Reliability Evaluation of Distribution System Considering Distributed Generation

Raju Kaduru, Narsaiah Srinivas Gondlala

***Abstract*—**This paper presents an analytical approach for evaluating distribution system reliability indices in the presence of distributed generation. Modeling distributed generation and evaluation of distribution system reliability indices using the frequency duration technique. Using model implements and case studies are discussed. Results showed that location of DG and its effect in distribution reliability indices. In this respect, impact of DG on distribution system is investigated using the IEEE Roy Billinton test system (RBTS2) included feeder 1. Therefore, it will help to the distribution system planners in the DG resource placement.

***Keywords*—**Distributed Generation, DG Location, Distribution System, Reliability Indices.

I. Introduction

DISTRIBUTED GENERATION can be defined as a small-scale generating unit, typically less than 10 MW, which is located at the substation, distribution feeder or customer load points. Appearance of DG in the customer side; it will have a great impact on distribution system reliability [1]. The paper presented an improvement of reliability is calculated by reliability indices includes SAIFI, SAIDI, CAIDI, ASAI, and ASUI. The distribution system is the part of a power system. The power systems 80% outages are due to faults in the distribution systems. The paper contained DG applications, methodologies for assessing the distribution system reliability indices and also focuses on low voltage distribution networks [2]. The paper showed reliability modeling techniques for DG on distributed systems and develops methods to analyze them using predictive reliability assessment tools [3]. The paper addressed to implement a complete economic modeling and using optimization methods such as a genetic algorithm for problem-solving in large-scale distribution system [4].

The paper also discussed the analysis show that the reliability indices are highly sensitive to with respect of DGs. The authors presented the optimization process can be solved by the combination of genetic algorithm techniques with methods to evaluate impacts of DG in distribution system reliability, losses and voltage profile [5]. The author studied an analytical technique is used to study the DG impact on the distribution system reliability [6]. In addition to impacts of different parameters such as component failure rates, load, DG location and DG generation parameters are considered in the analysis. The authors showed an appropriate tool for reliability assessment in both the operation and planning of distribution system connected with distributed generations [7]. The paper described the reliability of the distribution system by connecting DGs is calculated using a Monte Carlo method and covered with forward a new method for failure state assessment on distribution system based on minimal path including zone wise concepts [8]. The paper presented the impact of DG in the distribution system operating characteristics, such as voltage profile, electric losses, voltage stability, DG definition, current status of DG technologies, potential advantages and disadvantages for optimal placement of DG systems [9]. The authors presented the integration of renewable energy based on distributed generation (DG) units provides for potential benefits to conventional distribution systems and also the location of DG units should be carefully determined by the consideration of different planning incentives [10]. Several researches have been conducted on distribution network with distributed generation. However, as customers are needed to lower expenses and higher reliability. Therefore, distribution system reliability evaluation is one of the issues in the power system networks. So it is required for modeling of DG and location effects on distribution system reliability. This paper, an analytical approach based on the mathematical model applying frequency and duration technique is proposed for evaluating reliability indices, including SAIFI, SAIDI, CAIDI, ASAI, and ASUI by adding of distributed generation. The proposed method is applied to test system, which is seven sections, seven load points with single DG [11], [12]. In addition to, a test system can be conducted in seven cases with respect to DG location at every load point. And also, identify the best location of DG on the distribution system. The results indicate that how the effect of DG on distribution system reliability. It will help to supply is given to the load during the contingencies appeared on the distribution systems and planning of the distribution network. The rest of the paper is arranged as follows: next section broadly discusses the distribution system reliability indices in section II. The proposed method is investigated in sections III. The method is then applied to a sample distribution system in section IV. The result shows the application of the proposed approach to consider DG and compared with no DG on a distribution feeder in section V. Conclude the paper in section VI.

II. Distribution System Reliability Indices

In this section, a reliability evaluation technique is applied to the distribution system. A sample distribution test system is

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as shown in Fig. 1.

