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Employing an Improved Loss Sensitivity Factor Approach for Optimal DG Allocation at Different Penetration Level Using ETAP

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Abstract: The ability of distributed generation to deliver cost-effective, environment friendly, high-quality and more reliable solutions have resulted in a rise in its use for electricity generation around the world. To balance power demand closer to load centers, DGs and capacitors are preferred over centralized power generation. An appropriate position and capability of DG plays a crucial role in addressing common power system issues like system loss reduction, voltage profile enhancement and stability. The best location for DG in the test system is determined using the loss sensitivity factor in this paper. The top five suitable locations are chosen, and all feasible combinations for DG integration are tested. To achieve minimal losses, Type I and Type II DGs are incorporated individually in the IEEE 33-bus test system at varying penetration levels using ETAP. The penetration levels chosen for the same are 30%, 50%, and 70% for three different scenarios, namely with single DG, two DG, and three DG. The outcomes are then compared to those of other methods.

INTRODUCTION

The rising global demand for electricity has increased the burden on power system utilities. Since conventional fuels used for electricity generation has some adverse effect on environment, therefore to meet this demand, renewable sources of energy are preferred for generation. The ability of DG to supply both active and reactive power helps in power quality improvement. Along, with power, DG also helps in making system more reliable by enhancing voltage profile. The placement and sizing of distributed generation has a significant impact on its performance. Various methods have been used to obtain the ideal location for DG placement. Abdurrahman Shuaibu Hassan et al [1] obtained the ideal location for DG using hybrid BPSO-SLFA algorithm. Waseem Haider et al [2] minimized the system power losses and enhanced voltage profile by optimally placing DG using PSO. Oscar Andrew Zongo et al [3] adopted a hybrid PSO and NRPF technique to place DG and reduce real and reactive power losses in the system along with voltage stability enhancement. Mohamed A. Tolba et al [4] used hybrid PSOGSA for optimal sizing and sitting of DG. MCV Suresh et al [5] used a hybrid GOA-CS technique to reduce power losses in the system by integrating DG. Tuba Gözel et al [6] proposed a loss sensitivity factor based analytical method for DG placement and sizing. Apart from power loss minimization and voltage profile augmentation, other objectives for DG placement are also taken into account. For example, Srinivasa Rao Gampa et al [7] properly located and sized DG by considering average hourly load variation. C. Hari Prasad et al [8] employed the EHO method to do a cost-benefit analysis for appropriate DG placement in a distribution system. Another important factor for DG integration is penetration level. Various studies show that integration of DG beyond a certain limit has a negative impact on the system. The level of penetration is another crucial component in DG integration. Several studies have found that integrating DG beyond a certain point has a deleterious effect on the system. Minh Quan Duong et al [9] integrated wind and PV system into the grid and found that when these generators are penetrated at less than 30%, the system operates satisfactorily. K. Balamurugan et al [10] studied the impacts of DG at different penetration levels and DG location in the system. Desmond Okwabi Ampofo et al. [11] conducted a study on the effects of high DG penetration levels on distribution line thermal limitations and voltage rise. There are four types of DG

- Type I: DG supplying real power

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- Type II: DG supplying reactive power
- Type III: DG supplying real and reactive power
- Type IV: DG supplying real power and consuming reactive power [12]

The power system is affected differently by each type. The impact of various DG types on the power system was investigated by A.M. Abd-rabou et al [13].

The best position for DG placement in the IEEE 33-bus test system is determined using LSF in this paper. The type I and type II DGs are then pierced at various levels on the best location obtained. ETAP software is used to run the simulation. The size of DG in the test system is such that minimal losses are attained. After then, the findings are compared to those of other studies.

