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Original Article

DG Placement in Distribution Systems using Analytical Techniques

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Abstract *- The distributed generation to power distribution lines has become a trend in the world. The reasons behind the increasing use of distributed generation include the high cost of energy, environmental concerns, and the latest advancements in DG technology. Renewable DG sources are preferable to place near load center inject power in the system, hence support the system voltage, minimizing losses, and improve reliability. Location selection is an essential aspect of planning. A Selection method for DG placement with minimization of power loss objective is implemented in this research work. An Analytical technique was adopted here for DG placement with Voltage sensitivity index along with Voltage profile improvement indicator (VPII). A ranking created on voltage sensitivity index and VPII has been obtained for the best placement of DGs. Distribution load flow is implemented for loss calculation. Results and performance of the system are evaluated on33-bus test system.*

Keywords - *Minimization of power loss, DG, voltage sensitivity index, VPII, and 33-bus test system.*

I. INTRODUCTION

The encouraging impact and efficient performance of small size Distributed generation paid a lot of interest in recent times. The utilization of DG is one of the practicable alternatives in the existing distribution network, which provides various benefits to customers, service utility, and society[1]. All the technical advantages such as; power quality of system improved, voltage profile improved, reliability improved with DG integration, and problem from congestion is greatly relieved with significant losses reduction.

The distribution losses are greatly increased due to poor voltage regulation and high line resistance. In most cases, the minimization of line losses is done by network reconfiguration as it is most economical reported by [2]; however, the complex control circuitry is required for network reconfiguration. The capacitor placement is also one of the promising solutions in high distribution networks [3]-[4] but having a limited impact on low voltage distribution.
The electrical utilities are also paying more attention to power system protection, coordination, and dynamic stability [5] due to the integration of new Distributed generation technology. The incremental voltage sensitivity is presented by [6] to enhance system stability margin in the sub-transmission system. The line load of the distribution network change from low to high levels frequently face critical loading conditions, which leads the system toward voltage collapse. Many incidents of blackouts have been reported due to voltage stability issues worldwide[7].

To place the local distribution generation in line. Several studies have shown the DG may have a positive or negative influence depending on the operating factors of a system and kind of Distributed generation[8]-[9]. The connection of DG to the customer or utility site affects the power flow change in voltage conditions [10]. The 2/3 rule [11]that straightforwardly implemented on 2/3 location gives the best DG placement result applies only to a uniform distribution, which was found to exist the smooth method for DG allocation. Still, it does not apply to other load distributions[12]. Placement of distributed generation by analytical approach compared to classical optimization techniques, meta-heuristic techniques, or any different optimization technique have few benefits over other techniques, such as giving fast and simple calculations. Analytical approaches adopt simple formulation, unlike iterative programs[13]. Analytical methods with good convergence speed can efficiently handle single-objective problems [14]. However, the analytical method is not suitable for complex and multi-objective problems. Classical optimization techniques, meta-heuristic techniques, or any other optimization technique give more practical solutions[15].

The reactance of the distribution line is negative, which makes the system ill-conditioned, with a high R/X ratio.[16]–[17] The load flow methods adopted in a transmission line is not such Newton Raphson, and Fast Decoupled is not suitable here[18]. The distribution load flow solution recommended by [19]developed an algebraic equation that is fast and simple in implementation. Various other DSLF methods [20], such as backward-forward sweep mostly used due to simplicity. The internal factors and load imbalance make radial distribution systems inherently unbalanced. Load balancing assumption is not applicable in each case. Distribution load flow program with balanced and unbalanced radial distribution DG placement algorithm with simple maths equation is developed by[21].

Study work deals with the placement of distributed generators with having loss minimization objectives. The worked divided into five sections. The first section deals with the introduction. Section II deals with calculating losses and implementing a voltage sensitivity index and a voltage profile improvement index. The ranking is created based on indexes. Section III outlines a step-by-step procedure for DG placement at an optimal location, with exercises to locate DG with capacity planning. Section IV deals with the test system's simulation results. The last section covers the conclusion part.

