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Impact of Distributed Generator for Loss Reduction and Improvement in Reliability of Distributed System

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Abstract *— Distributed Power generation has gained a lot of attention in recent times due to constraints associated with conventional power generation and new advancements in DG technologies .The need to operate the power system economically and with optimum levels of reliability has further led to an increase in interest in Distributed Generation. By placing distributed generator on an optimal location lead to improvement in voltages. This paper investigates the impact of DG unit installation on electric losses, reliability and voltage profile of distribution networks. To find optimal distributed generator allocation for loss reduction subjected to constraint of voltage regulation in distribution network. Distributed Generator offers the additional advantage of increase in reliability levels as suggested by the improvements in various reliability indices such as SAIFI, SAIDI, CAIDI, ASAI and ASUI. Comparative studies are performed and related results are addressed. The suggested technique is programmed to IEEE-33 bus system by using MATLAB software. The results clearly indicate that DG can reduce the electrical line loss while simultaneously improving the reliability of the system.*

Keywords — ***Distributed generation, Distribution load flows, loss Reduction, DG placement, Reliability.***

I. INTRODUCTION

Distribution systems deliver power from bulk power systems to retail customers. To do this, distribution substations receive power from sub transmission lines and step down voltages with power transformers. These transformers supply primary distribution systems made up of many distribution feeders. Distribution transformers step down voltages to utilization levels and supply secondary mains or service drops [1]. Distribution planning departments at electric utilities have historically concentrated on capacity issues, focusing on designs that supply all customers at peak demand within acceptable voltage tolerances without violating equipment ratings. Capacity planning is almost always performed with rigorous analytical tools such as power flow models. Reliability, although considered important, has been a secondary concern usually addressed by adding extra capacity and feeder ties so that certain loads can be restored after a fault occurs. Although capacity planning is important, it is only half of the story. A distribution system designed purely for capacity (and minimum safety standards) costs between 40% and 50% of a typical US overhead design [2]. This minimal system has no switching, no fuse cutouts, no tie switches, no extra capacity and no lightning protection. Poles and hardware are as inexpensive as possible, and feeders protection is limited to fuses at substations. Any money spent beyond such a "minimal capacity design" is spent to improve reliability. Viewed fr m this perspective, about 50% of the cost of a distribution system is for reliability and 50% for capacity [3]. To spend distribution reliability dollars as efficiently as capacity dollars, utilities must transition from capacity planning to integrated capacity and reliability planning4. Such a department will keep track of accurate historical reliability data, utilize predictive reliability models, engineer systems to specific reliability targets and optimize spending based on cost per reliability benefit ratios. The impact of distribution reliability on customers is even more profound than cost. For a typical residential customer with 90 minutes of interrupted power per year, between 70 and 80 minutes will be attributable to problems occurring on the distribution systems [4]. This is largely due to the radial nature of most distribution systems, the large number of components involved, the sparsity of protection devices and sectionalizing switches and the proximity of the distribution system to end-use customers.

The main objective is to minimize the total real power loss of the system. This method is tested for IEEE 33-Bus standard test system. The tight connection between the optimal location and size is to be studied by allocating the optimal size at different buses in the network and by allocating different DG capacities at the optimal bus resulted from the proposed method [5].

A basic problem in distribution reliability assessment is measuring the efficacy of past service. A common solution consists of condensing the effects of service interruptions into indices of system performance. Reliability indices are used by system planners and operators as a tool to improve the level of service to customers. Planners use them to determine the requirements for generation, transmission, and distribution capacity additions. Operators use them to ensure that the system is robust enough to withstand possible failures without catastrophic consequences.

Reliability indices are considered to be reasonable and logic way to judge the performance of an electrical power system [6]. Reliability indices used for the purpose of analysis in power system. The proposed methodology is tested on a standard IEEE-33 bus radial distribution system and the scenarios yields efficiency in improvement of voltage profile and reduction of power loss, it also permits an increase in reliability of the system.

II. LOADFLOWS

In this paper, a modified load-flow technique is considered for solving radial distribution networks. The proposed method involves only the evaluation of a simple algebraic expression of receiving-end voltages also node and line identification utilized [7] in load flow has been proposed. The proposed method is very efficient. It is also observed that the proposed method has good and fast convergence characteristics. The proposed method uses the simple voltage equation. The proposed method takes the zero initial loss for computation of voltage of each node and considers flat voltage start to incorporate voltage convergence.

A. Assumptions

It is assumed that three-phase radial distribution networks are balanced and represented by their single-line diagrams and charging capacitances are neglected at the distribution voltage levels.

