Optimal Placement of DG for Power Loss Minimization: A Review

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Abstract- **Distributed generation is the future of electrical energy because the fuels (such as coal) used in conventional methods are depleting day by day. The demand for electricity is increasing rapidly. Hence, consumption of conventional fuels is also increasing resulting in depletion of these resources and high carbon emissions. Also, the harmful impacts caused by these resources has shifted the focus towards more eco-friendly methods i.e. renewable sources of energy. Integrating these renewables with existing system is the new trend. Various studies have been carried out discussing the merits and demerits of DG integration with the central grid. The process of adding distributed generators with the power system is quite challenging. The DG's should be added such that it enhances the system performance and increases reliability. This paper discusses about the optimal placement of DG to reduce power losses in the network.**

Keywords- Distributed generation, Power losses, DG penetration, Optimal placement, Voltage stability.

1. INTRODUCTION

Distributed generation also known as decentralized generation or embedded generation is broadly defined as the generation of electricity at or near the site of consumption. The method of generation usually involves renewable resources; therefore, these are referred as distributed energy resources. Renewable energy sources are the current trends in electricity generation (mainly hydropower) because they are present in abundance and also cause no harm to the environment. The hydropower alone contributes to the 62.83% of total world renewable energy generation followed by wind (19.03%), solar (8.76%) and others. The countries across the globe are targeting to synchronize the DG's with the existing grids to reduce the carbon emission and other harmful impacts of conventional generation. Integrating such type of generation units with existing grid helps not only in reducing losses but also enhances the power quality by improving the voltage profile. But the major problem arises when the integration level increases and reaches a value where these DG starts showing a negative impact on the system. The penetration of DG into the grids is a major concern because when more load is shifted to DG's, the load on existing generating units is reduced which leads to various unbalancing problems in the system. Hence, before planning any system it is important to study whether it can cope with increasing use of DG or not. The existing grids were not designed to accommodate DG, but with time, the use of DG has increased and hence, the system should be updated accordingly.

There are mainly four types of DG's

1. Type 1: DG which inject both active power and reactive power in the system.
2. Type 2: DG capable of injecting only active power.
3. Type 3: DG delivering reactive power only.
4. Type 4: DG which absorb reactive power and inject active power in the system.[1]

The methods of generation can vary from solar photovoltaics, wind energy conversion system to fuel cells, diesel engines etc. Each method has a different impact on the power system. The negative impact includes the voltage quality degradation, induction of harmonics in the system, increased voltage fluctuations on the consumer side which further results in poor power quality, voltage stability issues, power system inertia, increasing fault currents, false current detection by power system protection equipment.

Penetration level of DG in the system is obtained by,

$$\%DG_P = \frac{P_{DG}}{P_{DG} + P_{CG}} x\ 100$$

Where, $\%DG_P$ = percentage of DG penetration

P_{DG} = power generated by DG

P_{CG} = power generated by centralized grid

Studies show that siting of DG in the system is a crucial factor to determine its impact on the grid. Inappropriate placement of DG in the network leads to overvoltage and phase imbalances. However, when placed at suitable nodes, it enhances the voltage profile and phase imbalance is comparatively low. [2] Integration of DG with a weak distribution network causes a voltage rise during low load demand. Although, by strengthening the overhead lines and placing a shunt reactance at critical points, the electrical power losses are reduced along with the enhancement of voltage profile. [3] Large integration of DG also results in injection of high short circuit currents in the system. At an appropriate penetration level, the short circuit currents are not of much concern in reference to protection system. [4]. Due to uncertainty in load demands, power system utilities are facing problems related to control and stability of the system. Hence, it is important to improve the power quality of the system by integrating it with

DG. But integration of DG in the system such that the system remains balance is a challenge for utilities and researchers as well. To enhance the system performance, the location of distributed generators along with proper size should be used. Many researchers observed various ideal location in different test system considering multiple factors to add DG in the system. Neenu Rose Antony et. Al [5] obtained the ideal location of DG by enhancing voltage stability. Satish Kumar Injeti et al. placed DG along with plug in electric vehicle to enhance voltage profile and minimize power losses. [6] Mir Emad Hamidi et al. reduced the negative impact of DG on distribution system by placing it with fault current limiter. [7] M.M. Aman used approach based on power stability index. [8]Galiveeti Hema kumar Reddy et al placed DG to enhance system reliability and response. [9] Various studies have been carried out to improve voltage stability along with decrease in power losses. [10][11][12][13][14][15] This paper focuses on the researches carried out so far on optimal placement of DG in order to minimize power losses in the system.