II.METHODOLOGY

A. Problem Formulation

The work focuses on power loss minimization to a significant amount by adding the DG in a distribution network with optimal site and size. DG with optimal size calculation given as follows for each bus i,

$$P_i = P_{DG} - P_{Di} \tag{1}$$

Where, P_i = Power injection, at node i.

P_{DG} = Power generation, at node i.

P_{Di} = Power demand, at that node i.

Suppose branch current in the distribution system is represented by I , the resistance of the line is r and jj is the branch number, then generalized real power loss (LP) can be mathematically written as

$$\text{Power loss} = \sum_{jj=1}^{n} LP(jj) = \sum_{jj=1}^{n} I(jj)^2 \times r(jj) \tag{2}$$

Subjected ;

Voltage constraint;

Voltage magnitude at each node must lie within their permissible range.

$$|V_{i\min}| \le |V_i| \le |V_{i\max}| \tag{3}$$

Equality Constraints;

Total Power generation by the DG (P_{DG}) and supply of power from the substation(P_G) to the load point must be equal to the power demand of load (P_D) and line losses (P_{LOSS}) in the distribution system.

The Power balance equation is written as

$$P_G = P_D + P_{LOSS} - P_{DG} \tag{4}$$

$$|P_{DG}| \le P_{Dmax} \tag{5}$$

Whereas P_{DGmax} - maximum power generation by DG.

B. Optimal Location placement

a) Voltage Sensitivity index

Aiming power loss reduction objective for placement of distributed generation utilizes the set of the index containing voltage-sensitivity-index[21]-[22] and voltage profile improvement indices. For the selection of DG, Lower value and higher value respectively for voltage sensitivity index, and VPII have been chosen for ranking. Voltage Sensitivity index is defined as:

$$v_{index} = \sqrt{\frac{\sum_{k=1}^{n}(1-V_k)^2}{n}} \tag{6}$$

V_{index} is the voltage sensitivity index, V_k is k_{th} node voltage.

b) Voltage- profile- improvement- Indices (VPII)

This index prominently verifies the improvement in voltage- profile[23]. As the Distributed generation is placed in the system, it provides the voltage enhancement to the corresponding node.

$$VPII = \frac{VP_{wDG}}{VP_{woDG}} \tag{7}$$

The value of VPII>1 shows voltage improvement. More the value of VPII better the voltage profile. When VPII=1 shows no change in voltage profile, If the VPII is<1, which indicates the DG is inappropriate for voltage improvement.

Assumptions consider here; Active power is only supplied by DG, Load points are connected with DG. Generally, source nodes are not connected with DG.

Steps followed for optimal rating and siting the local generation

- Firstly the penetration of DG with 25 % substation loading capacity is applied at each node one by one at a time.
- The voltage sensitivity index of all nodes is calculated by equation (6) at each node at a time. To prepare a ranking list for the system, the lowest index placed at the top rank.
- The placement of DG is prioritized based on the ranking list. Now vary the rating of DG from the lowest value to highest substation loading capacity in fixed step sizes till maximum reduction of losses is not achieved.
- A distribution generator with reduced losses is selected for optimal placement.

III. SIMULATION RESULTS AND ANALYSIS

Implementation of work has been performed on MATLAB environment with 33-bus radial distribution system [24]. The voltage sensitivity index obtained is shown in Fig.2. The real and reactive power from the substation is 3.715MW and reactive 2.3 MVAR.

The single line diagram of the test system shown in Fig. 1.

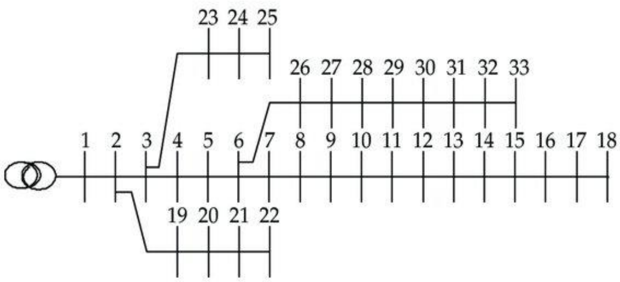

Fig.1 Single line diagram 33-bus radial distribution system.

