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Less Power Loss and More Reliability of Radial Distribution System by placing of Distributed Generator using Fuzzy Approach

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***Abstract* - In India, due to lack of adequate investments on the distribution networks, the losses have been consistently on the higher side. Higher distribution losses in the system are primarily due to inadequate investments over the years for system improvement works and these inadequate investments resulted in unplanned extensions of the distribution lines, overloading of the system element like transformers and conductors and lack of adequate reactive power support. By undertaking suitable system improvement schemes based on computer studies, it is possible to bring down the distribution losses. 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. The system is further analyzed for increased levels of Reliability. A Fuzzy Approach is used in order to find the optimal location of Distributed Generator. The suggested technique is programmed to IEEE-15 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, Analytical load flows, Power loss Reduction, Fuzzy Approach, Reliability.**

I. INTRODUCTION

Distributed generation unlike centralized electrical generation aims to generate electrical energy on small scale as near as possible to load centers, which provide an incremental capacity to power system. In the deregulated power market, concerns about the environment as well as economic issues have led increased interest in distributed generations [1]. The emergence of new technological alternatives (photovoltaic systems, wind power, cogeneration, etc.) allows generating part of the required energy closer to the point of use, improving quality levels and minimizing the investments costs associated with of transmission and distribution systems. With electricity market undergoing tremendous transformation, more price instability in the market, ageing infrastructure and changing regulatory environments are demanding users and electric utilities to exploit benefits of DG [2]. DG applications are growing due to environmental and economic issues, technological improvements, and privatization of power systems. DG application, however, has positive and negative side effects for public industries and consumers [3].

In this paper, locations of distributed generators are identified by single DG placement method [4] and DG placement involves two variables: location and size. These are not independent. If DG is placed at the optimal location, but with a different capacity, system losses will increase. Moreover, if the size of DG is optimal but is connected to a bus different from the optimal one, losses also increase. This is why the solution method for DG allocation is very important and it has to provide simultaneously both values of the variables.

The main objective is to minimize the total real power loss of the system. This method is tested for IEEE 15-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 -15 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. ANALYTICAL LOADFLOWS

The total I^2R loss (P_{lt}) in a distribution system having *n* number of branches is given by:

$$P_{lt} = \sum_{i=1}^{n} I_{ti}^{2} R_i \rightarrow (2.1)$$

Here I_{ti} is the magnitude of the branch current and R_i is the resistance of the i^{th} branch respectively. The branch current can be obtained from the load flow solution [7]. The branch current has two components, active component (*Iai*) and reactive component (*Iri*). The loss associated with the active and reactive components of branch currents can be written as

$$P_{la} = \sum_{i=1}^{n} I_{ai}^{2} R_i \rightarrow (2.2)$$

$$P_{lr} = \sum_{i=1}^{n} I_{ri}^{2} R_i \rightarrow (2.3)$$

Note that for a given configuration of a single-source radial network, the loss Pla associated with the active component of branch currents cannot be minimized because all active power must be supplied by the source at the root bus. However by placing DGs, the active components of branch currents are compensated and losses due to active components of branch currents are reduced [8]. This paper presents a method that minimizes the loss due to the active component of the branch current by optimally placing the DGs and thereby reduces the total loss in the distribution system [9].

III. DISTRIBUTED GENERATORS PLACEMENT

This work presents a fuzzy approach to determine suitable locations for Distributed Generators placement. Two objectives are considered while designing a fuzzy logic for identifying the optimal Distributed Generators locations. [10] The two objectives are: (i) to minimize the real power loss and (ii) to maintain the voltage within the permissible limits. Voltages and Power loss indices of distribution system nodes are modeled by fuzzy membership functions. A fuzzy inference system (FIS) containing a set of rules is then used to determine the Distributed Generators Placement suitability of each node in the distribution system. Distributed Generators can be placed on the nodes with the highest suitability [11].

In a distribution system with high losses and low voltage is highly ideal for placement of Distributed Generators. Whereas a low loss section with good voltage is not ideal for Distributed Generators placement [12]. A set of fuzzy rules has been used to determine suitable Distributed Generators locations in a distribution system.

