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Improvement in the reliability performance of power distribution systems

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Reliability assessment is of primary importance in designing and planning distribution systems that operate in an economical manner with minimal interruption of customer loads. Distributed Generation (DG) is expected to play an increasing role in emerging power systems because they use different type of resources and technologies to serve energy to power systems. DG is expected to improve the system reliability as its backup generation. Since DG units are subject to failures like all other generation units, the random behavior of these units must be taken into account in the analysis. Existence of DG units in a distribution system will effect on restoration time of load points. The algorithm for restoration time assessment of load point is developed when DG unit is installed. In this paper, the reliability performance of distribution system is analyzed in terms of SAIFI, SAIDI, CAIDI, ASAI, ASUI, ENS and AENS. The algorithm to calculate the reliability indices for simple 9-bus radial distribution feeder with and without DG is developed. The improvement in the reliability of the feeder is studied for different locations of DG with respect to fault point. All the above analysis is carried out by developing MATLAB software.

Keywords: *SAIFI, SAIDI, CAIDI, ASAI, ASUI, ENS and AEN.*

1.0 INTRODUCTION

Distributed Generation (DG) is normally defined as small generation units (<10 MW) installed in distribution systems. The applications of DG include combined heat and power, standby power, peak saving, grid support, and stand-alone power. The DG technologies include photovoltaic, wind turbines, fuel cells, small and micro-sized turbine packages, internal combustion engine generators, and reciprocating engine generators etc. Distributed power generation technology in a short period of time to gradually restore the importance of local power grid load, improve the reliability of an important user.

System reliability plays an important role in distribution systems since it has been reported that more than 80% of all customer interruptions occurred due to failures in the distribution systems [1]. Several studies have been illustrated the impacts of the installing DG units on distribution systems reliability [2, 3].

The methods for evaluating distribution system reliability could be categorized into two groups: analytical methods and simulation methods. In analytical methods, the system is presented in a mathematical model and reliability indices are evaluated from this model [4-7]. In simulation methods, the actual processes and system behaviors are simulated for estimating the reliability indices [8, 9]. In distribution systems, DG units could be considered as backup generators [4, 5]. The authors in [4] suggested that system reliability indices depended on locations of DG units, the

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number of DG units at each location and the availability of DG units. In [5], the authors showed the reliability impact of installing a large-scale DG vs. installing several small-scale DG units. Moreover, they calculated the system reliability of placing DG unit at various distances from the substation, where the best location for the DG placement, in terms of reliability improvement, was at the end of line.

In [6, 11], the authors presented an analytical method to calculate the system reliability indices with several DG units. The authors showed that system reliability depended on location of DG unit and DG capacity. In addition, DG should be installed at the end of feeder and the DG small size capacity should be installed at the upstream side of the DG with large capacity. In [7], the authors presented an interval algorithm to deal with the uncertainty of component data to calculate the system reliability indices. The authors showed comparison of the system reliability indices when DG unit connected in difference locations on distribution system.

In [8], the authors presented the Depth-First Search algorithm to divide distribution system into several smallest units and used the Monte Carlo simulation method to simulate the running status of distribution system with DG unit. The authors compared the reliability indices of the original system to those of the system with additional DG unit. In [9], the authors presented a method that combined the load duration curve with the characteristics of DG operation mode in order to evaluate the reliability. The authors showed the error of reliability indices based on the Monte Carlo simulation method.

In this paper, the analytical method based on [10] is used to evaluate reliability indices, including SAIFI, SAIDI, CAIDI, ENS and AENS in a radial distribution system, with and without DG installation. Restoration time assessment of each load point is presented when DG unit is installed along the distribution feeder. The DG is assumed to be operating as backup unit for the system. The test system can be studied in two different cases based on different customer scattering patterns. In each customer scattering pattern, the reliability indices are evaluated on the system without DG unit, and with DG unit being installed at various locations along the feeder.

2.0 DEFINITIONS

For the purpose of this study, the distribution system is classified into three parts: Sections, Lateral Distributors; and Load Points as shown in Figure 1 [10].

Restoration time is the time for load re-service after protection device operates to clear a fault. However, restoration time of each load point depends on location of DG and fault location.

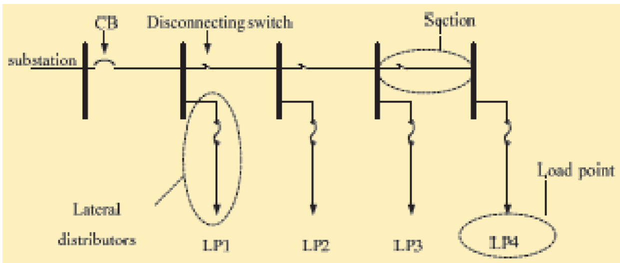

FIG. 1 DEFINITIONS OF SECTIONS, LATERALS AND LOAD POINTS

2.1 Reliability Indices

Reliability indices reflect the reliability level of the power system. In this study, distribution system reliability is classified into three types: load point indices, customer oriented indices and energy oriented indices [10].

