Analytical Modeling for Assessing the Impact of DG on Distribution system Reliability

Rohit K. Mathew, Ashok S., Kumaravel S.

Abstract— Distributed Generation in an electric power distribution system plays an important role in many ways. There are various kinds of DGs with different technologies. Due to clearly defined features of DG a suitable model is needed for reliability evaluation with DGs.In this paper a mathematical approach has been proposed for analyzing the effect of DG on reliability of electrical distribution networks. The proposed approach is based on conventional reliability evaluation algorithm. A probabilistic islanding technique has been used with multiple DGs for reliability assessment. Case studies for a typical utility feeder have been undertaken to validate the proposed method and the results have been compared with the single DG case.

Index Terms— Distribution System Reliability, Distributed Generation, analytical methods, power quality, Distribution Transformers, Voltage regulation, Frequency and Duration.

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1 INTRODUCTION

DG is becoming more significant in future generation systems [1]. It plays a major part in the the electric power network. DGs are of various technologies and specific characteristics. These have positive as well as negative effects on the system.

There are various benefits of DG applications which includes decrement in power losses, reliability enhancement, and reduction in power system expansion costs. On the other hand, the negative effects of DG includes voltage regulation issues, power quality problems etc.

Due to the increased use of electricity for residential, commercial and industrial applications, power system reliability has become a major area of interest [2]-[4]. As mentioned before, DG enhances the power system reliability. A lot of research has been conducted in this area to study the impact of DG on reliability. Earlier studies used conventional Reliability assessment techniques, which includes both analytical and simulation based approaches and the analysis has been limited to single DG case. In this paper multiple DGs has been used to analyze the reliability impact on a distribution system using Frequency and Duration approach. Probablistic based mathematical expressions were developed for failure rates and repair times with multiple DGs, and which is further used for computing the reliability indexes. Case studies are conducted on a typical utility feeder from Kerala, India and the results depict a considerable improvement in reliability. Results are also compared with an existing case study with single DG [6] and it is seen that use of multiple DGs at optimal location shows better.

The paper is structured into five sections. Section 1 deals with the overview of research. Section 2 gives a methodology of DG modeling for reliability assessment. Section 3 details about the mathematical formulation for reliability evaluation. Sections 4 and 5 discusses about the application methodology on typical utility system and Conclusions respectively.

2 DG MODELING METHODOLOGY

The insertion of DG in distribution systems would considerably improve system reliability through supplying loads by islanding, and disconnecting with substation during contingencies, until the utility can restore additional capacity. Considering a radial network all the load points are being supplied by a single source, and method of series systems is applied for reliability evaluation. When a DG is introduced in the radial network, multiple paths are developed to supply the demand. In such a case, appropriate parallel models should be used for reliability evaluation [5].

DG can supply the loads partially or completely in an island, depending on the DG capacity and load demand. Therefore they are treated as neither conventional generations nor substations in implementing reliability evaluation. Renewable energy technologies have considerable contribution in DG technologies. Their output power varies with the availability of resource at each moment. Uncertainty in the DG output is represented using a 3-state model as shown in Fig.1.

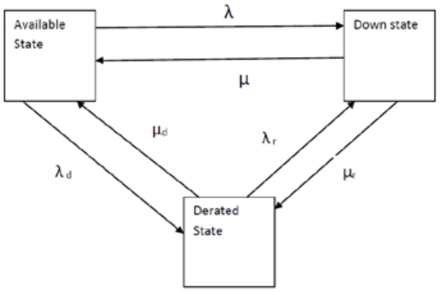

Fig. 1. Three State Model of a DG

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Average reliability indexes are evaluated as:

$$\lambda_{C,p} = \sum_j \lambda_j \quad (1)$$

$$U_{C,p} = \sum_j \lambda_j r_j \quad (2)$$

$$r_{C,p} = \frac{U_{C,p}}{\lambda_{C,p}} = \frac{\sum_j \lambda_j r_j}{\sum_j \lambda_j} \quad (3)$$

Where,

$\lambda_{C,p}$ = average failure rate

$r_{C,p}$ = average outage time

$U_{C,p}$ = average annual outage time

Reliability in distribution system is assessed by means of certain predefined indexes. These indexes measure the performance of the system [7]-[11].

