END_c = (\sum_{i \in f} \lambda_i + \lambda_{up}) L_c \quad (3)$$

where, λ_i and r_i are the failure rate and repair time of section i of feeder f; λ_{up} and U_{up} are the number of interruptions and the unavailability of the higher level system, and L_C is the load of C^{th} consumer.

It should be noted that all the failures that affect the consumers are considered in the above equations. The total END is also given by:

$$END = \sum_c ((\sum_{i \in f} \lambda_i + \lambda_{up}) L_c) \quad (4)$$

Afterwards, it is assumed that the LV network has some renewable energy resources that can operate as a microgrid. If the capacity of microgrid's generation is more than its consumption, the microgrid will not be affected by upstream network's faults and it can continue feeding its consumers. For the situation of presence of microgrids in network, the reliability indices will be as follow:

$$\lambda_c = \sum_{i \in f} \lambda_i \quad (5)$$

$$U_c = \sum_{i \in f} \lambda_i r_i \quad (6)$$

$$END_c = \sum_{i \in f} \lambda_i r_i L_c \quad (7)$$

For consumers in networks without any microgrid, the reliability indices will be the same as the previous formulas given by (1-3).

Now, it is important to mention that the isolation of the microgrid from the upstream network is completely probable in the fault times. However, we consider the probability of the error in isolation and show it with P_M. Also, it should be noted that the microgrid has not a considerable effect on the fault current while a fault occur in the MV network. Moreover, during a fault on upstream network, the microgrid may maintain the voltage and frequency in an acceptable range.

The scenario is completely different when a fault occurs inside the microgrid. In this case, all the microgrids may be forced to shut down instantly. This probability is also taken into account through the probability of shut-down as P_L. Including these parameters, the previous reliability indices will be:

$$\lambda_c = \sum_{i \in f} \lambda_i + \sum_{i \in \gamma} \lambda_i P_L + \lambda_{up} P_M \quad (8)$$

$$U_c = \sum_{i \in f} \lambda_i r_i + \sum_{i \in \gamma} \lambda_i P_L T_a + \lambda_{up} P_M T_a \quad (9)$$

$$END_c = (\sum_{i \in f} \lambda_i r_i + \sum_{i \in \gamma} \lambda_i P_L T_a + \lambda_{up} P_M T_a) L_c \quad (10)$$

where, γ is the set of feeders of the LV excluding the feeder f, and T_a is the average time to restore the microgrid.

The time required for the system to recovery (T_a) is defined only based on the synchronization and changes in the control mode of the inverters. This operation is made automatically by the central controller of the microgrid. Consequently, T_a does not depend on the location of the micro generators. If the rules are applied for any fault inside microgrid, it will result in shut-down which means P_L =1.

P_M represents probability of all of the factors that lead to the unsuccessful isolation processes. Therefore, this item must include the entire possible scenarios resulting in an unsuccessful islanding. The probability of such an occurrence depends on the several issues, such as the features of the controllers of the microgrid, the storage capacity of the microgrid, and the load shedding mechanism, which is used in the islanding procedure, and the load and generation levels while the isolation is occurred. The P_M value can be set based on the statistical studies. An adequate random number generator may sample load and generation quantities and the success data are used for probability calculation.

The ability of the capacity of resources locating in the microgrid and their ability to supply the loads has to be considered. If it is not possible to feed all of the loads, shedding some loads will be inevitable. Load shedding is carried out based on the interruption costs. It may be more reasonable to shed the loads that force lower costs to the system. Hence, the reliability indices for the shedloads will be as follow:

$$\lambda_c = \sum_{i \in f} \lambda_i + \sum_{i \in \gamma} \lambda_i P_L + \lambda_{up} \quad (11)$$

$$U_c = \sum_{i \in f} \lambda_i r_i + \sum_{i \in \gamma} \lambda_i P_L T_a + U_{up} \quad (12)$$

$$END_c = (\sum_{i \in f} \lambda_i r_i + \sum_{i \in \gamma} \lambda_i P_L T_a + U_{up}) L_c \quad (13)$$

It should be noted that in normal operation, the upstream network feeds the load that microgrid cannot feed them.