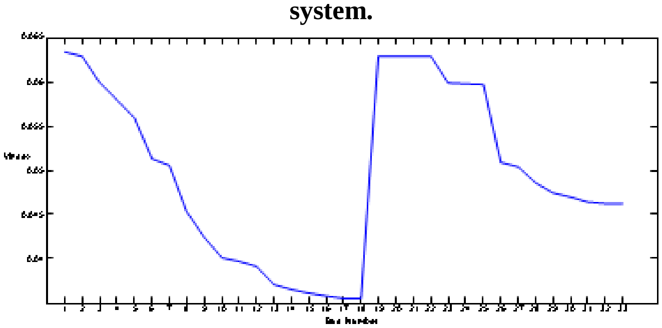

Fig.2$\mathbf{V_{index}}$ with 25% feeder capacity penetration

A. Research proposal

Here choices are proposed for single DG placement in table 1. The upper five cases were considered as per voltage sensitivity index and VPII, and case 6&7 shows maximum loss reduction capability in that range. DG rating up to 1000kW, node 18 is selected as candidate node with 910kW optimal size. DG rating from 1000kW to 1100kW, node 16 is selected as candidate node with 1050kW optimal size. The VPII is also shown in table-1 for all cases considered with Different penetration at optimal locations, as shown in fig .3 and Fig.4.

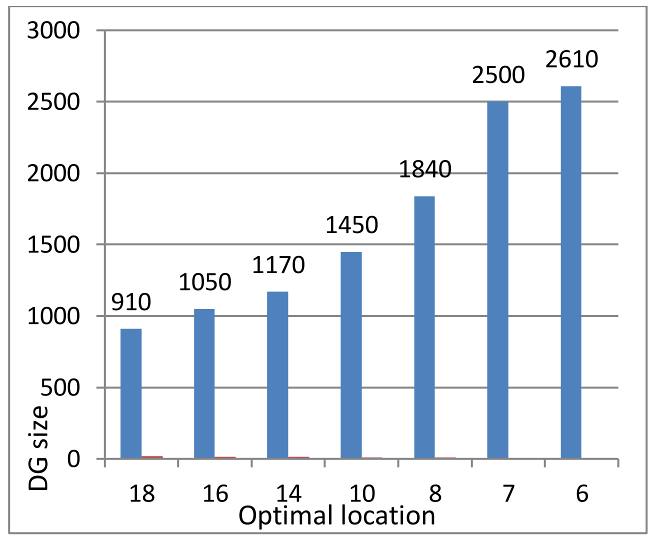

Fig.3 Different penetration at optimal locations

TABLE-I

case	DG Capacity (KW)	Optimal Size kW	Optimal lacation	VPII	P_{loss} $(kW))$	$Q_{loss}(kVAR)$	Min. bus voltage (pu)
Base case	-		-	-	210.0541	141.435	0.9042
Case-1	$0 \leq P_{DG} \leq 1000$	910	18	1.085	141.9799	98.974	0.9314
Case-2	$1000 \leq P_{DG} \leq 1250$	1050	16	1.081	133.5730	90.8783	0.9336
Case-3	$1100 \leq P_{DG} \leq 1250$	1170	14	1.078	127.971	87.302	0.9355
Case-4	$1250 \leq P_{DG} \leq 1500$	1450	10	1.067	120.98	82.845	0.9397
Case-5	$1500 \leq P_{DG} \leq 2000$	1840	8	1.055	115.66	81.662	0.9454
Case-6	$2000 \leq P_{DG} \leq 2500$	2500	7	1.042	110.077	83.363	0.9458
Case-7	$2500 \leq P_{DG} \leq 3000$	2610	6	1.040	109.540	80.826	0.9438

