# An analytical approach for optimal integration of Distributed Generation for Reliability Assessment

[1]Dr. H.R. Sudarshana Reddy, [2]Dr. Sanjeeva Kumar R A,
[1]Professor, [2]Assistant Professor,
[1,2] Department of Electrical and Electronics,
[1]University BDTCE, Davangere, India, [2]PDACE kalaburagi, India.

***Abstract : The electrical distribution networks are affected by disturbances and failures due to environmental as well as human issues. The invention of Distributed Generation (DG) will enhance the reliability of the system by improving the energy supplied. This is advantageous to the services where the interruption in energy is unacceptable, like in health and industrial sectors. The improvement in the reliability can be measured in terms of the reliability indices. This paper presents the analysis of the system cases by calculation of the reliability indices by providing the comparison of the system performance before and after the installation of the DG. The analysis is carried out under matlab platform on standard 10 bus radial distribution system.***

***IndexTerms* - *Distributed Generation, Reliability indices, system performance .***

## I. Introduction

There are two aspects of reliability in the power system namely the system adequacy and the system security. The aspect of the system adequacy is focused in this paper. The reliability evaluation of the power system is divided into three zones of functionality namely generation, transmission and distribution. Whose hierarchical levels are given by HL-I, HL-II, and HL-III. All the three zones are included in the reliability analysis of the HL-III making it the most complex of all. Hence, the distribution zone is analyzed separately. It aims at obtaining the suitable reliability indices at the customer load point.

The electrical distribution network posses the maximum contribution to unavailability of supply in the whole series of the electrical network operation[1-2]. The improvement of the management and planning of the distribution network can improve the quality of the service. The assessment and optimization of the reliability are the main parts of the studies related to the distribution network [3-4]. Many types of analytical and simulation techniques have been designed and proposed by the researchers for the evaluation of reliability in the systems [4-5].

The capability to deliver the power uninterrupted is called as the reliability. The power distribution network as the continuity in the service is an important factor of consideration. This can be defined by series of system indices and three basic load point indices. The average failure rate (‘λ’), average outage time (‘r’) and average annual unavailability or average annual outage time (‘U’) are the three basic load point data. This data can be used to analyze the performance of the considered system.

## II. Problem Formulation

The optimal DG integration in this paper concentrates on the improvement of Reliability indices, Reduction of active power losses and Reduction of voltage deviation.

The main objective is to improve the system reliability by optimal integration of DGs under certain conditions. In literature the reliability analysis is carried out based on the basic and standard performance indices, such as system average interruption duration index (SAIDI), system average interruption frequency index (SAIFI) and energy not supply index (AENS) in order to improve the system performance to improve the reliability of the power system. In this proposed work logarithmic voltage deviation (LVDI) and system average voltage interruption index is considered for optimal placement of DG in the distribution system for different cases as mentioned below.

The following basic equations are used for the calculation of load point reliability indices

$$\lambda L = \sum_{i=0}^{n} \lambda i \quad \ldots\ldots (2.1)$$

$$rL = \frac{\sum_{i=0}^{n} \lambda i * ri}{\sum_{i=0}^{n} \lambda i} \quad \ldots\ldots (2.2)$$

$$UL = \lambda L * rL \quad \ldots\ldots (2.3)$$

Where

i= feeder sections connecting the load points to the supply.

$\lambda_l$ = Average failure rate at load point L

$r_L$ = Average outage time at load point L

$U_L$= Average annual unavailability or average annual outage time at load point L

*2.1 System Average Duration Index (SAIDI)*

The average time of customers interrupted information can found by SAIDI

$$SAIDI = \frac{\sum_{i=0}^{n} Ui * Ni}{\sum_{i=0}^{n} Ni} \quad \ldots\ldots (2.4)$$

*2.2 System Average Interruption Frequency Index(SAIFI)*

It is the average number of interruptions per customer per unit time also defined as the ratio of a total number of interruptions to the total number of customers served.

$$SAIFI = \frac{\sum_{i=0}^{n} \lambda i * Ni}{\sum_{i=0}^{n} Ni} \quad \ldots\ldots (2.5)$$

*2.3 Average Service Unavailability Index (ASUI)*

It is the ratio of service availability of a total number of customer hours during a year to the customer hour demanded.

$$ASAI = \frac{\sum_{i=0}^{n} Ni * 8760 - \sum_{i=0}^{n} Ui * Ni}{\sum_{i=0}^{n} Ni * 8760} \quad \ldots\ldots (2.6)$$

Where

Ni = number of customers at load point I, i=1, 2, 3, , , , , n

$\lambda i$ = failure rate at load point I, i=1,2,3,,,,, n

Ui = $\lambda$*r, where r is the outage time and 8760 is the number of hours in calendar year.