2.2. Impacts on MV network

Performance of LV networks including micro-grids has some effects on upstream MV network. As shown in Fig. 2, if a fault occurs on branch 14, the following scenario is carried out:

- F_2 trips to prevent the consequences of the fault.
- S_5 and S_6 will be opened to isolate the faulted zone from the other parts of the feeder.
- S_4 will be closed to supply the loads, and finally F_2 will be closed to restore the previous conditions.

In some cases, the reconfiguration may be impossible. Hence, the microgrid can improve the condition by feeding some of the loads inside and perhaps the loads out of the microgrid. The Generation-Load Level (GLR) ratio is a significant factor in this situation, which is defined as the ratio of the maximum value of the generation to the maximum value of the load. The GLR determines availability or unavailability of the generation within a microgrid for supplying its own loads and/or supplying the external loads in the power distribution network. The GLR of a microgrid can be smaller, greater or equal to one. It is smaller when a microgrid does not supply all the needs of the consumers inside it. Higher GLRs will result in better reconfiguration process. The reconfiguration will also be dependent on the positions of the microgrid and the fault. However, after clearing the fault the system will be recovered and resumed the feeding procedure.

Not that only the microgrids, located on the part of the feeder that will be supplied by an alternative feeder of the MV network, have the ability to influence the process of reconfiguration. These microgrids can help reducing the power that alternative feeder supplies. When they reconnect, the contribution to the reconfiguration process tends to be more significant for larger GLR values, because there is the possibility of increasing the microgrid generation. As a result, possible technical constraints can be surpassed more easily.

Also, a microgrid that is located on the alternative feeder can help the reconfiguration process. In this case, the GLR of the microgrid will be very significant. If the microgrid can feed more loads, lesser loads will remain to feed by the feeder and hence, the reconfiguration will be more probable. Therefore, it can be derived that these microgrids can improve the reliability indices of the MV parts can be enhanced significantly.

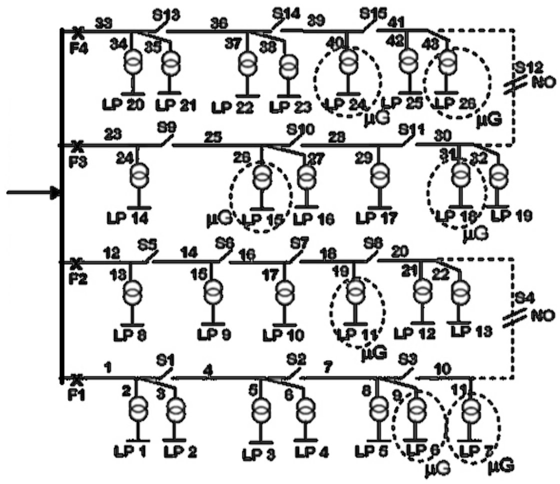

Fig. 2. Sample MV system [8].

3. PROPOSED TECHNIQUE

In evaluating the reliability performance of a power distribution system, containing microgrids renewable-based DG units, specific issues should be taken into account. Among them, this paper concentrates on uncertainty involved with the available generations and load demands. The main steps of the proposed method for evaluating the reliability performance of a sample power system are as follows:

1. Introducing uncertainty functions related to generation and loads. In this paper, this uncertainty function or probabilistic density function (pdf) is assumed to be normal distribution.

2. Finding the operational zone of microgrid by subtracting pdf of generation from that one the load.
3. Identifying different working area based on the related equations. In this paper, seven area have been included.
4. Calculating the failure rate, the unavailability and the energy not delivered to the consumer.