PROBLEM FORMULATION

The goal of this article is to reduce the test system's reactive power losses. The total real and reactive power at bus I can be given as,

$$P = P_{\mathrm{i}} + R_{\mathrm{ik}} \frac{P_{\mathrm{i}}^2 + jQ_{\mathrm{i}}^2}{V_{\mathrm{i}}^2} \tag{1}$$

$$Q = Q_{\mathrm{i}} + X_{\mathrm{ik}} \frac{P_{\mathrm{i}}^2 + jQ_{\mathrm{i}}^2}{V_{\mathrm{i}}^2} \tag{2}$$

The system's power losses are given by,

$$P\iota_{(\mathrm{ik})} = R_{\mathrm{ik}} \frac{P_{\mathrm{i}}^2 + jQ_{\mathrm{i}}^2}{V_{\mathrm{i}}^2} \tag{3}$$

$$Q\iota_{(\mathrm{ik})} = X_{\mathrm{ik}} \frac{P_{\mathrm{i}}^2 + jQ_{\mathrm{i}}^2}{V_{\mathrm{i}}^2} \tag{4}$$

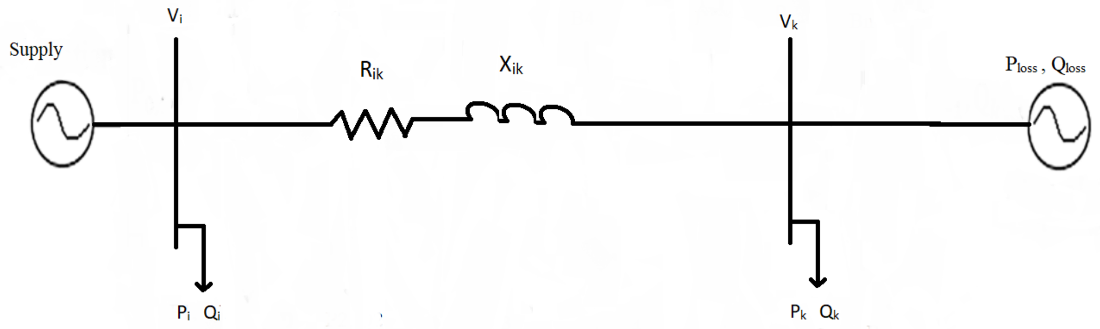

Fig 1. Distribution system as single line diagram

The diagram above depicts a distribution system with buses i and k. These buses have voltages of Vi and Vk, respectively and a line impedance $R_{ik} + jX_{ik}$.

PROPOSED TECHNIQUE

The best placement for DG is determined utilizing the improved loss sensitivity factor approach, which aids in determining the bus with the greatest reduction in loss when DG is added. The shift in losses corresponding to compensation given by putting the DGs is referred to as loss sensitivity. [14] The ILSF is given by,

$$\frac{\partial P\iota}{\partial Q_{\mathrm{net}}} = \frac{2 \times \mathrm{Q_k} \times \mathrm{R_{ik}} \times V_k^2}{V_k^2} \tag{5}$$

$$\frac{\partial Q\iota}{\partial Q_{\mathrm{net}}} = \frac{2 \times \mathrm{Q_k} \times \mathrm{X_{ik}} \times V_k^2}{V_k^2} \tag{6}$$

To obtain the ILSF, equation (6) is used. Based on the loss sensitivity parameters and voltage magnitude, the best places for DG deployment are selected. The magnitude of the voltage aids in evaluating the need for compensation, and the ILSF aids in deciding the priority order. The brief procedure to obtain the DG locations is

- Obtain load and line data, then run the load flow
- Losses in reactive and real power are calculated
- Obtain ILSF using equation (6)
- Store ILSF values in vector form
- Obtain voltage magnitudes
- Select the bus maximum loss reduction and high voltage magnitude

For DG installation, the top five locations are chosen. Three distinct penetration levels are used to penetrate the DG: 30%, 50%, and 70%. In case I, a single DG is pierced at various penetration level at all of the locations. Case II involves penetrating two DGs using all conceivable combinations of locations obtained at various penetration levels. In case III, three DGs using every feasible combination are employed. The results are then compared with other methods.

RESULTS

The test system used in this study is IEEE 33-bus. The base voltage and MVA is 12.66kV and 100 MVA respectively. The total load on the system is 3.715 MW and 2.315 MVar. The optimal locations obtained for DG placement are bus number 6,13,24,30. The results are obtained using all the possible combinations of these buses for case II and case III. The magnitude of DG is calculated by observing and analyzing prior research findings. After attempting all conceivable combinations, the best results are compared to those achieved using alternative methods. The losses for base case (without DG) are 203 kW and 136 kVar.