*2.4 System Average Interruption Voltage Index (SAIVI)*

$$SAIVI = \frac{Total\ number\ of\ customers\ affected\ by\ voltage\ sag\ at\ their\ load\ points}{\text{Total number of customers served}}$$

## III. OPTIMAL LOCATION AND SIZE

*3.1 To find the optimal location of DG*

The best location of DG is chosen based on the multi-objective function which gives the least Blended Index, Three different cases to improve the reliability indices are considered as follows

*Weighted sum of multi objective function (wmofi) for Optimal DG Placement for Reduction of Voltage deviation, Power loss, and Improvement of SAIVII*

$$BI = w1 * LVDI + w2 * PLRI + w3 * SAIVII \qquad (3.1)$$

**Where,**

$$LVDI = \text{Log10} * \frac{V_{DG}}{V_{\text{Base}}} \qquad (3.2)$$

$$PLRI = \frac{P_{\text{loss Base}} - P_{loss\ DG}}{P_{\text{loss Base}}} \qquad (3.3)$$

$$SAIVII = \frac{\text{SAIVI}_{\text{Base}} - SAIVI_{DG}}{\text{SAIVI}_{\text{Base}}} \qquad (3.4)$$

LVDI= Logarithmic Voltage Deviation Index,

Voltage Base = Base Case Voltage in Volts

Voltage Dg= Voltage after Installation of DG in Volts,

PLRI = Real Power Loss Reduction Index

$P_{loss}$ Base = Base Case Active Power Losses in KW,

$P_{loss}$ DG = Active Power Losses with DG in KW

SAIVI= System Average Interruption Voltage index,

SAIVII= System Average Interruption Voltage improvement index,

BI= Blended Index.

*3.2 To find the optimal size of DG*

The penetration level of DG is chosen based on the following equation.

$$PLDG\% = \frac{Size\ of\ DG}{Total\ demand} * 100 \qquad (3.5)$$

Where,
PLDG = penetration level of DG

*3.3 Procedure for DG integration*

Step 1: Read the data of the test system.

Step 2: Calculate the actual size of DG for a particular penetration level using eq 11.

Step 3: Select and Compute the weighted sum of multi-objective function index (WMOFI) by penetrating DG at all buses of the test system and rank the indices on all buses.

Step 4: Select the bus with least value of WMOFI which is considered as the optimal location of DG.

Step 5: The above steps are repeated for another penetration level of DG with relevant WMOFI.

## IV. RESULTS AND DISCUSSION

The analysis is carried out on 10 Bus radial feeder as shown in fig 4.1. having 10 laterals which feed the load. The total active power load on the feeder is 47.5 MW. The active failure rate of the 11 kV lines is taken as 0.0065f/yr-km, switching and repair time are assumed to be 1 and 5 hours respectively. Load, number of customers and length of respective laterals are shown in table 4.1.