4. STUDY RESULTS

Figure 3 shows probability distribution functions for sample generation, load and the operational margin with in typical microgrid. The distribution mean is the forecast peak load in microgrids. The distribution can be divided intoa discrete number of class intervals.This is shown in Fig. 4, where the distribution is divided into seven steps. Such probability distribution functions have been used for modifying the reliability evaluation procedure proposed in [14]. The same reliability case studies as those mentioned in [14] have been directed with considering the uncertainties in generation and load demand as described above. These case studies are as follow:

- **Case 1**: Test system with microgrids and without reconfiguration
- **Case 2**: Test system with microgrids and having reconfiguration

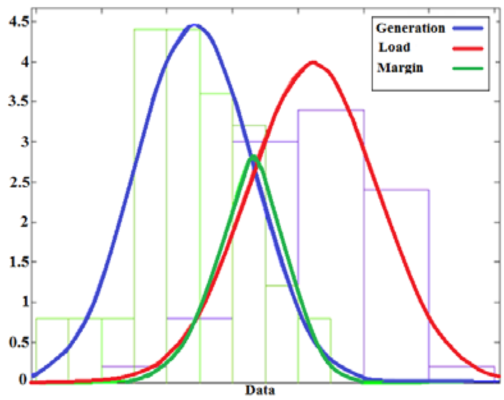

Fig. 3. Pdf for Generation, Load and Margin.

With considering normal distribution function for generation (G) and load (L), we can earn probability distribution function which represents the margin (M) between generated power and load. Since both functions are normal, we can use characterizes of normal function, thus:

$$G-L=M \Rightarrow \frac{G}{L}-1=\frac{M}{L} \Rightarrow GLR=1+\frac{M}{L} \qquad (14)$$

$$\mu_m=\mu_g-\mu_l \qquad (15)$$

$$\delta_m{}^2=\delta_g{}^2+\delta_l{}^2 \qquad (16)$$

where, μ and δ are the mean and the standard deviation of normal function, respectively.

The normal distribution of operational margin function from equations 14-16 is divided into seven parts. Failure rate (λ_c), unavailability (U_c) and Energy Not Delivered (*END*) for each costumer c have already been given in equation 1-13 from [14], but in modified method which is proposed in this paper, uncertainties in generation and load are exposed to calculation and therefore the mentioned equations can be replaced with equations as shown below:

$$\lambda_c=\sum_{i=1}^{7}(\lambda_i(mi)\times P_{mi} \qquad (17)$$

$$U_c=\sum_{i=1}^{7}(U_i(mi)\times P_{mi} \qquad (18)$$

$$END=(\sum_{i=1}^{7}(U_i(mi)\times P_{mi})\times L_c \qquad (19)$$

where, *mi* represents *i*th interval of pdf and P_{mi} is the corresponding probability.

It should be noted that for the non-microgrid areas, calculations are carried out based on formulas mentioned in [14]. In order to compare the proposed method with the previous one, load point 6 will be considered and reliability evaluation for different states are analyzed as follow:

1. For *GLR*=1 (*M*=0) and with generation and load parameters given in Table 1. from (14-16) we have:

   $\mu_m=\mu_g-\mu_l=0$ and $\delta_m\approx 0.1$

Table 1. Distribution function data for *GLR*=1.

$\mu_l=500$ kW	$\mu_g=500$ kW
$\delta_l=0.07$	$\delta_m\simeq 0.1$
$\delta_g=0.07$	$\mu_m=\mu_g-\mu_l=0$

δ can change and take different values, thus, for this case, normal distribution of margin will be as shown in Fig. 4. It is assumed that when

M =0, there is no storage in microgrids and all microgrid generation's will be consumed by its domestic costumers. In $M \geq 0$ area (green section), generation is more than load demand, and storage systems in microgrids are assumed to be 0.1. Finally, $M \langle 0$ (red area) represents shedding some of loads of microgrid. As we discussed above the safe or supported area (parts) are those parts that's their M value is greater than or equal to zero (green area) and the parts that their load has to be shed are the parts that their M value is less than zero (red area).