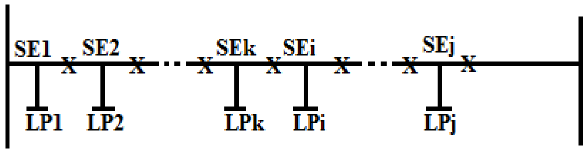

Fig. 1 Sample Distribution System

Reliability indices are classified into two types, firstly, load based reliability secondly, and customer based reliability indices. Load point reliability indices can be calculated using minimal cut set technique. Three basic reliability parameters of average failure rate, λ_s, average outage time, r_s, and average annual outage time, U_s, are given by

$$\lambda_s = \sum_{i=1}^{N} \lambda_i \text{ f/yr} \quad (1)$$

$$U_s = \sum_{i=1}^{N} \lambda_i r_i \text{ hrs /yr} \quad (2)$$

$$r_s = \frac{U_s}{\lambda_s} \text{ hrs} \quad (3)$$

where λ_i is the failure rate of component i and r_i is the repair time of component i.

System Average Interruption Frequency Index (SAIFI):

$$\text{SAIFI} = \frac{\text{total number of customer interruptions}}{\text{total number of customer served}}$$

$$\text{SAIFI} = \frac{\Sigma\lambda_i N_i}{\Sigma N_i} \text{ (int./yr. cust)} \quad (4)$$

where λi is the failure rate and Ni is the number of customers at load point i.

System Average Interruption Duration Index (SAIDI):

$$\text{SAIDI} = \frac{\text{sum of customer interruption duration}}{\text{total number of customer}}$$

$$\text{SAIDI} = \frac{\Sigma U_i N_i}{\Sigma N_i} \text{ (hr./yr. cust.)} \quad (5)$$

where Ui is the annual outage time and Ni is the number of customers at load point i.

Customer Average Interruption Duration Index (CAIDI):

$$\text{CAIDI} = \frac{\text{sum of customer interruption durations}}{\text{total number of customer interruption}}$$

$$\text{CAIDI} = \frac{\Sigma U_i N_i}{\Sigma \lambda_i N_i} \quad (6)$$

where λi is the failure rate, Ui is the annual outage time and Ni is the number of Customers at load point i.

Average Service Availability (Unavailable) Index ASAI

$$\text{ASAI} = \frac{\text{customer hours of available service}}{\text{Customer hours demanded}}$$

$$\text{ASAI} = \frac{\Sigma N_i (8760) - \Sigma U_i N_i}{\Sigma N_i} \quad (7)$$

Average Service Unavailability Index ASUI

$$\text{ASUI} = \frac{\text{customer hours of unavailable services}}{\text{Customer hours demanded}}$$

$$\text{ASUI} = 1\text{-ASAI} \quad (8)$$

where 8760 is the number of hours in a calendar year

III. Evaluation Technique and Modeling of DG

Consider a single line diagram of a sample distribution system is as shown in Fig. 2. There are some difficulties for reliability evaluation of distribution system consisting of distribution transformer and junctions on a feeder. According to Fig. 3 all parts of the feeder, which is located between two adjacent breakers, is considered as a section. Both breakers will be operated if any fault occurrence of a section with respect to protection system. The failed part of the feeder should be modeled by both a line and a centralized load point. In order to evaluate the reliability of the distribution system, a typical feeder is as shown in Fig. 3

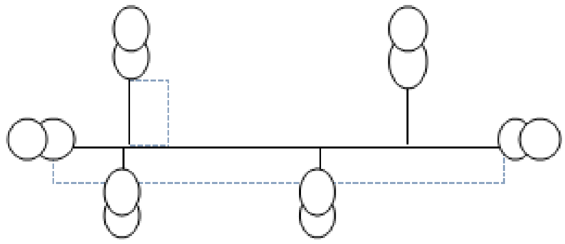

Fig. 2 Schematic of a Distribution Feeder

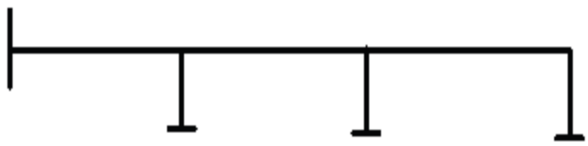

Fig. 3 Simplified feeders

In generally assumed that there are two different types of installation DGs from the placement point of view. Firstly, DG is considering locating in the middle of the feeder, whereas the other installed at the end of the feeder section. Secondly, both types of DG are installed in the middle of the feeder. In this connection, both types of installation of DGs would be separately evaluated. DGs models are based on the differentiating conventional DGs (coal, gas, diesel) and intermittent energy (wind). The feeder section ended with circuit breakers. This is used to suggest a framework for the assessment of the reliability impact of DG on the distribution system as shown in Fig. 4. The model should consider intrinsic attributes of DG and the way it applied in the distribution system. It can be assumed that all failures are active. Therefore, any faults happened in the section, respected circuit breakers at its ends should be opened.