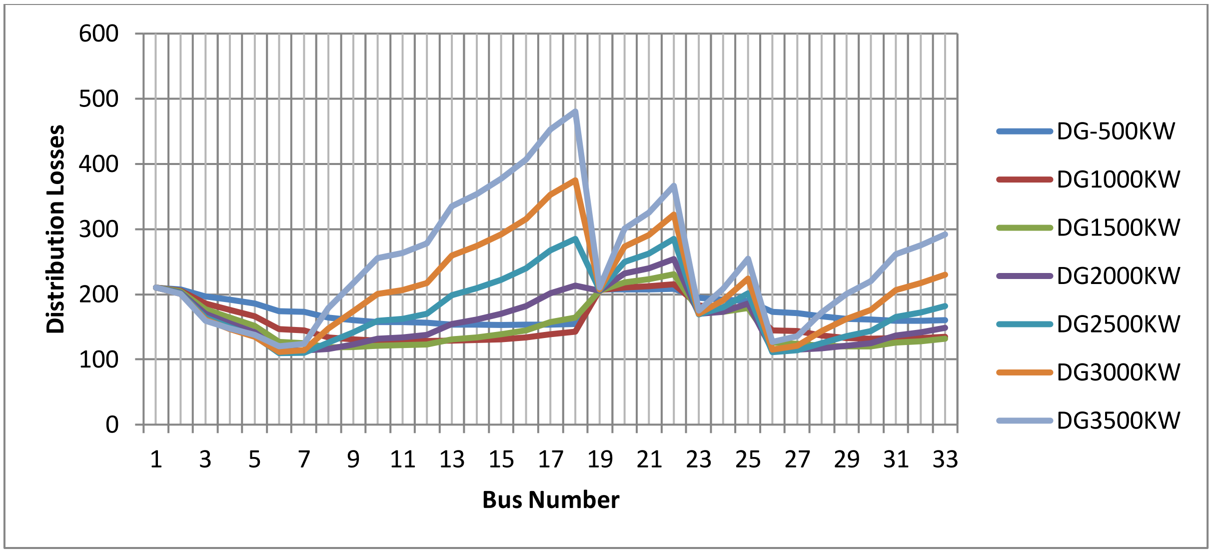

Fig.4 P_{loss} **(kW) Losses with Different penetration at optimal locations**

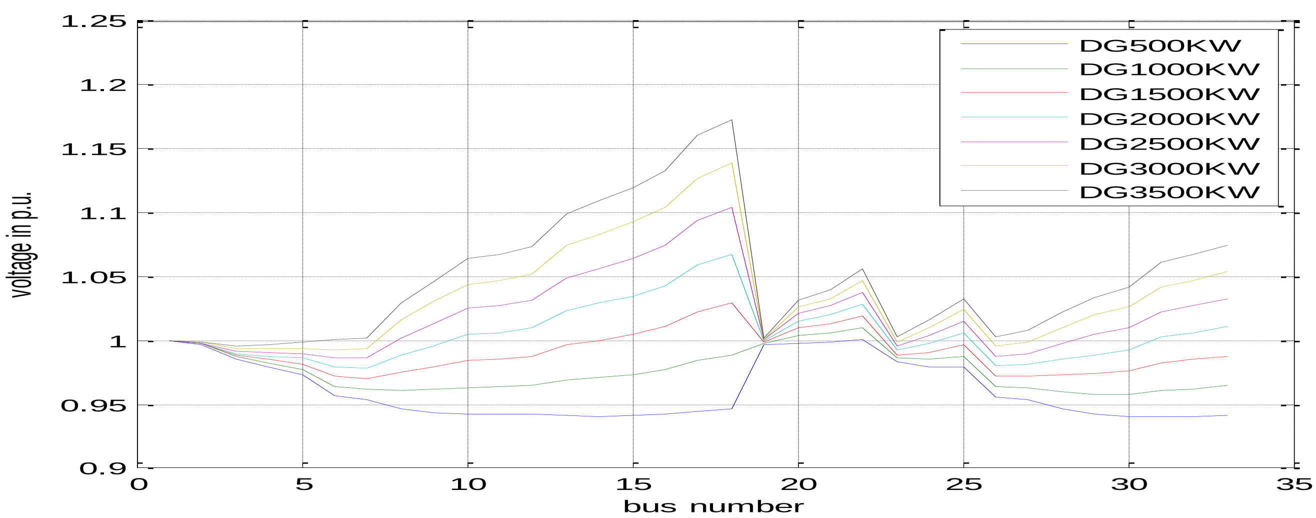

Fig.5 Bus Voltage with Different DG Penetration level

B Result with 1-DG and 2-DG Placement

Firstly the power loss calculation is done by running the distribution load flow program. The optimal location of DG is chosen by voltage sensitivity index and VPII. The lowest value of V_{index} is obtained at bus no. 18 is 0.0369, and the second-lowest value of V_{index} is obtained at the bus no. 16 is 0.037. Both the cases could be considered for single DG placement. DG placement result is given in Table 2. The losses are reduced by DG-1 at location-18 is 32.40% the minimum bus voltage obtained is 0.9314. The losses are reduced by DG-1 at location-16 is 36.41% the minimum bus voltage obtained is 0.9336. For two DG placements at 18 and 6 locations, reduction of losses is 55.66% achieved. The voltage with base case and voltage improvement with single and two DG placement is shown in fig. 6.