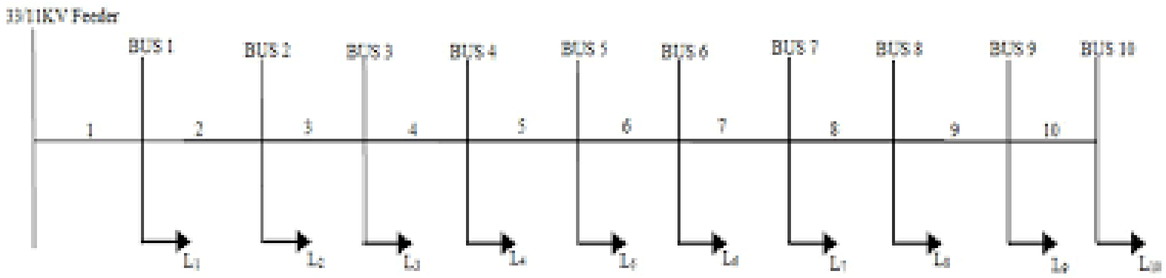


**Fig.4.1. Standard 10 Bus RDS for Reliability studies**

**Table 4.1 Load and customers and length of respective laterals**

| Laterals/section | Load(MW) | NO. of Customers | Length (kms) |
|---|---|---|---|
| 1 | 3 | 50 | 1.0 |
| 2 | 4.5 | 70 | 0.85 |
| 3 | 6 | 100 | 0.8 |
| 4 | 5 | 80 | 0.75 |
| 5 | 2 | 30 | 0.65 |
| 6 | 5.5 | 70 | 0.65 |
| 7 | 6 | 100 | 0.80 |
| 8 | 3 | 50 | 1.0 |
| 9 | 4.5 | 70 | 1.0 |
| 10 | 8 | 100 | 0.75 |

**Table 4.2 Values of Reliability indices at 50% DG Penetration for Standard 10 BUS RDS**

| Load Point | At 50% DG Penetration | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | LOSS | PLRI | LVDRI | SAVI | SAIFI | SAIDI | ASAI | BIA |
| 1 | | | | | | | | |
| 2 | 0.513 | 0.3667 | 0.000769 | 0.527 | 1.38 | 3.75 | 0.9995 | 0.171428 |
| 3 | 0.417 | 0.4852 | 0.001142 | 0.472 | 1.43 | 3.53 | 0.9996 | 0.211729 |
| 4 | 0.389 | 0.5198 | 0.004984 | 0.467 | 1.41 | 3.53 | 0.9996 | 0.224581 |
| 5 | 0.498 | 0.3852 | 0.008407 | 0.499 | 1.53 | 3.39 | 0.9996 | 0.165423 |
| 6 | 0.319 | 0.6062 | 0.018139 | 0.444 | 1.55 | 3.42 | 0.9996 | 0.450923 |
| 7 | 0.45 | 0.4444 | 0.022505 | 0.437 | 1.51 | 3.33 | 0.9996 | 0.243879 |
| 8 | 0.378 | 0.4099 | 0.056283 | 0.513 | 1.32 | 3.57 | 0.9995 | 0.160723 |
| 9 | 0.256 | 0.684 | 0.054659 | 0.459 | 1.47 | 3.65 | 0.9999 | 0.29707 |
| 10 | 0.356 | 0.5605 | 0.057149 | 0.431 | 1.41 | 3.71 | 0.9996 | 0.280176 |

**Table 4.3 Values of Reliability indices at 75% DG Penetration for Standard 10 BUS RDS**

| Load Point | At 75% DG Penetration | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | LOSS | PLRI | LVDRI | SAVI | SAIFI | SAIDI | ASAI | BI |
| 1 | | | | | | | | |
| 2 | 0.499 | 0.38398 | 0.00112 | 0.498 | 1.33 | 3.31 | 0.9995 | 0.26478 |
| 3 | 0.399 | 0.50742 | 0.0021 | 0.451 | 1.39 | 3.49 | 0.9996 | 0.23797 |
| 4 | 0.371 | 0.54202 | 0.00682 | 0.431 | 1.37 | 3.47 | 0.9997 | 0.26642 |
| 5 | 0.367 | 0.42347 | 0.06053 | 0.473 | 1.49 | 3.29 | 0.9999 | 0.20025 |
| 6 | 0.299 | 0.63089 | 0.02107 | 0.411 | 1.51 | 3.39 | 0.9996 | 0.47681 |
| 7 | 0.413 | 0.49008 | 0.02581 | 0.401 | 1.49 | 3.25 | 0.09998 | 0.29071 |
| 8 | 0.318 | 0.48397 | 0.0357 | 0.477 | 1.29 | 3.21 | 0.9995 | 0.21325 |
| 9 | 0.212 | 0.73831 | 0.05821 | 0.419 | 1.43 | 3.23 | 0.9999 | 0.34792 |
| 10 | 0.311 | 0.61605 | 0.06084 | 0.411 | 1.37 | 3.12 | 0.9996 | 0.3126 |

Table 2 and 3 shows the values of different reliability indices and corresponding power losses, power loss reduction index and algorithmic voltage deviation index values at all the load points for 50% and 75% of DG penetration respectively. Values of Blended index (BI)at all the load points are shown from which the optimal location of DG will be decided at the minimum value bus.