B. Solution methodology

The load flow method of radial distribution network can be solved in three sets of equations.

1. Identification of the nodes beyond all the branches.
2. Determination of branch currents.
3. Determine the nodal voltages.

C. Procedure to determine the voltage at each bus

The distribution load flow method is used to calculate the voltage at each bus and total real and reactive power losses. Before proceeding to the fundamentals of power system control and stability limits, some factors influencing active and reactive power flows on the power system are needed to be discussed. The power transfer between two buses is related to some parameters:

- Sending and receiving bus voltages
- Power angles between two buses
- Series impedances of the transmission line connecting the two buses.

Consider a single line diagram of two buses of a radial distribution system as shown in Fig.4.1, the number of branches nb and the number of buses t are related through t = nb+1. at

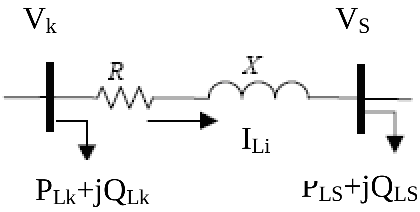

Fig 4.1: Single line diagram of two buses of a distribution system.

Where R and X are resistance and reactance of the branch. P_{Lk} and Q_{Lk} are the active and reactive powers of node k. I_{Li} is the current flowing in the line. Subscript 'L' in P_{LS} and Q_{LS} refers to the load connected

Initially, a flat voltage (1 p.u) of all the nodes is assumed and load currents and charging currents of all the loads are computed using Eqs. (3.1) and (3.2) respectively.

The load current of node k is

$$I_{Lk}(k) = \frac{P_{Lk}(k) - jQ_{Lk}(k)}{V^*(k)} \tag{2.1}$$

for k = 2, 3,……. nb

Where P_{Lk}(k) and Q_{Lk}(k) are active and reactive power of load connected to node k, respectively.

The charging current at node k is

$$I_{Ck}(k) = y_0(k)^* V(k) \tag{2.2}$$

for k = 2, 3… nb

Here shunt admittance y_o is considered as small.

D. Branch current

Branch Current I(n) is equal to the sum of the load currents of all the nodes beyond that branch n plus the sum of the charging currents of all the nodes beyond that branch n i.e.,

$$I(n) = \sum_{k=n+1}^{nb} I_{Lk}(k) + \sum_{i=n+1}^{nb} I_{Ck}(k) \tag{2.3}$$

Where branch impedance is Z = R + j X

Therefore, if it is possible to identify the nodes beyond all the branches, it is possible to compute all the branch currents.

E. Voltage at buses

A generalized equation of receiving-end voltage, sending-end voltage, branch current and branch impedance is

$$V(a_2) = V(a_1) - I(i) * Z(i) \tag{2.4}$$

Where i is the branch number and a_1 and a_2 are

a_1 = RE (i)

a_2 = SE (i)

Where RE (i) is the receiving end and SE (i) is the sending end of branch i.

F. Power losses

The real and reactive power loss of branch i are given

$$L_{real}(i) = |I(i)|^2 * R(i) \tag{2.5}$$

$$L_{reactive}(i) = |I(i)|^2 * X(i) \tag{2.6}$$

Where L_{real} (i) and $L_{reactive}$ (i) are the active and reactive power losses at branch i.

Algorithm : Identification of nodes beyond a branch

```
Step 1.    Read the system data.
Step 2.    i =1
Step 3.    k = i + 1, set $i_p$ = 0
Step 4.    nc = 0
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            if {RE (i) = SE(k)} and {$i_p$ = 0} go to step 10
            Otherwise go to step 12
Step 5.     if {$i_p$ = 0} go to step 10
            Otherwise go to step 6
Step 6.     it = 1
Step 7.     if {RE(i) = ie(i, $i_p$+1)}then nc = 1
            Otherwise go to step 8
Step 8.     it = it +1
            If {it $\le$ $i_p$} go to step 7
            Otherwise go to step 9
Step 9.     if {nc = 1} go to step 12
            Otherwise go to step 11
Step 10.    ie (i, $i_p$ + 1) = RE(i)
Step 11.    $i_p$ = $i_p$ +1
            IN($i_p$) =1
            ie(i, $i_p$ + 1) = RE(i)
            N(i) = $i_p$ + 1,
Step 12.    s = s + 1
            If {s $\le$ nb} go to step 6
            Otherwise go to step 13
Step 13.    if {$i_P$ =0} go to step 14
            Otherwise go to step 15
Step 14.    ie(i, $i_p$ + 1) = RE(i)
            N(i) = $i_p$ + 1, go to step 15
Step 15.    i = i + 1
            If {i $\le$ nb-1}go to step 3
            Otherwise go to step 16
Step 16.    ie(nb, 1) = RE(nb)
            N(nb) = 1
Step 17.    Stop
```

By using this algorithm we can find the identification of nodes beyond all branches.