A. Load Point Indices

Load point indices are used to measure the reliability of each load point in the system. These indices include average failure rate (λs), average outage time (rs), and average annual outage time (Us), at any load point ‘s’. For the calculation of these indices, failure rate (λi) and repair time (ri) of each component in the system are required. Load point indices calculation is shown in Eqns. (2.1-2.3).

$$\lambda S = \sum_i \lambda i \text{ (failures/year)} \qquad \text{....(1)}$$

$$US = \sum_i \lambda i\ ri \text{ (hours/year)} \quad ....(2)$$

$$rS = US / \lambda S \text{ (hours/interruption)} \quad ....(3)$$

B. Customer Oriented Indices

Customer oriented indices are used to measure the reliability of the system. These indices are SAIFI, SAIDI and CAIDI. For the calculation of these indices, average failure rate, average annual outage time and customer information are required.

SAIFI (System Average Interruption Frequency Index) is the average value of interruption frequency in the system that effects customers during the year, which can be computed as:

$$\text{SAIFI} = \frac{\text{Total no.of customer interruptions}}{\text{Total no.of customers served}}$$

$$\text{SAIFI} = \frac{\sum_s \lambda s Ns}{\sum_s Ns} \text{ (interruptions/customer yr)} \quad ....(4)$$

SAIDI (System Average Interruption Duration Index) is the average value of outage duration time in the system that effects customers during the year, which can be computed as:

$$\text{SAIDI} = \frac{\text{Total no.of customer interruption} * \text{no.of customers}}{\text{Total no.of customers}}$$

$$\text{SAIDI} = \frac{\sum_s UsNs}{\sum_s Ns} \text{ (hours/customer year)} \quad ....(5)$$

CAIDI (Customer Average Interruption Duration Index) is the average value of outage duration time in the system that effects customers per interruption, which can be computed as:

$$\text{CAIDI} = \frac{\text{Total no.of customer interruption Duration}}{\text{Total no.of customer interruption}}$$

$$\text{CAIDI} = \frac{\sum_s Us\,Ns}{\sum_s \lambda s\,Ns} = \frac{SAIDI}{SAIFI} \quad ....(6)$$

C. Energy Oriented Indices

Energy oriented indices are used to measure the reliability of the system. In this study, these indices include ENS and AENS. For the calculation of these indices, average annual outage time, customer and load information are required.

ENS (Energy Not Supplied index) is total energy not supplied by the system during the year.

$$\text{ENS} = \sum_s Ls\,Us \text{ (kWh/year)} \quad ....(7)$$

AENS (Average Energy Not Supplied index) is the average value of energy not supplied by the system that effects customers during the year.

$$\text{AENS} = \frac{\sum_s UsLs}{\sum_s Ns} \text{ (kWh/customer year)} \quad ....(8)$$

3.0 RELIABILITY EVALUATION TECHNIQUE

In this paper, evaluation of reliability indices of distribution system with one DG installed at any load point along the feeder line by considering the two patterns of customers scattering is studied. Total number of customers and the average number of customers of all load points are considered as identical. In this paper, reliability assessment also considers restoration time calculation for each load point with additional DG, which depends on DG location and fault location. When a fault occurs in any section of the distribution feeder as shown in Figure 1, the main circuit breaker is automatically opened and steps of the restoration process is as follows:

Step 1: Find the location of the fault;

Step 2: If the fault occurs on the upstream side of DG, find the numbers and locations of load points to be served by backup DG;

Step 3: Clear the fault from the system by the isolated switches (upstream and downstream of the fault);

Step 4: Operate the isolated switches in order to eliminate the other load points that DG can't serve;

Step 5: Start up the DG unit to serve load points found in Step 2;

Step 6: Close the main circuit breaker.

The restoration time of the above process is given by:

$$\textbf{RTLP}=\begin{cases} FLT+SWT\ , & if LPL < FL \\ FLT+SWT+DG\_SUT\ , & if LPL *< FL \\ FLT+SWT+RPT\ , & otherwise \end{cases} \quad \text{....(9)}$$

Where,

RTLP --> is the repair time of a load point,

FLT --> is the average fault location time,

SWT --> is the average switching time,

DG_SUT --> is the DG unit start up time,

RPT --> is the average repair time,

LPL --> is the load point location,

LPL* --> is the load point location restored by DG,

FL --> is the fault location.