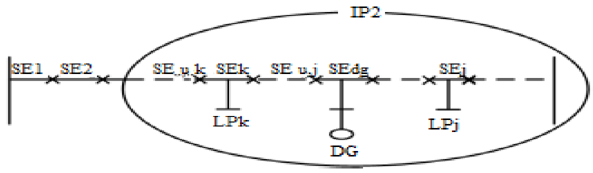

Fig. 4 Simple distribution system with DG

The following assumptions are required to evaluate the proposed method

1. Electrical power available at all load points/ DG acts as a sole reliable criterion.
2. The DG can continue in the island operation if the DG output generation is more than the load demand.
3. DG can supply to the feeder in the contingency mode unless the contingency appeared on the DG section.
4. All load points are taken to be same load duration patterns and feeder load is considered for uniformly distributed along the feeder. It can be energized to all load points and IP2 is one for all possible islands if the DG is modeled as distribution substation. During the islanding operation, the load network considered to be Meshed network it can be applied to the reliability evaluation of the distribution system. Load point failure rate and repair time can be calculated as

$$\lambda_{IS,K} = \sum_{j=1}^{ND}\sum_{i=1}^{NU}\lambda_{UK,i}\,\lambda_{DK,j}(r_{UK,i} + r_{DK,j}) \qquad (9)$$

$$U_{IS,K} = \sum_{j=1}^{ND}\sum_{i=1}^{NU}\lambda_{UK,i}\,\lambda_{DK,j}r_{UK,i}\;r_{DK,j} \qquad (10)$$

where $\lambda_{UK,i}$ is the failure rate and $r_{UK,i}$ is the repair time of section SE $_i$ on the upper stream of both DG and load point LP_k. $\lambda_{DK,j}$ is the failure rate and $r_{DK,j}$ is the repair time of section SE_i on the downstream of both DG and load point LP_k NU is the number of upper side sections. ND is the sections including the DG section. Suppose a fault occurs in the section between the DG and the load, this effect of such section should be added to (9) and (10), the results are shown in (11) and (12)

$$\lambda^*_{IS,K} = \begin{cases} \lambda_{IS,k} + \lambda_k & \text{USL} \\ \lambda_{IS,k} + \lambda_k + \sum_{i=1}^{ND}\lambda_{DK,i} & \text{DSL} \end{cases} \qquad (11)$$

$$U^*_{IS,k} = \begin{cases} U_{IS,k} + U_k & \text{USL} \\ U_{IS,k} + U_k + \sum_{i=1}^{ND}\lambda_{DK,i} & \text{DSL} \end{cases} \qquad (12)$$

$$r^*_{IS,k} = \frac{U^*_{IS,k}}{\lambda^*_{IS,k}} \qquad (13)$$

where * represents the modified index

In case of islanding operation, the failure rate is decreasing, where the DG is applied. The concept of islanding probability is given the load point has a dominant effect of reduction in its failure rate and outage time. For the different issues with respect to DG must be considered for the calculation of islanding probability. In Both cases, DG acts substation and a central station. Therefore, islanding probability and resource limitations are ignored.

IV. Case Study

In this paper, the proposed method, to investigate the impact of distributed generation on distribution system reliability indices. In this section, distribution test system is taken from a Roy Billiton Test System, in [13] as shown in Fig. 5

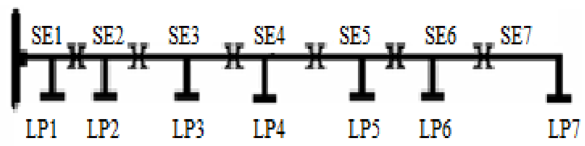

Fig. 5 Sample distribution system

A distribution test system has 7 sections, 7 load point and a DG. Seven cases have been analyzed for the analysis of the location of DG on the test feeder. Reliability test system data given in Table I. Consider the failure rate of each section is proportional to the section length. There are different DG models are: firstly, DG, as distribution substation, secondly, DG, as central station and finally DG resources.

In this case study, DG acts as distribution substation, we mean that DG can alternatively supply to the load without capacity limitation. In the case of a DG conventional station, produces its nominal capacity, i.e. 2 MW for all time. The DG acts as DG resource, we can include the DG generation and load demanded. Islanding probability can be neglected where the DG considers as distribution substation and DG acts as a conventional station. Whereas DG acts as resource behavior, islanding probability is taken into the account. The peak load of the feeder rating is 4 MW. The DG rating is 2MW. The reliability of the distribution test system is performed first without the DG and with DG on the test feeder starting from LP7 to LP2.