In the first step, load flow solution for the original system is required to obtain the real and reactive power losses. The Loss Sensitivity Factors ($\partial P_{lineloss}/\partial Q_{eff}$) are calculated from the base case load flows and the values are arranged in descending order for all the lines of the given system [13]. The loss Sensitivity Factors are then, linearly normalized into a [0, 1] range with the largest loss Sensitivity Factors having a value of 1 and the smallest one having a value of 0. Power Loss Index value for nth node can be obtained using equation (3.1).

$$PLI(n) = \frac{\text{LSF (n)} - \text{LSF (min)}}{\text{LSF (max)} - \text{LSF (min)}} \qquad (3.1)$$

These power loss reduction indices along with the p.u. nodal voltages are the inputs to the Fuzzy Inference System (FIS), which determines the node more suitable for capacitor installation [14].

In this work, two input and one output variables are selected. Input variable-1 is power loss index (PLI) and Input variable-2 is the per unit nodal voltage (V). Output variable is Distributed Generator suitability index (DSI) [15]. Power Loss Index range varies from 0 to 1, P.U. nodal voltage range varies from 0.9 to 1.1 and Distributed Generator suitability index range varies from 0 to 1.Five membership functions are selected for PLI. They are L, LM, M, HM and H. All the five membership functions are triangular as shown in Figure 1. Five membership functions are selected for Voltage. They are L, LN, N, HN and H. membership functions are trapezoidal and triangular as shown in Figure 2. Five membership functions are selected for DSI. They are L, LM, M, HM and H. These five membership functions are also triangular as shown in Figure 1.

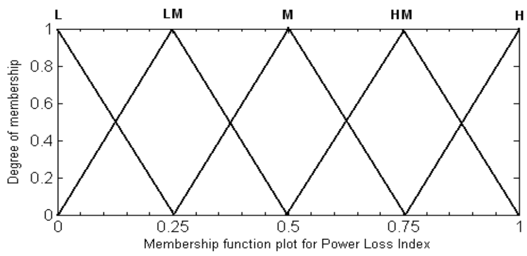

Figure 1: Membership function plot for P.L.I.

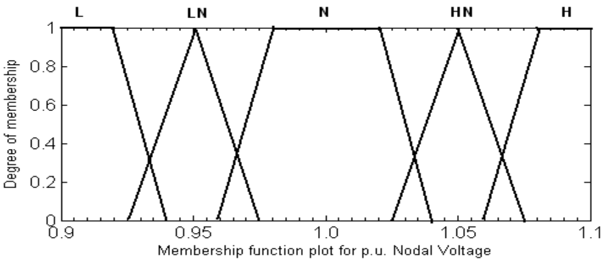

Figure 2: Membership function plot for p.u. Nodal voltage

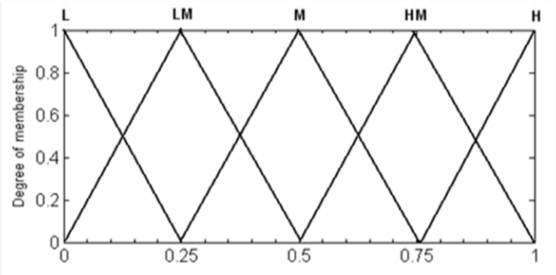

Figure3: Membership function plot for D.S.I.

For the Distributed Generator allocation problem, rules are defined to determine the suitability of a node for Distributed Generator installation. Such rules are expressed in the following form:

AND		**Voltage Magnitudes**				
		L	**LN**	**N**	**HN**	**H**
PLI / Real Load	**L**	**LM**	**LM**	**L**	**L**	**L**
	LM	**M**	**LM**	**LM**	**L**	**L**
	M	**HM**	**M**	**LM**	**L**	**L**
	HM	**HM**	**HM**	**M**	**LM**	**L**
	H	**H**	**HM**	**M**	**LM**	**LM**
		DSI				

IF premise (antecedent), THEN conclusion (consequent) for determining the suitability of Distributed Generator placement at a particular node, a set of multiple antecedent fuzzy rules has been established. The inputs to the rules are the voltage and power loss indices and the output is the suitability of Distributed Generator placement. The rules are summarized in the fuzzy decision matrix in Table 1. The consequents of the rules are in the shaded part of the matrix.

Table 1: Decision matrix for determining the optimal Distributed Generator locations

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 [16, 17].