La --> number of laterals

The proposed algorithm for reliability assessment can be described as follows and the flowchart is shown in Figure 2:

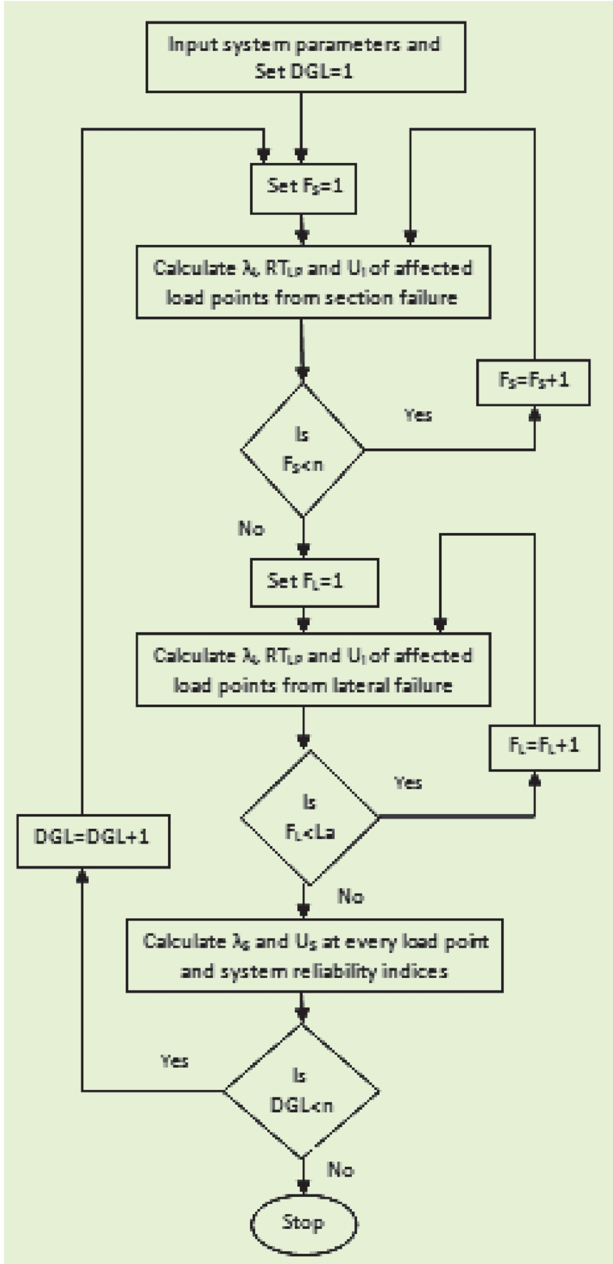

FIG. 2 FLOWCHART FOR RELIABILITY ASSESSMENT

4.0 CASE STUDY

The configuration of the distribution system used to illustrate the proposed technique for reliability assessment is shown in Figure 3. The length of this main feeder and each lateral distributor are 45 km and 10 km, respectively. The system has 9 load points which are distributed evenly along the length of the feeder. The total number of customers for this system is 603 with the total load of 1,800 kW.

For the analysis, operating conditions of the components and their parameters are assumed as follows:

- A single DG unit is installed as backup generator, where its operational availability is 100%.
- Circuit breaker, disconnecting switches and fuses has the operational availability of 100%.
- The failure rate of each section is 0.1f/km-yr and that of each lateral distributor is 0.2f/km-yr.
- The average repair time of each section is 2 hours, and that of each lateral distributor is 4 hours.
- The average switching time, average fault location time and DG unit start up time are 0.25, 0.5 and 0.0333 hours, respectively.

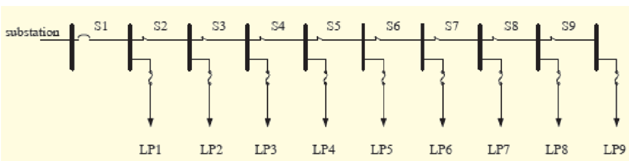

FIG. 3 TEST SYSTEM

In Table 1, the number of customers at each load point for two cases are shown.

TABLE 1

NUMBER OF CUSTOMERS IN TWO CASES

Load Point (LP)	1	2	3	4	5	6	7	8	9
Case-i	67	67	67	67	67	67	67	67	67
Case-ii	100	120	100	85	70	57	36	20	15

5.0 RESULTS AND ANALYSIS

The proposed algorithm is applied to the test system with and without additional DG for different customer scattering patterns. The results of reliability indices are shown and discussed below.

5.1 SAIFI

The values of system SAIFI calculated for different locations of an additional DG and without DG and for different customer scattering cases are shown in Table 2.