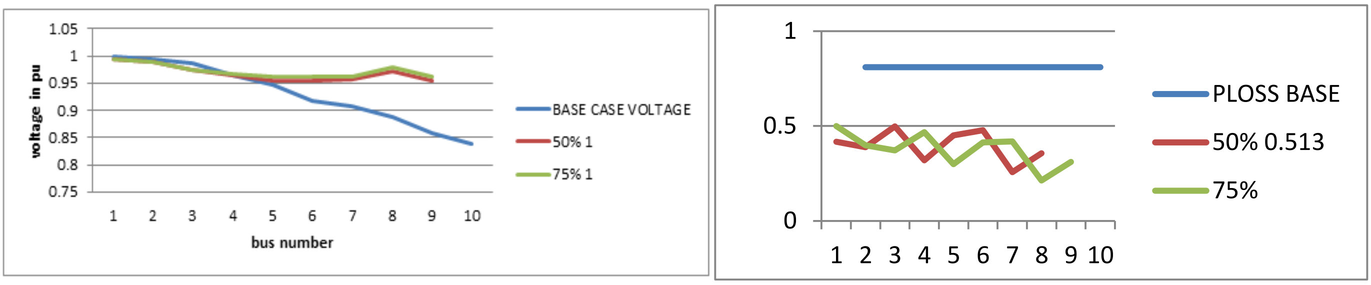


**Fig.4.1. Voltage and power loss Profiles at Different Penetration levels of DG for Standard 10 BUS RDS**

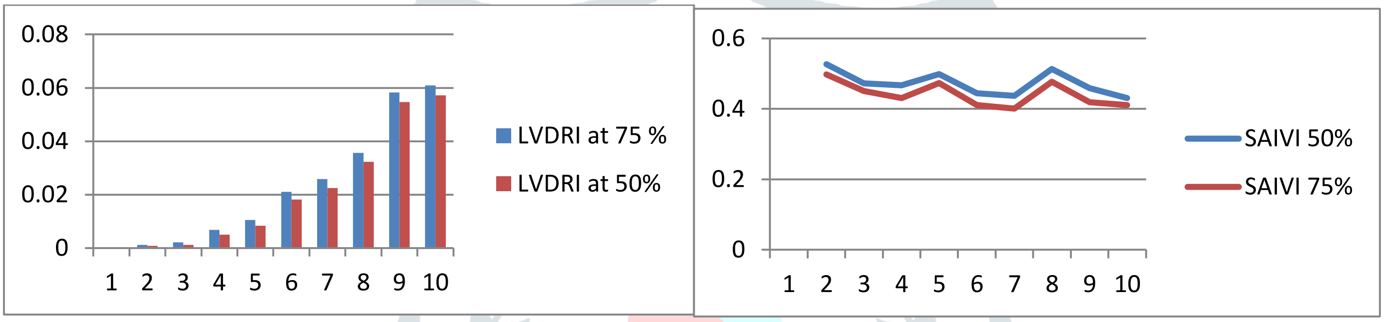


**Fig.4.2. LVDRI and SAIVI values at different penetration levels of DG for Standard 10 BUS RDS**

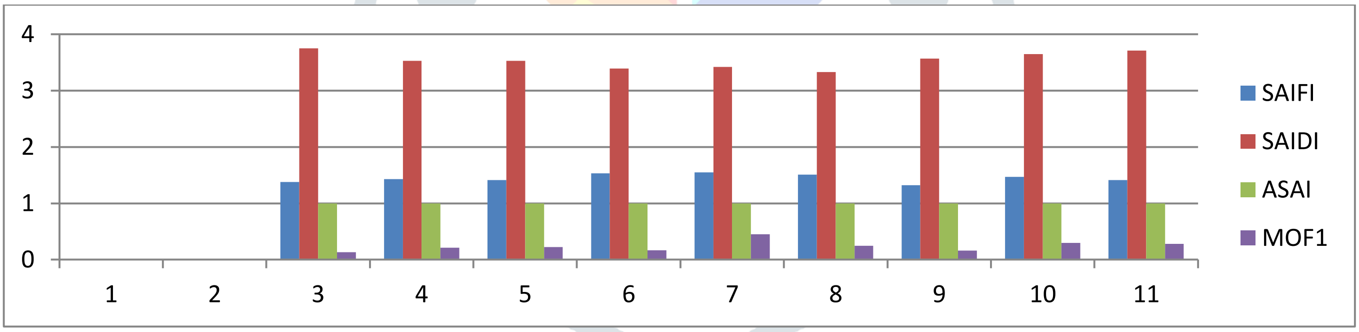


**Fig.4.3. Different Reliability indices values at 50% penetration level of DG for Standard 10 BUS RDS**

**Table.4.4. Summary of results with different penetration levels of DG for Standard 10 BUS RDS**

| Optimal allocation of DG based on Reliability index SAIVI | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DG | Location | Size of | Bus | No of | Losse | PLRI | LVDRI | SAIVI | SAIFI | SAIDI | ASAI | BI |
| | | | 5-10 | 420 | 0.810 | 0.7683 | 0.00123 | 0.583 | 1.758 | 3.894 | 0.999 | 0.4234 |
| 50 % | 08 | 0.256K | 7,8,10 | 250 | 0.378 | 0.4099 | 0.05628 | 0.513 | 1.32 | 3.57 | 0.999 | 0.16072 |
| 75% | 05 | 0.432K | 10 | 100 | 0.367 | 0.4234 | 0.06053 | 0.473 | 1.49 | 3.29 | 0.999 | 0.20025 |

Voltage and power loss Profiles, LVDRI and SAIVI and Values of different reliability indices at Different Penetration levels of DG for Standard 10 BUS RDS are shown Figures 4.1,4.2 and 4.3 respectively. Table 4.4 shows the Summary of results with different penetration levels of DG.

From table 4.5 it is clear that with the integration of DG at optimal location with different penetration levels will reduce the number of customers getting affected by the voltage sag and their voltage profile at load points from a specified value of 0.96 p.u . In the base case without DG integration the number of customers getting affected by voltage sag is 420 and with 50% and 75% of DG penetration the customers getting affected by voltage sag will be reduced to 250 and100 respectively