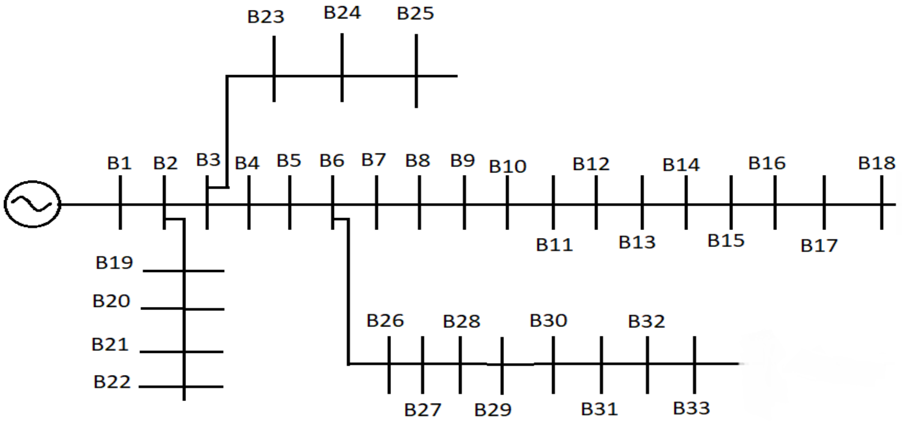

Fig 2. IEEE 33-bus as single line diagram

Simulation results using proposed method for different cases at different penetration levels are shown in table below.

Table 1. Results obtained using type I DG

Penetration level	DG size (kW)	Bus no. - DG size (kW)	Losses		% V_{min} (Bus no.)
			Active power(kW)	Reactive power(kVar)	
1 DG					
30%	1115	13	130	87	93.81 (33)
50%	1856	6	116	82	93.78 (18)
70%	2600	6	105	76	94.72 (18)
2 DG					
30%	1113	30-527 13-587	114	76	94.11 (33)
50%	1988	13-851 30-1137	87	60	96.20 (33)
70%	2599	13-1107 30-1492	88	61	97.55 (33)
3 DG					
30%	1114	6-283 13-380 30-451	118	80	93.97 (33)
50%	1860	13-634 25-375 30-851	88	60	95.27 (33)
70%	2632	30-1035 13-854 25-743	74	51	96.21 (33)

Table 2. Results obtained using type II DG

Penetration level (approx.)	DG size (kVar)	Bus no. - DG size (kVar)	Losses		% V_{min} (Bus no.)
			Active power(kW)	Reactive power(kVar)	
1 DG					
30%	693	30	159	106	92.42 (18)
50%	1218	30	144	97	92.42 (18)
70%	1620	30	145	99	92.77 (18)
2 DG					
30%	693	13-282 30-411	160	107	92.55 (18)
50%	1155	13-525 30-630	145	97	93.50 (18)
70%	1550	13-400 30-1150	136	91	93.28 (18)
3 DG					
30%	693	6-180 13-240 30-273	163	109	92.46 (18)
50%	1155	6-411 30-510 13-234	146	98	92.87 (18)
70%	1827	13-360 6-510 30-957	134	90	93.75 (18)

Table 3. Comparison of simulation results for type I DG integrated with 33 bus test system