1) SAIFI (System Average Interruption Frequency Index):

$$\text{SAIFI} = \frac{\sum \lambda_j N_j}{\sum N_j} \text{ f / customer.yr} \quad (4)$$

2) SAIDI (System Average Interruption Duration Index):

$$\text{SAIDI} = \frac{\sum U_j N_j}{\sum N_j} \text{hr / customer.yr} \quad (5)$$

3) CAIDI (Customer Average Interruption Duration Index):

$$\text{CAIDI} = \frac{\sum U_j N_j}{\sum N_j \lambda_j} \text{hr / customer interruption} \quad (6)$$

4) ASAI (Average Service Availability Index):

$$\text{ASAI} = \frac{\sum N_j \times 8760 - \sum U_j \times N_j}{\sum N_j \times 8760} \text{p.u.} \quad (7)$$

5) ASUI (Average Service Unavailability Index):

$$\text{ASUI} = 1 - \text{ASAI} = \frac{\sum U_j N_j}{\sum N_j \times 8760} \text{p.u.} \quad (8)$$

. EENS (System Expected Energy Not Supplied):

$$\text{EENS} = \sum \text{EENS}_j \text{ MWhr / yr} \quad (9)$$

Where,

$\text{EENS}_j = P_j U_j$

P_j is the load of load point j

7) AENS (Average Energy Not Supplied):

$$\text{AENS} = \frac{\sum \text{EENS}_j}{\sum N_j} \text{MWhr / customer.yr} \quad (10)$$

where,

N_j = number of consumers at load point j

λ_j = average failure rate at load point j

U_j = Unavailability

3 MATHEMATICAL FORMULATION

In this section a mathematical model for the reliability impact of DG in the distribution system is presented. A sample distribution system is shown in Fig. 2.

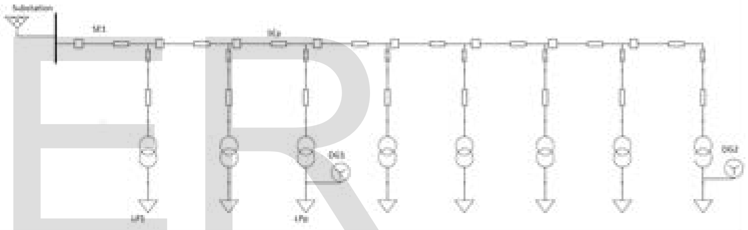

Fig. 2. A Sample system with DG

Assumptions for evaluating the proposed method:

1. Continuity has to be maintained between load point and utility DG.
2. The islanding operation is possible if the load demand is less than the generation.
3. Effects of power flow and protection are not considered

For any load point LP_P, the islanding probability of the load point is the islanding probability of smallest island which includes LP_P. As shown in Fig.3, section $SE_{U,p}$ determine the minimal island on upstream side of the DG and LP_p. Also, for the load point LP_P on the upstream side of the DG, $SE_{U,P}$ is SE_{p-1} and for L_{Pq} on the downstream, it is SE_{DG-1}.

During Islanding the failure rate and repair time of load point LP_P, can be found using (11) and (12).