As a result, for this case reliability indices are easily calculated as shown in this example. Using formulas (17-19) and after weighting employing the above figure, calculations are as follows:

$$\lambda_6 = (0.125\times0.006)+(0.125\times0.061)+ (0.125\times0.242)+(0.125\times0.382)+(0.167\times0.242) +(0.188\times0.061)+(0.209\times0.006) = 0.14$$

$$U_6 = (0.742\times0.006)+(0.742\times0.061)+ (0.742\times0.242)+(0.742\times0.382)+(2.18\times0.242) +(2.899\times0.061)+(3.62\times0.006) = 1.24$$

Thus, for all system load points calculation are done and result presented here.

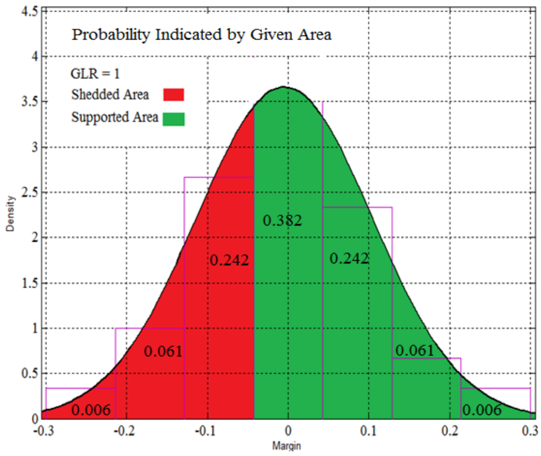

Fig.4. Pdf for *GLR*=1.

2. For GLR= 0.8 and load parameters given in Table 2 it can be pointed out that: $\mu_m = -0.2\mu_l$ and $\delta_m \approx 0.1$

In this case, as shown in Fig. 5 generation level is less than load demand and load in the majority area of the microgrids will be sheded; therefore, reliability indices will be worse than the previous state as presented in Tables 3-4.

Table 2. Distribution function for *GLR*=0.8.

$\mu_l = 500KW$	$\mu_g = 400KW$
$\delta_l = 0.07$	$\delta_m \simeq 0.1$
$\delta_g = 0.07$	$\mu_m = -0.2\mu l$

3. A critical case: *GLR* =0.6. As it can be seen in Fig. 6 all parts cannot be supported by microgrid. Therefore, all microgrid's loads will be sheded and they can be supplied from MV feeders.

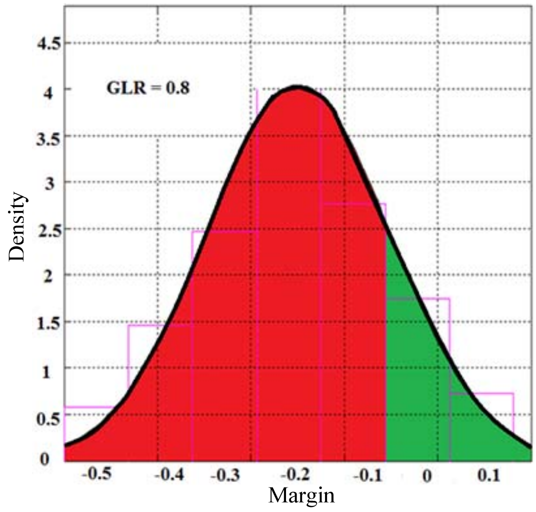

Fig. 5. Pdf for *GLR* = 0.8.

4. GLR> 1. When *GLR*>1, for example *GLR*=1.2, microgrid has better performance on reliability improvement and can exchange energy with external power distribution network. Related calculations are presented in Tables 5, 6 and normal distribution function is shown in Fig. 7.

To measure the system performance, some reliability indices which, are described in introduction of the paper are used as follows.