Reference	Method	DG Size in kW (location)	Total DG Size (kW)	Total Active power loss (kW)	Total Reactive power loss (kVar)	V_{min}
1 DG						
	Proposed	2445 (6)	2445	106	76	0.9453
[15]	GAMS	2589.52	2589.52	110.69	-	0.9433
[16]	WOA	2589.60	2589.60	111	81.69	0.9424
[14]	Dragonfly algorithm	2590.2	2590.2	111.033	81.6859	0.9424
[17]	HHO	2584.1287	2584.1287	110.214	81.4524	0.9426
[17]	TLBO	2584.5546	2584.5546	110.706	81.4517	0.9424
[18]	MRFO	2590.217	2590.217	110.271	-	-
2 DG						
	Proposed	851 (13), 1137 (30)	1988	87	59.60	0.9620
[15]	GAMS	851.05 (13), 1157.57(30)	2008.62	86.87	-	0.9684
[17]	HHO	863.0261 (13), 1139.0726 (30)	2002.0987	87.1337	59.765	0.9681
[17]	TLBO	846.1427 (13), 1156.9739 (30)	2003.1166	87.1503	59.7918	0.9680
[18]	MRFO	1157.6 (30), 851.5089 (13)	2008.5	87.1664	-	-
3 DG						
	Proposed	1036 (30), 854 (13), 743 (25)	2633	74	51	0.9621
[18]	MRFO	1017.10 (24), 788.276 (13), 1035.3(30)	2840.67	72.876	-	-
[15]	GAMS	801.22 (13), 1091.31 (24), 1053.59 (30)	2946.12	72.49	-	0.9686
[17]	HHO	811.749 (13), 1051.6753 (24), 1045.9353 (30)	2909.3599	72.718	50.6231	0.9685
[17]	TLBO	856.678 (13), 772.488(25), 1072.83 (30)	2701.996	73.75	51.03	0.9688

It was observed that when type I DG was integrated, the minimum losses obtained were 76 KVar and 106 KW at 70% penetration level for case I. For case II, the minimum losses obtained were 87 KW and 59.60 KVar at 50% penetration level. For case III, the minimum losses obtained were 74 KW and 51 KVar at 70% penetration level. For case I, the minimum losses obtained when type II DG was integrated in the system were 144 kW and 97 KVar at 50%. For case II, the minimum losses obtained were 137 KW and 93 kVAr at 70% penetration level. For case III, the minimum losses obtained were 136 kW and 91 KVar at 70% penetration level. The table below shows the comparison of results obtained with other methods.

Table 4. Comparison of simulation results for type II DG integrated with 33 bus

Reference	**Method**	**DG Size in kVAr (location)**	**Total DG Size (kVAr)**	**Total Active power loss (kW)**	**Total Reactive power loss (kVar)**	**V_{min}**
			1 DG			
	Proposed	1218 (30)	1218	144	97	0.9242
[17]	HHO	1257.436 (30)	1257.436	150.638	103.613	0.9168
[17]	TLBO	1258 (30)	1258	151.364	103.8906	0.9165
[19]	HGWO	1258 (30)	1258	151.36	-	0.9163
			2 DG			
	Proposed	400 (13), 1150 (30)	1550	137	93	0.9328
[17]	HHO	463.9532 (12), 1064.4184 (30)	1528.3716	141.1227	95.9922	0.9306
[17]	TLBO	464.9027 (12), 1063.8724 (30)	1528.7751	141.8298	96.5048	0.9303
[19]	HGWO	467 (12), 1054 (30)	1521	141.83	-	0.9338
			3 DG			
	Proposed	957 (30), 510 (24), 360 (13)	1827	136	91	0.9339
[17]	HHO	368.161 (13), 555.0606 (24), 1025.4766 (30)	1948.6982	137.711	93.9395	0.9318
[17]	TLBO	390.8282 (13), 540.5043 (24), 1036.1466 (30)	1967.4791	138.2529	94.277	0.9318
[20]	CSA	400 (11), 400 (24), 950 (30)	1750	138.7612	-	0.9277

CONCLUSION

The optimal location of DG is obtained using improved loss sensitivity analysis in this paper. Type I and type II DG are integrated at best locations, obtained at different penetration levels. It is observed that with solar DG, for cases I and III the minimum losses are obtained at 70% penetration level where as for case II, minimum losses are obtained at 50% penetration level. With capacitors, the minimum losses are obtained at 70% for cases II and III where as for case I, the minimum losses are obtained at 50%. It is observed that the losses acquired using the suggested technique are lower than those obtained using other methods. The system loss minimization can be achieved by DG integration but the penetration level varies according to the DG type and number of DG used in the system. It can be stated that increasing penetration levels above 50% leads in a modest change in percentage loss reduction.

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