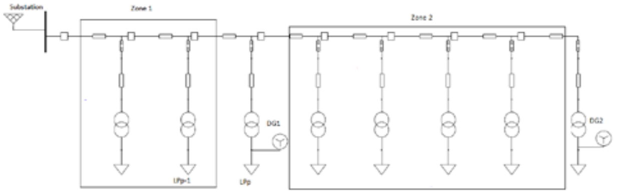

Fig.3 A sample system with zones for DG placement

$$\lambda_{IL,p} = \sum_{g=1}^{D2}\sum_{f=1}^{D1}\sum_{e=1}^{U}(\lambda_{Up,e}\lambda_{Dp,f}\lambda_{Dp,g}) \times (r_{Up,e}.r_{D1p,f} + r_{D1p,f}.r_{D2p,g} + r_{D2p,g}.r_{Up,e}) \quad (11)$$

$$U_{IL,p} = \sum_{g=1}^{D2}\sum_{f=1}^{D1}\sum_{e=1}^{U}(\lambda_{Up,e}\lambda_{D1p,f}\lambda_{D2p,g}) \times (r_{Up,e}.r_{D1p,f}.r_{D2p,g})$$

$\lambda_{Up,e}$ = failure rate of section between LP_p and substation
$\lambda_{D1p,f}$ = failure rate of sections between LP_p and DG1
$\lambda_{D2p,g}$ = failure rate of sections between LP_p and DG2
$r_{Up,e}$ = repair time of section between LP_p and substation
$r_{D1p,f}$ = repair time of sections between LP_p and DG1
$r_{D2p,g}$ = repair time of sections between LP_p and DG2
U = total number of upper side sections
$D1$ = number of sections between LP_p and DG1
$D2$ = number of sections between LP_p and DG2

For a Fault in Zone 2.

$$\lambda_{IL,p} = \sum_{g=1}^{D}\sum_{f=1}^{U2}\sum_{e=1}^{U1}(\lambda_{U1,e}\lambda_{U2,f}\lambda_{Dp,g}) \times (r_{U1p,e}.r_{U2p,f} + r_{U2p,f}.r_{Dp,g} + r_{Dp,g}.r_{U1p,e})$$

$$U_{IL,p} = \sum_{g=1}^{D}\sum_{f=1}^{U2}\sum_{e=1}^{U1}(\lambda_{U1p,e}\lambda_{U2p,f}\lambda_{Dp,g}) \times (r_{U1p,e}.r_{U2p,f}.r_{Dp,g}) \quad (12)$$

In the above equations incorporating the failure rate of section SE_p , the modified equations are as (13) and (14).

$$\lambda'_{IL,p} = \lambda_{ILp} + \lambda_p \quad (13)$$

$$U'_{IL,p} = U_{ILp} + U_p \quad (14)$$

$$r'_{IL,p} = \frac{U'_{IL,p}}{\lambda'_{IL,p}} \quad (15)$$

Where “ ‘ “ indicates the modified index.

UPS and DNS refers to upstream and downstream respectively.

The associated failure rate and repair rate of load point LP_p , during Islanding is given by (16) and (17) respectively.

$$\lambda_{L,p} = P_p\lambda'_{IL,p} + (1-P_p)\lambda_{C,p} \quad (16)$$

$$r_{L,p} = P_p r'_{IL,p} + (1-P_p) r_{C,k} \quad (17)$$

Where,
P_p = probablity of islanding
Comparing (16) and (1), the amount of change in the failure rate of load point LP_p is given as

$$\Delta\lambda_{L,p} = P_p(\lambda'_{IL,p} - \lambda_{C,p}) \quad (18)$$

From (18) it is observed that during islanding, the failure rate of the load point decreases and it is highly dependent on the islanding probability of the load point.

The modified failure and repair rates are substituted in the (4)-(10) and system indices are determined.
The Section Data, Load Data, Transformer and Breaker Reliability Data and DG Reliability Data are given in Table 1, Table 2, Table 3 and Table 4 respectively [12].