2. IMPORTANCE OF DG SIZING AND SITING

Various studies have been carried out discussing the impacts of placing a DG at different nodes in the system. These studies suggested that placement of DG is an important factor to extract the maximum benefit from the system. The size of DG along with suitable location is another crucial factor for enhancing power system performance. The best location depends on the type of DG used. When integrating a single-phaseDG, the allocation should be done at varying phases such that the phase imbalance limits are not violated. The size of DG defines the penetration limit and varies with system. [2]

3. FACTORS CONSIDERED FOR OPTIMAL PLACEMENT OF DG

3.1 DG Penetration Factor (DGPF):

Losses are required to be minimized in order to achieve a healthy and stable operation power system. These losses are either active power losses or reactive power losses. The power losses between line (i) and (i+1) are given by,

$$\mathrm{P_{loss}}(i, i+1) = \frac{(P_i^2 + Q_i^2)}{|V_i^2|} \times r(i, i+1)$$

where, P_i is active power flow at bus i and Q_i is reactive power flow at bus i[5]. High penetration of DG results in more reduction of losses, but penetration of DG beyond a certain limit can adversely affect the power system.

3.2 Voltage Profile

What impact will DG have on system voltage profile depends on how much active and reactive capacity the DG has. Overvoltage caused due to DG can be avoided by making slight adjustments in capacitor switching on the node at which DG is placed.[2] The voltage can be controlled either by controlling devices or by properly designing the system.

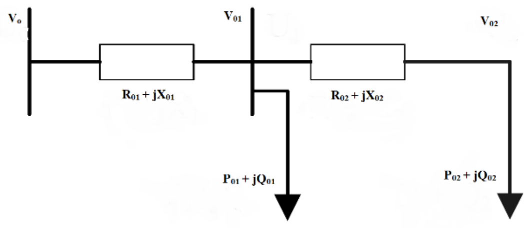

Fig.1 Sample network

The voltage drop between the lines can be given as,

$$\Delta V_i = \frac{P_{0i}R_{0i} + Q_{0i}X_{0i}}{V_r}$$

V_r is the rated system voltage. The voltage at node 2 is given as,

$$V_{02} = V_0 - \Delta V = V_0 - \frac{P_{01}R_{01} + Q_{01}X_{01}}{V_r} + \frac{P_{02}R_{02} + Q_{02}X_{02}}{V_r}$$

With addition of DG at bus 1, the voltage at node 2 becomes,

$$V_{02} = V_0 - \Delta V$$

$$= V_0 - \frac{(P_{01} - P_{dg})R_{01} + (Q_{01} - Q_{dg})X_{01}}{V_r} + \frac{P_{02}R_{02} + Q_{02}X_{02}}{V_r}$$

From above equation, it can be derived that the voltage levels in the system varies with variation in integration level and position of the distributed generation in the power system. The penetration level of DG in the system should be such that it enhances the system voltage profile. [16]

3.3 .Transient stability of system

When a system is subjected to a large disturbance, it tends to return to its initial stable conditions. This ability of power system is known as transient stability of system. The penetration of DG means meeting the increased load demand with DG or by supplying the increasing demand caused by unit outage due to any reason. The transient can be analysed by analysing the maximum deviation in rotor speed and the duration of oscillations during and after fault. The weak connection between generators and loads on a heavily loaded line causes large oscillations. Hence, increased power flow has a harmful effect on the damping of oscillations. Integrating DG with controllers can reduce oscillations in the system.[35] The equations showing the unbalancing between mechanical and electromagnetic torque of a single machine for transient stability analysis can be given as,

$$\frac{d\omega}{dt} = \frac{1}{2H}(T_m - T_e - K_d\omega)$$

Where T_m and T_e are mechanical and electromagnetic torque respectively. K_d is the damping factor, H denotes inertia constant and ω represents angular velocity of rotor. This equation is applicable to DG using synchronous generators, wind turbines etc. Since, there is no moving part in solar generation therefore there is no inertia. The above equation in terms of power is given as,

$$\frac{d\omega}{dt} = \frac{1}{2H}(P_m - P_e - K_d\omega)$$

Where P_m and P_e is the input mechanical power and output electrical power respectively. [17]

3.4 Fault current

During a fault, the DG contributes to the fault current, which leads to malfunctioning of the system and affecting the system security and reliability. Studies show that a fault occurring at generation node contributes to maximum fault current ratio (ratio of fault current with DG and without DG) whereas at low voltage nodes the impact of fault current is significantly low. [2]