III. DG PLACEMENT METHODOLOGY

The basic idea behind the method is that when a DG is placed at a bus, the real load connected to that bus is compensated and hence the branch currents are reduced. This causes reduction in system real power loss [8]. The description of the method is given in the following sections.

A. Background

The total I^2R loss (PL$_t$) in a distribution system having *n* number of branches is given by

$$P_{lt} = \sum_{i=1}^{n} I_{ti}{}^{2} R_i \qquad (3.1)$$

Here I_i and R_i are the current magnitude of branch current and the resistance of the i^{th} branch. The branch current can be obtained from the load flow solution. The branch current has two components, active component (I_a) and reactive component (I_r). The loss associated with the active and reactive components of branch currents can be written as

$$\mathrm{PL_a} = \sum_{i=1}^{n} I_{ai}^{2} R_i \qquad (3.2)$$

$$\mathrm{PL_r} = \sum_{i=1}^{n} I_{ri}^{2} R_i \qquad (3.3)$$

Where I_{ai} and I_{ri} are the active and reactive components of current of branch i.For a given configuration of a single-source radial network, the loss associated with the active component of branch currents (PL-*$_{a)}$ can be minimized by placing DG units, and the loss associated with the reactive component of branch currents (PL$_{r)}$ can be minimized by supplying part of the reactive power demand locally [9].

For formulating new real power and losses following formulae are derived

P_{new}=$P_{p.u}$-DG Where DG is varied upto 5MW

New Spu is given by

$$S_{pu}=P_{new}+jQ_{pu} \qquad (3.4)$$

Corresponding current values is calculated as

I_{new}=(S_{pu})*/(V_1)*

The loss associated with the active and reactive components of branch currents can be written as

$$PL_a = \sum_{i=1}^{n} I_{newai}^{2} R_i \qquad (3.5)$$

$$\mathrm{PL_r} = \sum_{i=1}^{n} I_{newri}^{2} R_i \qquad (3.6)$$

Where I_{newai} and I_{newri} are the active and reactive components of current of branch i.

B. Algorithm for DG Placement

Step 1: Read system data and conduct load flow analysis for the original system.

Step 2: Initialize DG=0.25

Step 3**:** P_{new} =P_{pu}

Step 4: i=1

Step 5: At bus 'i' P_{new} (i)=P_{pu}(i)-DG

Step 6: Conduct load flow, find the losses for new 'P' value.

Step 7: Check i<N if yes go to step 5 with i=i+1 else next step.

Step 8: After calculating losses for all the buses with new P values, loss with minimum

Value is assigned to 'N' corresponding location to 'Y'.

Step 9: Check DG=<5MW if yes go to step 3 with DG=DG+0.25 else stop.

IV. RELIABILITY

To measure system performance, the electric utility industry has developed several measures of reliability. These reliability include measures of outage duration, frequency outages, system availability, and response time performance indices, important definitions for reliability including what are momentary interruptions, momentary interruption events, and sustained interruptions [10].

- Momentary Interruption -

A single operation of an interrupting device that results in a voltage zero.

- Momentary Interruption Event -

An interruption of duration limited to the period required to restore service by an interrupting device. This must be completed within five minutes.

- Sustained Interruption –

Any interruption not classified as a momentary event.

The most common distribution indices include the System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), System Average Interruption Frequency Index (SAIFI), and the Average Service Availability Index (ASAI).

A System Average Interruption Duration Index (SAIDI)

The most often used performance measurement for a sustained interruption is the System Average Interruption Duration Index (SAIDI). This index measures the total duration of an interruption for the average customer during a given time period. SAIDI is normally calculated on either monthly or yearly basis; however, it can also be calculated daily, or any other time period.

To calculate SAIDI, each interruption during the time period is multiplied by the duration of the interruption to find the customer-minutes of interruption. The customer-minutes of all interruptions are then summed to determine the total customer-minutes [11]. To find the SAIDI value, the customer-minutes are divided by the total customers. The formula is, $\text{SAIDI} = \Sigma(r_i * N_i) / N_T$

Where, SAIDI = System Average Interruption Duration Index, minutes.

Σ = Summation function.

r_i= Restoration time, minutes.

Ni = Total number of customers interrupted.

N_T = Total number of customers served.