- 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, $SAIDI = \Sigma(r_i * N_i) / N_T$

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, 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, SAIFI $=\Sigma(Ni) / NT$

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, ASAI $= [1 - (\Sigma (ri * Ni) / (NT* T))] * 100$

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. TEST BUS SYSTEM

The proposed model is tested on IEEE - 15 bus system. For this we require system data. Data for 15-bus system. Figure 4 shows the IEEE standard 15 bus system.

No of Buses = 15

No of Branches=14

Base Voltage = 11 kV

Base MVA = 100 MVA

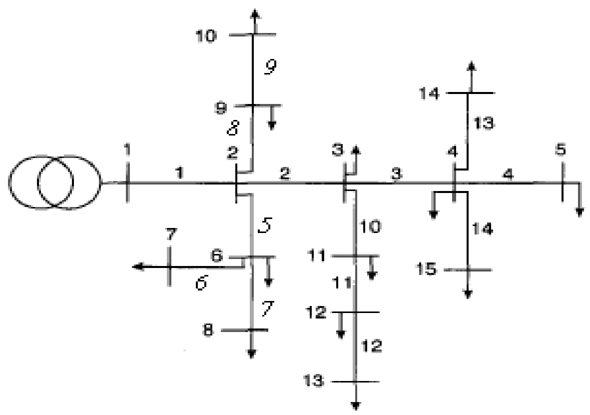

Figure 4: Single Line Diagram of the Test Network

Table 2: The Load Data of IEEE-15Bus System

Branch No	Sending end node	Receiving end node	R (Ohms)	X (Ohms)	P (kW)	Q (kVAr)
1	1	2	1.1183	1.0938	44.10	44.99
2	2	3	0.9671	0.9460	70.00	71.41
3	3	4	0.6951	0.6799	140.00	142.82
4	4	5	1.2591	0.8493	44.100	44.99
5	2	6	2.1135	1.4255	140.00	142.82
6	6	7	0.8993	0.6066	140.00	142.82
7	6	8	1.0342	0.6976	70.00	71.41
8	2	9	1.6638	1.1222	70.00	71.41
9	9	10	1.3940	0.9402	44.10	44.99
10	3	11	1.4839	1.0009	140.00	142.82
11	11	12	2.0235	1.3649	70.00	71.41
12	12	13	1.6638	1.1222	44.10	44.99
13	4	14	1.8436	1.2436	70.00	71.41
14	4	15	0.9893	0.6673	140.00	142.82

VI. RESULTS AND ANALYSIS

First load flow is conducted for IEEE - 15 bus test system. The power loss due to active component of current is 30.4169 kW and power loss due to reactive component of the current is 31.3768 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 5.

Table 5: Total losses of 15-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**
30.4169	31.3768	61.7937

The proposed fuzzy approach is applied to 15-bus system. Optimal Distributed Generator locations are identified based on the D.S.I. values. For this 15- bus system, three optimal locations are selected based on loss reduction.

Table 3: PLI and Voltage values of 15-bus system

PLI VALUES	VOLTAGE VALUES (P.U)
1.0000	0.9717
0.4952	0.9572
0.1703	0.9515
0	0.9505
0.5245	0.9587
0.0537	0.9565
0.0123	0.9574
0.0994	0.9684
0.0030	0.9673
0.2515	0.9505
0.1384	0.9464
0.0146	0.9451
0.0576	0.9492
0.0650	0.9490

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.

Table 4: D.S.I values of 15-bus system

DSI VALUES	BUS NUMBER
0.5493	2
0.5363	6
0.4924	3
0.2522	11
0.25	8
0.25	14
0.25	15
0.25	5
0.25	4
0.25	7
0.25	12
0.25	13
0.2208	9
0.2191	10

Best three locations = [6 3 11]

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 [18]. 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.

VII. CONCLUSION

To determine the locations Fuzzy approach is developed. The proposed fuzzy approach is capable of determining the optimal DG locations based on the D.S.I. values. The validity of the proposed method is proved from the comparison of the results of the proposed method with and without DG. By placing DG the total power loss of the system has been reduced drastically and the voltage profile of the system is also improved. Inclusion of the real time constrains such as time varying loads and different types of DG units and discrete DG unit sizes into the proposed algorithm is the future scope of this work. 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 is congestion relief, loss reduction; voltages profile improvement and improvement in reliability.

This paper 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.

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