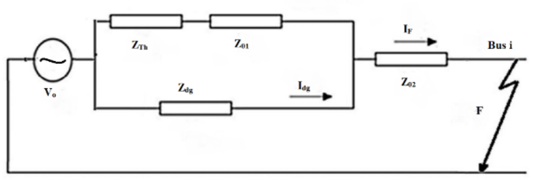

Fig.2.Sample model for short circuit

In above figure, I_F represents fault current at bus i, which is given as,

$$I_F = \frac{V_o}{\frac{(Z_{Th}+Z_{01})\text{ x }Z_{dg}}{Z_{Th}+Z_{01}+Z_{dg}} + Z_{02}}$$

Where Z_{01} and Z_{02} are line impedances, Z_{Th} is Thevenin equivalent. $Z_{dg}$is the impedance of DG. [7]

3.5.Economical factors

These factors are considered in order to reduce the DG investment, operation and maintenance cost. For example, the ideal location for setting up solar plant is where sufficient amount of sunlight is available throughout the year in order to maintain smooth operation of the plant. Similarly, wind plants must be placed where winds at desirable speed flows. Srinivasa Rao Gampa et. al. used cost ratio to calculate the most economical size of DG which is given as,

$$CR = \frac{\sum C_{dg}P_{dg}}{\sum C_{dg}\text{ x }P_{dg}^{max}}$$

C_{dg} represents the cost of DG and P_{dg}represents the power generated from DG. P_{dg}^{max} denotes the maximum power generated from DG.[18] Considering economy, the investment includes the cost to set up the DG and the benefit obtained from it. [19] Benefits include reduction in emissions, environmental effects etc.

4. OPTIMIZATION TECHNIQUES USED IN DG ALLOCATION

4.1.Metaheuristic approaches

Based on diversifying and exploring these algorithms have been used in past to solve different optimization issues. Krischonme Bhumkittipich et al. [36] used Particle Swarm optimization technique to reduce power losses by integrating and optimally placing DG in the system. PSO was given by Kennedy and Eberhart in 1995 and since then it has been widely used to solve various optimization problems. [37][23][24]. An algorithm based on genetics is another technique to provide solutions to problems. Researchers have used these algorithms to reduce the time of computation. [30][36][28]. Other approaches consist of Ant colony optimization, Artificial Bee colony, Tabu search, Bat algorithm, Modified Shark Smell optimization etc. [38][39][40][41][42][43]

4.2 Heuristic approaches

Such approaches are employed where approximate solutions are acceptable. Sara YuliethBocanegra et al. [44] used this approach to obtain the ideal location and size of distributed generation in network system. Similarly, Sheeraz Kirmani et al [45] used this approach to correctly place the distributed generators in network system in order to reduce the power system losses[20]

4.3.Analytical approaches

Since, these approaches do not use iterations, therefore problems associated with it such as convergence are also absent. [46] ParthaKayalet al used a method based on voltage stability and loss sensitivity factor to derive the best location and size for distributed generation in the system. Tuba Gözel et al. optimally placed DG using loss sensitivity factor approach. [47][48][20][22]

4.4.Hybrid approaches

Hybrid approach is when two or more optimization techniques are combined together to obtain more accurate result with a smaller number of iterations.[20] Ambika Ramamoorthy et al. used combined particle swarm and GSA for enhancing the voltage profile and minimizing power losses. [23] Another hybrid approach for identifying best location to place DG is combined Clonal algorithm and PSO. [24] Similarly, various other examples of hybrid approaches are Grasshoper and cuckoo search optimization methods, PSO and Improved analytical method, PSO and honey bee mating optimization,Grey wolf optimization and PSO, etc. [11][25] [26] [27][28]