TABLE 1
SECTION DATA

Feeder Type	Length (km)	Feeder Sections	Failure Rate (f/yr)	Repair Time(h)
1	0.7	L1 L4 L7 L10 L13 L16 L19 L22 L25 L28 L31 L34 L37 L40 L43 L46 L49 L52 L55 L58 L61 L64 L67 L70	0.0325	5
2	0.85	L2 L5 L8 L11 L14 L17 L20 L23 L26 L29 L32 L35 L38 L41 L44 L47 L50 L53 L56 L59 L62 L65 L68 L71	0.04225	5
3	1	L3 L6 L9 L12 L15 L18 L21 L24 L27 L30 L33 L36 L39 L42 L45 L48 L51 L54 L57 L60 L63 L66 L69	0.052	5

TABLE 2

LOAD DATA

Load Points	Consumer category	Peak Load (MW)	Average load (MW)	Number of consumers
LP1 LP3 LP5 LP7 LP9 LP11	residential	0.7625	0.4269	210
LP2 LP4 LP6 LP8 LP10 LP12 LP14 LP16 LP18 LP20	residential	0.7450	0.4171	240
LP13 LP15 LP17 LP19	residential	0.5740	0.3213	195
LP21 LP23 LP25 LP27 LP29 LP31	Government and institutional	1.1100	0.6247	1
LP32	commercial	0.7400	0.4089	15
LP34 LP36 LP38				
LP22 LP24 LP26 LP28 LP30 LP33	Office buildings	0.6167	0.3786	1

TABLE 3
TRANSFORMER RELIABILITY DATA

Type of Unit	Active Failure Rate (f/yr)	Passive Failure rate(f/yr)	Repair Time(h)
T1-T38 (250 kVA)	0.0150	0.0150	200

TABLE 4
DG RELIABILITY DATA

Type of unit	Failure rate(f/yr)	Repair Time(h)	Switching Time(h)
10 Kw DG unit	0.032	50	2