Tables II and III show failure rate and unavailability of DG at different locations on distribution test system. In these tables, the second column indicates that the reliability indices without DG installation. The result of the proposed method is shown from the second column in the last column. According to Tables II and III, results shown that the load point reliability indices by changing in DG location on distribution test system. By Comparing the failure rate and unavailability with respect to with DG and without DG installation.

TABLE I
FEEDER DATA

SE	Length (KM)	Failure rate (f/yr)	Repair Time(hr)	Number of Customer
SE1	1	0.0650	5	210
SE2	2	0.1300	5	210
SE3	3	0.1950	5	210
SE4	1	0.0650	5	1
SE5	0.5	0.0325	5	1
SE6	1	0.0650	5	10
SE7	0.5	0.0650	5	10

V. DISCUSSION OF RESULTS

TABLE II
FAILURE RATE OF DG AT DIFFERENT LOCATION

	NO DG	DG at 7	DG at 6	DG at 5	DG at 4	DG at 3	DG at 2
LP1	0.06500	0.06500	0.06500	0.06500	0.06500	0.06500	0.06500
LP2	0.19500	0.13002	0.13002	0.13002	0.13001	0.13000	0.13000
LP3	0.39000	0.19502	0.19501	0.19500	0.19501	0.19500	0.32500
LP4	0.48500	0.06501	0.06502	0.06501	0.06500	0.26000	0.19501
LP5	0.48750	0.03251	0.03253	0.03250	0.09750	0.22751	0.16251
LP6	0.55250	0.06501	0.06500	0.09750	0.13001	0.26000	0.19502
LP7	0.58500	0.03250	0.09750	0.06500	0.09751	0.22751	0.16252

TABLE III
UNAVAILABILITY OF DG AT DIFFERENT LOCATIONS

LP	NO DG	DG at 7	DG at 6	DG at 5	DG at 4	DG at 3	DG at 2
LP1	5	5	5	5	5	5	5
LP2	10	5	5	5	5	5	5
LP3	15	5	5	5	5	5	10
LP4	20	5	5	5	5	10	10
LP5	25	5	5	5	10	10	10
LP6	30	5	5	10	10	10	10
LP7	35	5	10	10	10	10	10

TABLE IV
RESULTS OF SAIFI

S. No	SAIFI (int. /yr. Cus.)
Case1	0.22825
Case2	0.12726
Case3	0.12876
Case4	0.12826
Case5	0.12935
Case6	0.133838
Case7	0.173018

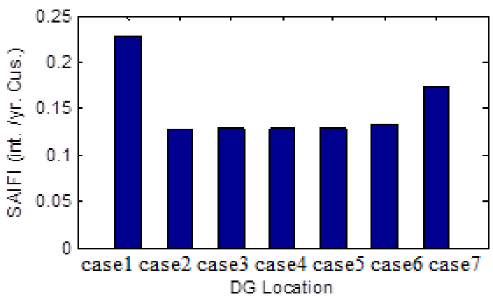

Fig. 6 SAIFI for all cases

Fig. 6 showed the calculated value of SAIFI for all cases. It can be observed that expect case 1 and case 7, the remains cases slightly changes in system reliability with the DG location.

TABLE V
RESULTS FOR SAIDI

S. No	SAIDI(hr/sys. inst)
Case1	10.72
Case2	5.0004
Case3	5.0269
Case4	5.1534
Case5	5.1610
Case6	5.1687
Case7	6.7791

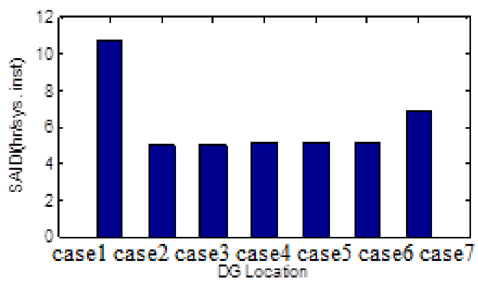

Fig. 7 SAIDI for all cases

Fig. 7 indicates that results for SAIDI, for each case. It is clear that SAIDI value is the lowest for Case-2 where DG is located at LP7, which is the farthest load point from the 11 KV supply bus. DG is moved from LP7 to LP2, the value of SAIDI increases. For case-7 is higher SAIDI, the reason being DG is near to the supply point.