B Customer Average Interruption Duration Index (CAIDI)

Once an outage occurs the average time to restore service is found from the Customer Average Interruption Duration Index (CAIDI). CAIDI is calculated similar to SAIDI except that the denominator is the number of customers interrupted versus the total number of utility customers. CAIDI is, $\text{CAIDI} = \Sigma(r_i * N_i) / \Sigma(N_i)$

Where CAIDI = Customer Average Interruption Duration Index, minutes.

Σ = Summation function.

r_i= Restoration time, minutes.

N_i= Total number of customers interrupted.

C System Average Interruption Frequency Index (SAIFI)

The System Average Interruption Frequency Index (SAIFI) is the average number of times that a system customer experiences an outage during the year (or time period under study). The SAIFI is found by divided the total number of customers interrupted by the total number of customers served. SAIFI, which is a dimensionless number, is, $\text{SAIFI} = \Sigma(\text{Ni}) / \text{NT}$

Where, SAIFI = System Average Interruption Frequency Index.

Σ = Summation function.

N_i= Total number of customers interrupted.

N_T = Total number of customers served.

D Average Service Availability Index (ASAI)

The Average Service Availability Index (ASAI) is the ratio of the total number of customer hours that service was available during a given time period to the total customer hours demanded [12]. This is sometimes called the service reliability index. The ASAI is usually calculated on either a monthly basis (730 hours) or a yearly basis (8,760 hours), but can be calculated for any time period. The ASAI is found as, $\text{ASAI} = [1 - (\Sigma\,(\text{ri} * \text{Ni}) / (\text{NT}* \text{T}))] * 100$

Where, ASAI = Average System Availability Index, percent.

Σ = Summation function.

T = Time period under study, hours.

r_i= Restoration time, hours.

Ni = Total number of customers interrupted.

N_T = Total number of customers served.

V. RESULT ANALYSIS

The proposed model is tested on IEEE-33 bus system. For this we require system data. Data for 33-bus system. Figure 1 shows the IEEE standard 33 bus system.

Number of busses=33; Number of branches=32;

Base voltage=12.66 kV;Base MVA=5.246 MVA;

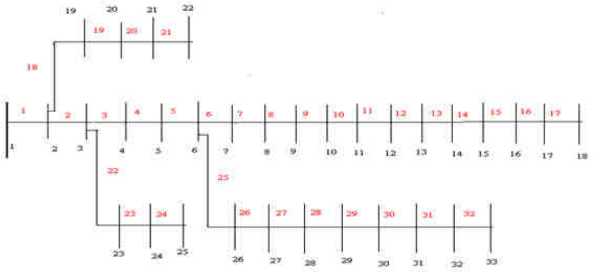

Fig.1: Single Line Diagram of the Test Network

Table 1: The Load Data of IEEE-33Bus System

Bus No	Sending Node	Receiving Node	Resistance (Ohms)	Reactance(Ohms)	P_L (KW)	Q_L (KVAR)
1	1	2	0.0922	0.0470	100	60
2	2	3	0.4930	0.2511	90	40
3	3	4	0.3660	0.1864	120	80
4	4	5	0.3811	0.1941	60	30
5	5	6	0.8190	0.7070	60	20
6	6	7	0.1872	0.6188	200	100
7	7	8	0.7114	0.2351	200	100
8	8	9	1.0300	0.7400	60	20
9	9	10	1.0440	0.7400	60	20
10	10	11	0.1966	0.0650	45	30
11	11	12	0.3744	0.1238	60	35

12	12	13	1.4680	1.1550	60	35
13	13	14	0.5416	0.7129	120	80
14	14	15	0.5910	0.5260	60	10
15	15	16	0.7463	0.5450	60	20
16	16	17	1.2890	1.7210	60	20
17	17	18	0.7320	0.5740	90	40
18	2	19	0.1640	0.1565	90	40
19	19	20	1.5042	1.3554	90	40
20	20	21	0.4095	0.4784	90	40
21	21	22	0.7089	0.9373	90	40
22	3	23	0.4512	0.3083	90	50
23	23	24	0.8980	0.7091	420	200
24	24	25	0.8960	0.7011	420	200
25	6	26	0.2030	0.1034	60	25
26	26	27	0.2842	0.1447	60	25
27	27	28	1.0590	0.9337	60	20
28	28	29	0.8042	0.7006	120	70
29	29	30	0.5075	0.2585	200	600
30	30	31	0.9744	0.9630	150	70
31	31	32	0.3105	0.3619	210	100
32	32	33	0.3410	0.5302	60	40

First load flow is conducted for IEEE-33 bus test system. The power loss due to active component of current is 136.9836 kW and power loss due to reactive component of the current is 66.9252 kW. A programme is written in MATLAB by using load flow algorithm which is discussed above. By executing that programme total loss in the power system and p.u nodal voltages are obtained and listed in Table 2.