TABLE-II

S.No.	Status	Optimal Location		Capacity (kW)		$P_{loss}\ (kW)$	$Q_{loss}(kVAR)$	Min. bus voltage(pu)
		DG1	DG2	DG1	DG2			
1	No DG	---	---	0	0	210.0541	141.435	0.9042
	1-DG	18	---	910	---	141.9799	98.974	0.9314
2	1-DG	16	---	1050	---	133.5730	90.878	0.9336
3	2-DG	18	6	500	2050	93.0763	66.700	0.9561

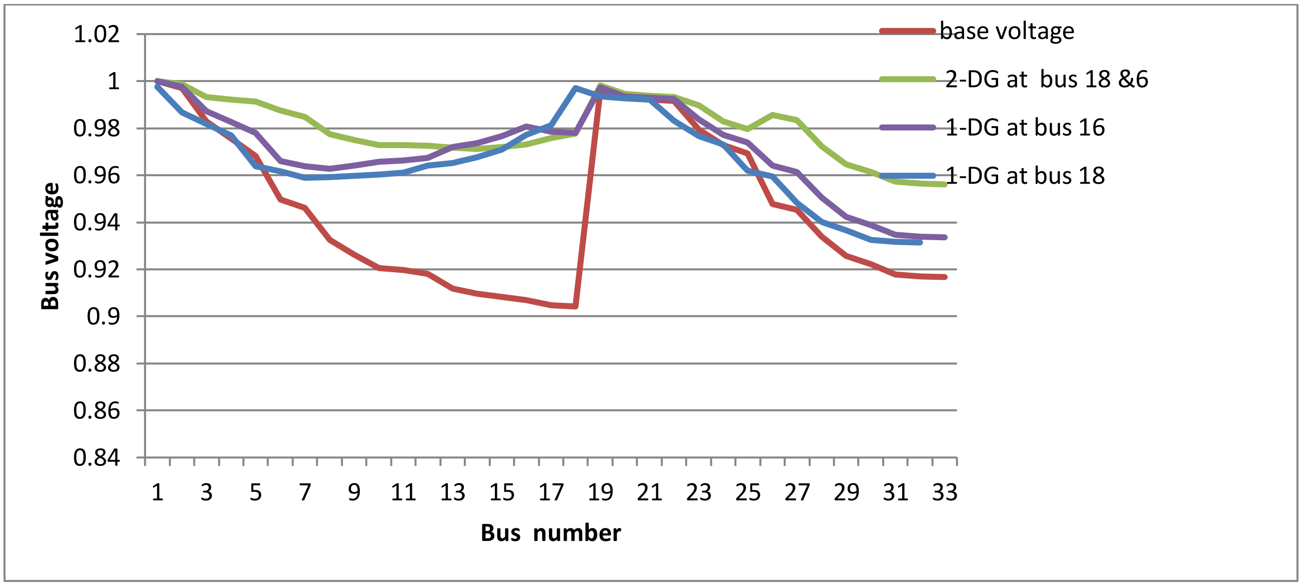

Fig.6 Bus Voltage with and without DG Penetration

V. CONCLUSIONS

Location selection of DG is presented in this work based on voltage sensitivity. Optimal locations are proposed in different DG capacity range with voltage improvement consideration. The results are displayed in table 2 with 1-DG and 2-DG placement. It is concluded that voltage profile improvement is achieved, and system losses are reduced by DG placement. DG provides the Power to the load locally, which reduces the current in the line, thus minimizing the losses and improving the voltage profile. For better capacity planning and placement of DG, an optimization algorithm could be helpful for a fast, accurate result.

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