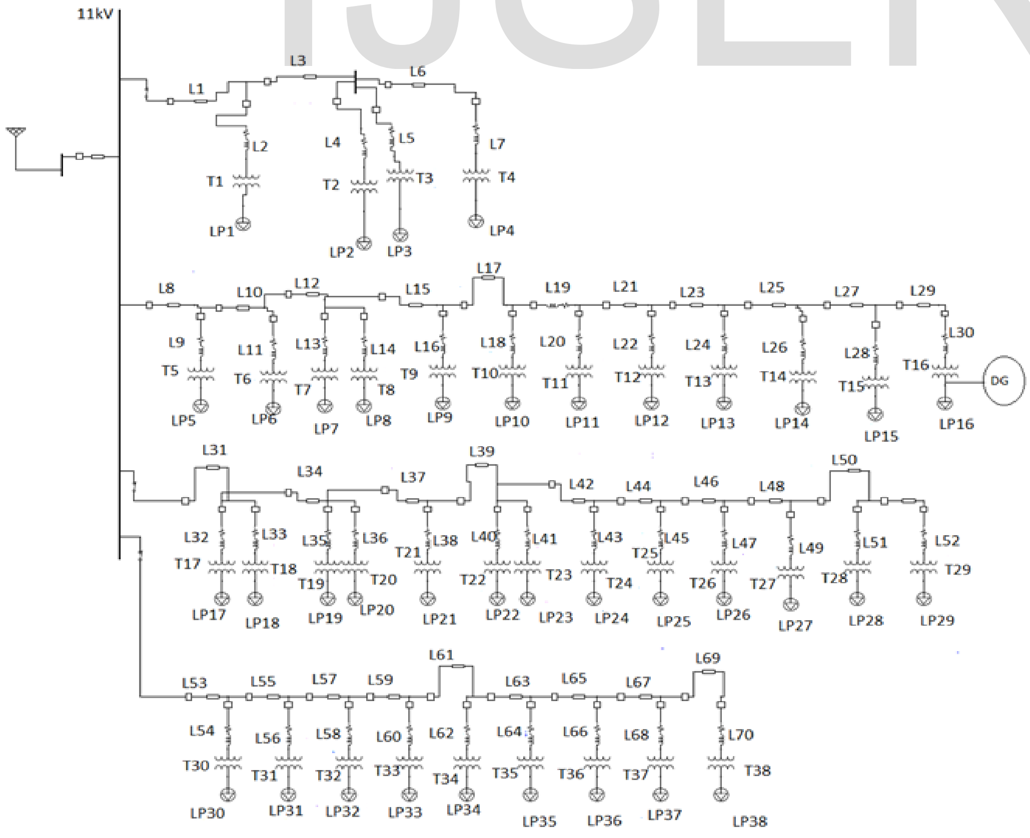

Fig. 4. A typical utility feeder of 11kV Electrical Section, Ollur

4. APPLICATION METHODOLOGY

A practical power system from Thrissur district in Kerala, is taken for a case study. The Electrical Substation at Ollur, in Thrissur is considered which has five feeders. A typical feeder is taken for the case study as shown in Fig. 4, which comprises of 38 distribution transformers (DTRs) each having a fixed number of consumers connected.

Case 1: When no DG is placed

Reliability Index	**Base Case**
SAIFI(f/customer.yr)	1.8479
SAIDI(h/customer.yr)	39.6743
CAIDI(h/customer interruption)	21.471
ASAI(pu)	0.9955
ASUI(pu)	0.00453
EENS(MWh/yr)	105.322
AENS(MWh/customer.year	0.0529

Case 2: When single DG is placed at Section 29.

This is the case when a single DG is placed at section 29.
Table 5 lists the reliability indexes for DG at section29.

TABLE 5
RELIABILITY INDEXES FOR DG AT SE 29

Reliability Index	**Single DG Case**
SAIFI(f/customer.yr)	1.5160
SAIDI(h/customer.yr)	38.2623
CAIDI(h/customer interruption)	25.239
ASAI(pu)	0.9956
ASUI(pu)	0.00437
EENS(MWh/yr)	101.150
AENS(MWh/customer.year)	0.0508

Case 3: When Two DGs are placed at section 10 and Section 27

In this case two identical DGs are placed at Section 10 and Section 27 respectively.
Table 6 lists the reliability indexes for DGs at section10 and section 27 respectively.

TABLE 6
RELIABILITY INDEXES FOR DGs AT SE 10 AND SE 27

Reliability Index	
SAIFI(f/customer.yr)	1.5166
SAIDI(h/customer.yr)	38.3065
CAIDI(h/customer interruption)	25.258
ASAI(pu)	0.9956
ASUI(pu)	0.00437
EENS(MWh/yr)	101.282
AENS(MWh/customer.year)	0.0509

Case 4: When two DGs are placed at Section 12 and Section 25.

Table 7 lists the reliability indexes when two DGs are placed at section 12 and section 25 respectively.

TABLE 7
RELIABILITY INDEXES FOR DGs AT SE 12 AND SE 25

Reliability Index	
SAIFI(f/customer.yr)	1.5257
SAIDI(h/customer.yr)	38.3428
CAIDI(h/customer interruption)	25.132
ASAI(pu)	0.9956
ASUI(pu)	0.00438
EENS(MWh/yr)	101.391
AENS(MWh/customer.year)	0.0510

Case 5: When two DGs are placed at Section 15 and Section 23.

Table 8 lists the reliability indexes when two DGs are placed at section 15 and section 23.

TABLE 8
RELIABILITY INDEXES FOR DGs AT SE 15 AND SE 23

Reliability Index	
SAIFI(f/customer.yr)	1.5393
SAIDI(h/customer.yr)	38.3972
CAIDI(h/customer interruption)	24.944
ASAI(pu)	0.9956
ASUI(pu)	0.00440
EENS(MWh/yr)	109.743
AENS(MWh/customer.year)	0.0551

The above results shows that introduction of DGs, shows considerable improvement in reliability of distribution systems

5. CONCLUSION

In this paper a mathematical technique has been proposed for analyzing the impacts of distributed generation (DG) on reliability of electrical distribution networks. This has been carried out by formulating mathematical equations for inclusion of multiple DGs in the electrical network. Case studies have been conducted and the results depict that multiple DGs show considerable improvement in reliability and also the optimal location for reliability enhancement. Results are also compared with a previously done single DG case study and it is seen that use of multiple DGs shows considerable improvement in the reliability.

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