TABLE 2

SAIFI, SAIDI AND CAIDI

DG location	SAIFI		SAIDI		CAIDI	
Case	I	II	I	II	I	II
No DG	40.7	40.8	67.4	55.9	1.65	1.37
Sect. 1	40.7	40.8	67.4	55.9	1.65	1.37
Sect. 2	40.7	40.8	59.5	48.5	1.46	1.19
Sect. 3	40.7	40.8	52.6	42.9	1.29	1.05
Sect. 4	40.7	40.8	46.7	38.8	1.15	0.95
Sect. 5	40.7	40.8	41.8	35.9	1.03	0.88
Sect. 6	40.7	40.8	37.9	34.1	0.93	0.83
Sect. 7	40.7	40.8	34.9	32.9	0.86	0.81
Sect. 8	40.7	40.8	32.9	32.4	0.81	0.79
Sect. 9	40.7	40.8	32.1	32.2	0.78	0.78

From Table 2, it is concluded that values of SAIFI are 40.72 and 40.83 int. /cust. yr. for case-i and case-ii, respectively for all the DG locations.

5.2 SAIFI

The values of system SAIDI calculated for different locations of an additional DG and without DG and for different customer scattering cases are shown in Table 2.

From Table 2, with different customer scattering and DG locations, it is concluded that SAIDI decreases when the DG location is far from substation.

5.3 SAIFI

The values of system CAIDI calculated for different locations of an additional DG and without DG and for different customer scattering cases are shown in Table 2.

From Table 2, with different customer scattering and DG locations, it is concluded that CAIDI decreases when the DG location is far from substation.

5.4 ASAI

The values of ASAI calculated for different locations of an additional DG and without DG and for different customer scattering cases are shown in Table 3.

From Table 3, with different customer scattering and DG locations, it is concluded that ASAI increases when the DG location is far from substation.

5.5 ASUI

The values of ASUI calculated for different locations of an additional DG and without DG and for different customer scattering cases are shown in Table 3.

From Table 3, with different customer scattering and DG locations, it is concluded that ASUI increases when the DG location is far from substation.

TABLE 3

ASAI AND ASUI

DG location	**ASAI**		**ASUI**	
Case	I	II	I	II
No DG	0.9923	0.9936	0.0077	0.0064
Sect. 1	0.9923	0.9936	0.0077	0.0064
Sect. 2	0.9932	0.9945	0.0068	0.0055
Sect. 3	0.9940	0.9951	0.0060	0.0049
Sect. 4	0.9947	0.9956	0.0053	0.0044
Sect. 5	0.9952	0.9959	0.0048	0.0041
Sect. 6	0.9957	0.9961	0.0043	0.0039
Sect. 7	0.9960	0.9962	0.0040	0.0038
Sect. 8	0.9962	0.9963	0.0038	0.0037
Sect. 9	0.9963	0.9963	0.0037	0.0037

5.6 ENS

The values of ENS calculated for different locations of an additional DG and without DG and for different customer scattering cases are shown in Table 4.

From Table 4, it is concluded that the ENS values are the same for every case of customer scattering and for different DG locations.

5.7 AENS

The values of AENS calculated for different locations of an additional DG and without DG and for different customer scattering cases are shown in Table 4.

From Table 4, it is concluded that the AENS values are the same for every case of customer scattering and for different DG locations.

TABLE 4

ENS AND AENS

DG location	**ENS**	**AENS**
No DG	121345	201.2
Sect. 1	121345	201.2
Sect. 2	107180	177.7
Sect. 3	94790	157.2
Sect. 4	84170	139.6
Sect. 5	75320	124.9
Sect. 6	68240	113.2
Sect. 7	62930	104.4
Sect. 8	59390	98.5
Sect. 9	57620	95.6

6.0 CONCLUSIONS

In this paper, the improvement in the reliability performance of power distribution system by considering restoration time assessment and the impact of customer scattering on distribution system reliability when DG unit is installed at various locations is proposed. The system reliability indices evaluated by the proposed algorithm included SAIFI, SAIDI, CAIDI, ASAI, ASUI, ENS and AENS for 2 cases of customer scattering and 9 possible locations for DG. The results showed the optimal location of DG unit for each pattern of customer scattering in terms of reliability assessment.

For all patterns of customer scattering, SAIFI is constant because restoration time assessment do not affect the interruption frequency of the distribution system. The best DG locations for SAIDI and CAIDI maximum improvement varied with the patterns of customer scattering. The ENS and AENS depended only on the locations of DG and not on the patterns of customer scattering. Their best values are at the last section of the system feeder. This study can be used to identify the optimal location of DG used as backup generator in a distribution system in order to improve reliability indices based on customer scattering.

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