TABLE VI
RESULTS FOR CAIDI

S. No	CAIDI(hr/cust.int)
Case1	43.81
Case2	39.28
Case3	39.57
Case4	40.17
Case5	39.89
Case6	38.61
Case7	39.06

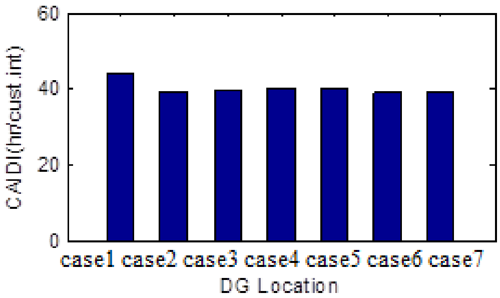

Fig. 8 CAIDI for all cases

Fig. 8 represented the results for CAIDI for each case. The value of CAIDI varies slightly change with DG location as compared with the base case-1.

TABLE VII
RESULTS FOR ASAI

S. No	ASAI
Case1	0.999877
Case2	0.999429
Case3	0.9994820
Case4	0.999411
Case5	0.999410
Case6	0.999409
Case7	0.999226

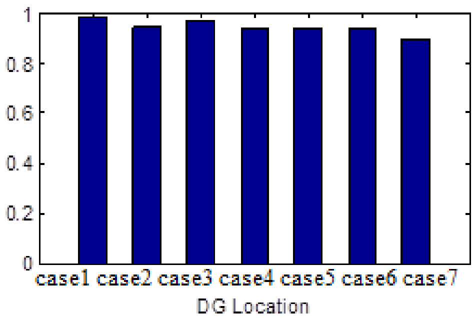

Fig. 9 ASAI for all cases

Fig. 9 showed ASAI in all cases. The value of ASAI for the case 1 is increased. With the effect of DG on the distribution system, the value of ASAI is decreased from case-2 to case- 7.

TABLE VIII
RESULTS FOR ASUI

S. No	ASUI
Case1	0.000123
Case2	0.000571
Case3	0.000518
Case4	0.000589
Case5	0.00059
Case6	0.000591
Case7	0.000774

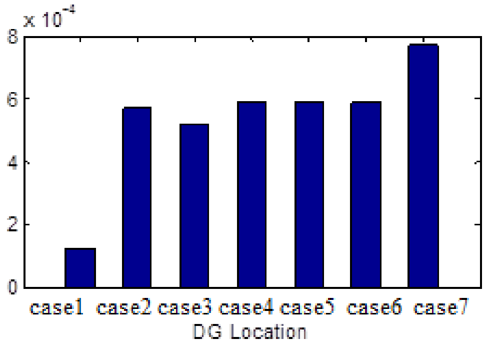

Fig. 10 ASUI for all cases

Fig. 10 indicates that calculate the value of ASUI for all the cases. The value of ASUI is lowest at the case-1 as compared to the all other cases. Case 7 to give higher value, where the DG is connected to the load point 2.

The results are shown in Figs. 6-10. These figures are indicating that the load point indices and system indices (SAIFI, SAIDI, CAIDI, ASAI, and ASUI) of the test system for different DG locations on a distribution feeder. Seven cases are investigated on distribution test system; (1) without DG, (2) DG at load point 7, (3) DG at load point 6, (4) DG at load point 5, (5) DG at load point 4, (6) DG at load point 3, and (7) DG at load point 2. In addition to SAIDI and ASAI are taken to be a measure of the reliability of the test system. Fig. 7 shows that the lowest value of SAIDI in the case-2 over all cases. This is the best location of DG. We can see that Fig. 9 shows the case-1 have the highest ASAI value as compared with the other cases. When the DG is moved towards the feeder, except for case-7 the ASAI is increased, where the DG is located at LP2.

VI. CONCLUSION

In this paper, case study observed that the proposed method evaluates reliability indices of the distribution system with the connection of DG at different load points. The results obtained from the analytical method gives how reliability indices are improved based on DG location on the distribution test system. Therefore, an impact of DG on reliability is negligible, when the DG is placed near to the substation. The results showed the DG modeling is one of the factors in the distribution system reliability analysis. In addition to the results show that case-2 is the best location of DG in the distribution feeder.

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