**Table 4.5. Total number of customers affected by voltage sag and their voltage profile at load points from a specified value of 0.96 p.u**

| Load Points | Number of customers | Base case | CASE A | |
|---|---|---|---|---|
| | | | Penetration Level | |
| | | | 50% | 75% |
| 1 | 50 | 1 | 1 | 1 |
| 2 | 70 | 0.99291 | 0.99467 | 0.99547 |
| 3 | 100 | 0.98738 | 0.98998 | 0.99216 |
| 4 | 80 | 0.96342 | 0.97454 | 0.97867 |
| 5 | 30 | 0.94804 | 0.96657 | 0.97131 |
| 6 | 70 | 0.91719 | 0.96131 | 0.96279 |
| 7 | 100 | 0.90718 | 0.95543 | 0.96272 |
| 8 | 50 | 0.88897 | 0.95757 | 0.96513 |
| 9 | 70 | 0.85871 | 0.97388 | 0.98188 |
| 10 | 100 | 0.83752 | 0.95531 | 0.95747 |
| Total number of customers affected | | 420 | 250 | 100 |

## V. CONCLUSION

An improved analytical approach for enhancing the reliability of the power system is developed In this paper. By integrating DG of selected penetration level at all nodes of the test system, a set of reliability indices including indices based on interruption, improvement indices and blended indices including the combination of LVDRI and PLRI with reliability improvement index are calculated selecting the blended indices as the multi-objective functions. For each function (BI) all the indices are calculated which gives the number of customers affected in the system. The minimum number of customer affected with 75% penetration of DG is 100. The system average interruption voltage index (SAIVI) is calculated to show the total number of customers affected by the voltage sag. Hence, a enhanced system reliability is achieved.

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