A: SAIDI (h/yr-customer);
B: CAIDI (h/int-custmer);
C: SAIFI (int./yr-customer);
D : ASAI: Average Service Availability Index;
E : END (kWh/yr);

The above-mentioned indices are used by utilities to measure their present performance against history and to compare their performance to other utilities. In some states, the public utility commissions are mandating reliability standards based on the indices and attaching revenue incentives to performance. Tables 3-5 compare the results directed on a typical test system, using the method proposed in [14] and this work based on considering the effect of uncertainties in generation and load demand. Actually, results show the integrated affect of various GLR values, which have been weighted by their probabilities. It is clarified that considering generation and demand uncertainties in GLR, resulted in modifying the method stated in [14].

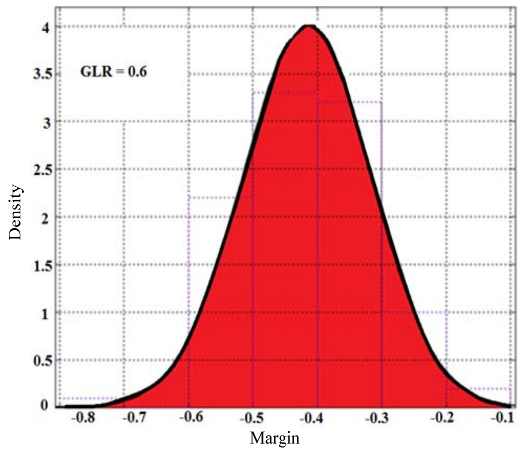

Fig. 6. Pdf for *GLR* = 0.6.

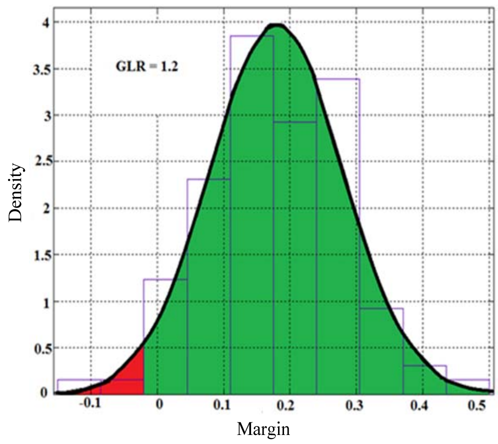

Fig.7. pdf for *GLR* = 1.2.

Table 3. Reliability indices for *GLR*=1 based on method proposed in[8]and this work.

Indices	Case 1		Case 2	
	This Work	Ref. [8]	This Work	Ref. [8]
SAIFI	0.2616	0.2639	0.2620	0.2639
SAIDI	4.0980	4.1732	4.0140	2.7916
CAIDI	15.6400	15.8113	15.3200	10.5770
ASAI	0.9995	0.9995	0.9996	0.9996
END	66896	71879.5	65977	44331.1

Table 4. Reliability indices for *GLR*=0.8 based on method proposed in [8] and this work.

Indices	Case 1		Case 2	
	This Work	Ref. [8]	This Work	Ref. [8]
SAIFI	0.2757	0.2765	0.2760	0.2765
SAIDI	4.5717	4.5902	4.2000	2.9647
CAIDI	16.5650	16.5987	15.2170	10.7208
ASAI	0.9995	0.9995	0.9997	0.9997
END	71747	76176	67841	45990

Table 5. Reliability indices for *GLR* = 1.2 based on method proposed in [8] and this work.

Indices	Case 1		Case 2	
	This Work	Ref. [8]	This Work	Ref. [8]
SAIFI	0.2570	0.2576	0.2570	0.2576
SAIDI	3.9570	3.9647	3.9560	2.7051
CAIDI	15.3970	15.3888	15.3900	10.4998
ASAI	0.9995	0.9995	0.9997	0.9996
END	65436	69731	65421	43502

5. CONCLUSIONS

As expected, the ability of microgrids in improving the reliability of power distribution networks is much depending on the ratio of their generation and load demand. The power produced by renewable-based microgrids normally depends on the environmental condition. In addition, the load demand also changes with factors such as hourly and seasonal customer activities. Consequently, some uncertainties always exist in generation and load demand that should be taken into account in reliability analysis. This paper has proposed a probabilistic based approach for modeling uncertainty issues. The results of applied method have been compared with one which probabilistic nature of the GLR has not been taken into account. The results indicate that performance of microgrids, are affected by the uncertainty nature of generation and load. In other words, uncertainties in load demand is an important factor for reliability analyses. As a result, this provides much more accurate estimation of reliability indices in LV networks containing microgrids.