Table 2: Total losses of 33-Bus system from load flows

Loss due to real part of I in kW	**Loss due to reactive part of I in kVAR**	**Total loss in kW**
136.9836	66.9252	203.9088

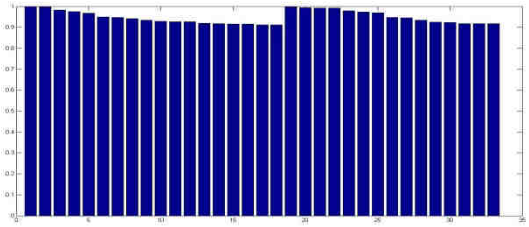

Fig 2: p.u Nodal Voltages

A program is written in "MATLAB" to implement single DG placement algorithm [13]. For the first iteration the maximum saving is occurring at bus 6. The candidate location for DG is bus 6 with a loss saving of 93.8323 kW.

Table 3: Optimal Locations and Losses for Corresponding Dg Size

DG size	0.25	0.50	0.75	1.00	1.25	1.50	1.75
Opt. Location	17	15	14	30	30	29	8
Loss with DG	107.2	86.891	73.491	64.664	57.821	54.089	50.329

DG size	2.00	2.25	2.50	2.75	3.00	3.25	3.5
Opt. Location	7	6	6	6	6	6	6
Loss with DG	46.788	44.378	43.186	43.674	45.807	49.553	54.879

DG size	3.75	4.00	4.25	4.50	4.75	5.00
Opt. Location	6	6	6	5	4	3
Loss with DG	61.754	70.148	80.032	88.685	93.788	97.274

The results of the DG placement method by proposed method are shown below table.

Table 4: DG Placement Method Results of 33 bus system

DG Location	6		
DG Size(MW)	2.5601		
	PL_t	**PL_a**	**PL_r**
Loss Before DG Placement(kW)	203.9088	136.9836	66.9252
Loss After DG Placement(kW)	105.0924	43.1513	61.8781
% Reduction in Loss	48.46	68.498	7.5336

By placing 2.5601 MW DG unit at Bus 6 the total real power loss is reduced to 105.0924 kW from 203.9088 kW and the loss associated with active component of the branch current (PL_a) is reduced to 43.1513 kW from 136.9836 kW. The reduction in total power loss is 48.46% and 68.498% reduction is achieved in the loss associated with active component of the branch current (PL_a) [14, 15]. The reduction in the loss associated with reactive component of the branch current (PL_r) is very small as it is already mentioned that placement of DG effects only active component of branch current. Though the objective is to reduce the losses, the voltage profile is also substantially improved as well. The below table shows the voltages profile after and before placement of DG.

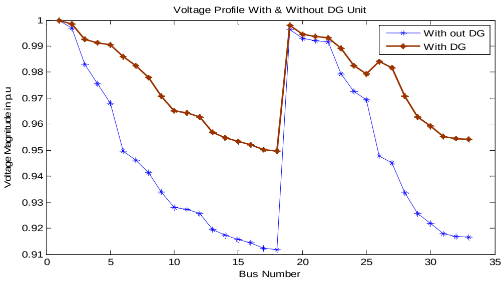

Fig.2: Voltage Profile with and without DG unit

The results of proposed method are shown in the Table 5 and can be compared with the results associated without DG. It can be seen from the results that the reliability indices will experience considerable changes when DG modelling is changed. Comparing the failure rates and unavailability associated with two cases of with and without DG installation, it can be seen that DG installation can improve reliability indices considerably especially SAIFI, SAIDI & ASUI and the effects are more obvious for ending sections of the feeder [16].

VI. CONCLUSION

Use of distributed generation is one of the many strategies electric utilities are considering to operate their systems in the deregulated environment. Inclusion of DG at the distribution level results in several benefits, among which are congestion relief, loss reduction; voltages profile improvement and improvement in reliability. This project has considered the benefit of DG on loss reduction, voltage improvement and Reliability for a simple case of a radial distribution line. The results clearly indicate that DG can reduce the electrical line loss while simultaneously improving the reliability of the system. However, the inclusion of DG does not always guarantee the reduced line loss. The DG rating and location are important factors for line loss reduction. Therefore, these factors have to be considered very carefully in order to determine the best location of DG. The improvement in reliability indices is maximum with DG at feeder end. Power losses decrease as location of DG from feeder end increases. We arrived at an optimal location by keeping into account these two mutually opposing factors.

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