REFERENCES

[1] A. Vaccaro, M. Popov, D. Villacci, and V. Terzija, "An integration framework for smart microgrids modeling, monitoring, control, communication, and verification," *Proceedings of the IEEE Conference*, vol. 99, pp. 119-132,

2011.

[2] B. Kroposki, R. Lasseter, T. Ise, S. Papatlianassiou, and N. Hatzziargyrio, "Making microgrids work," *IEEE Power and Energy Magazine*, vol. 6, no. 6, pp. 40-53, 2008.

[3] N. Hatzziargyrio, H. Asano, R. Iravani, and C. Marnay, "microgrids," *IEEE Power and Energy Magazine*., vol. 5, no. 4, pp. 78-94, 2007.

[4] H. Nikkhajoe and R.H. Lasseter, "Distributed Generation interface to the CERTS microgrids," *IEEE Transactions on Power Delivery*, vol. 24, no. 3, pp. 1598- 1608, 2009.

[5] L. Weixing, W. Peng, L. Zhimin, and L. Yingchun, "Reliability evaluation of complex radial distribution systems considering restoration sequence and network constraints," *IEEE Transactions on Power Delivery*, vol. 19, no. 2, pp. 753-758, 2004.

[6] D. Herman, "Investigation of the technical and economic feasibility of microgrid based power systems," *EPRI Technical Report* No. 1003973, California, Dec. 2001.

[7] M. Yiming, and N.M. Karen, "Switch placement to improve system reliability for radial distribution systems with distributed generation," *IEEE Transactions on Power Systems*, vol. 18, pp. 1346-1352, Nov. 2003.

[8] P. P. Barker, and R. W. De Mello, "Determining the impact of distributed generation on power systems- I. radial distribution systems," *Proceedings of the IEEE Summer Meeting*, vol. 3, pp. 1645-1656, 2000.

[9] J.-H. Teng, T.-S. Luor, and Y-H. Liu, "Strategic distributed generator placement for service reliability improvements," *Proceedings of the IEEE Summer Meeting,* Vol. 3, pp. 719-724, 2000.

[10] W. Peng, and R. Billinton, "Reliability benefit analysis of adding WTG to a distribution system*," IEEE Transactions on Energy Conversion*, vol. 16, pp. 134-139, 2001.

[11] A.A. Chowdhury, S.K. Agarwal, and D.O. Koval. "Reliability modeling of distributed generation in conventional distribution systems planning and analysis," *IEEE Transactions on Industry Applications,* vol. 39, no. 5,pp. 1493-1498, 2003.

[12] F. Katiraei, R. Hatziargyriou and A.N. Dimeas, "Microgrids management," *IEEE Power and Energy Magazine,* vol. 6, no. 3, pp.54-65, 2008.

[13] Y. Sun, M.H.J. Bollen, and G.W. Ault, "Probabilistic reliability evaluation for distribution systems with DER and microgrids," *Proceedings of the International Conference on Probabilistic Methods Applied to Power Systems,* pp. 1-8, 2006.

[14] P. M. Costa, M.A. Matos, "Assessing the Contribution of microgrids to the reliability of distribution networks," *Electric Power Systems Research*, vol. 79, no. 2, pp. 382-389, 2009.

[15] A. M. Leite da Silva, L.C. Nascimento, M. Augusto da Rosa, D. Issicaba and J.A. Peças Lopes, "Distributed energy resources impact on distribution system reliability under load transfer restrictions" *IEEE Transactions on Smart Grid*, vol. 3, no. 4, pp.2048-2055, 2012.