Table 1: Comparative study of loss minimization for 33-bus system

Reference	**Optimization method**	**DG type**	**DG Size**	**Total P(kW), Q (KVAR)loss**	**% Loss Reduction**	**Minimum Voltage (pu)**
With one DG						
[52]	Harris Hawk Optimization	I	2584.13	P- 110.214 Q-81.452	47.76	0.9426
[53]	Genetic Algebric Modelling system	I	2589.6	P-110.6	47.53	0.9433
[54]	Dragonfly algorithm	I	2590.2	P-111.03 Q-81.68	47.37	0.9424
[52]	Harris Hawk Optimization	II	1257.436	P-150.638 Q-103.361	28.6	0.9168
[55]	Hybrid approach	II	1230	P-151.41	28.24	-
[56]	Hybrid Grey Wolf Optimizer	II	1258	P-151.36	28.26	0.9165
[55]	Particle Swarm optimization	III	3034.99	P-67.9	67.82	-
[57]	Harmony search & parallel artificial bee	III	3011.70	P-68.29	67.63	0.9568
With two DG						
[58]	Mixed integer non-linear programming	I	2000	P-87.16	58.69	-
[59]	Krill Herd Algorithm	I	2066.20	P-87.42 Q-60.21	58.56	0.9667
[53]	Genetic Algebric modelling system	I	2008.62	P-86.87	58.82	0.9684
[56]	Hybrid grey wolf optimizer	II	1521	P-141.83	32.78	0.9338
[52]	Teaching learning-based optimization	II	1528.77	P-141.83 Q-96.504	32.78	0.93303
[55]	Particle Swarm Optimization	III	2448.99	P-28.6	86.44	-
[52]	Harris Hawk Optimization	III	2473.29	P-28.50 Q-20.39	86.49	0.9803
With three DG						
[60]	Whale optimization algorithm	I	2701.996	P-73.75 Q-51.03	65.05	0.9688
[59]	Krill Herd Algorithm	I	2807.584	P-73.29 Q-51.06	65.26	0.9701
[55]	Particle Swarm optimization	I	2930	P-72.79	65.5	-
[61]	Flower Pollination algorithm	II	2550	P-161.055	23.67	0.9496

[52]	Teaching learning-based optimization	II	1967.479	P-138.25 Q-94.27	34.47	0.9318
[55]	Particle Swarm Optimization	III	3482.0007	P-11.8	94.41	-
[52]	Harris Hawk Optimization	III	3472.25	P-11.789 Q-9.767	94.41	0.9922

Table 2: Comparative study of loss minimization for 69-bus system

Reference	**Optimization method**	**DG type**	**DG Size**	**Total P(Kw), Q(KVAR) loss**	**% Loss Reduction**	**Minimum Voltage (pu)**
With one DG						
[62]	Elephant Herding Optimization	I	1873.6	P-83.23 Q-40.54	63	0.9683
[54]	Dragonfly Algorithm	I	1872.7	P-83.22 Q-40.57	63.01	0.9685
[55]	Particle Swarm Optimization	I	1870	P-83.22	63.01	-
[52]	Harris Hawk Optimization	II	1328.298	P-152.041 Q-70.502	32.43	0.9307
[52]	Teaching learning-based optimization	II	1329.95	P-152.041 Q-70.5026	32.43	0.9307
[56]	Hybrid Grey Wolf Optimizer	II	1330	P-152.041	32.43	0.9311
[62]	Elephant Herding Optimization	III	2216.298	P-27.95 Q-16.46	87.58	0.9724
[54]	Dragonfly Algorithm	III	2217.30	P-26.963 Q-16.497	87.57	0.9728
[55]	Particle Swarm Optimization	III	2219.997	P-23.2	89.69	-
With two DG						
[59]	Krill Herd Algorithm	I	2699.142	P-77.035 Q-37.504	65.76	0.973
[55]	Hybrid approach	I	2240	P-71.8	68.09	-
[52]	Harris Hawk Optimization	I	2312.93	P-71.67 Q-35.94	68.14	0.9789
[56]	Hybrid Grey Wolf Optimizer	II	1641	P-146.44	34.92	0.9315
[52]	Teaching learning-based optimization	II	1634.715	P-146.442 Q-68.24	34.91	0.9311
[55]	Particle Swarm Optimization	III	2392.58	P-7.2	96.8	-
[52]	Harris Hawk Optimization	III	2343.22	P-7.158 Q-8.065	96.82	0.9943
With three DG						
[59]	Krill Herd Algorithm	I	3331.55	P-69.19 Q-31.98	69.25	0.9792

[52]	Harris Hawk Optimization	III	3108.34	P-4.26 Q-6.86	98.11	0.9943
[55]	Particle Swarm Optimization	III	3120.005	P-4.61	97.95	-
[52]	Teaching learning-based optimization	II	1876.39	P-145.116 Q-67.66	35.5	0.9314
[56]	Hybrid Grey Wolf Optimizer	II	1873	P-145.115	35.50	0.9317
[52]	Harris Hawk Optimization	I	2630.75	P-69.43 Q-34.96	69.14	0.9792
[55]	Hybrid approach	I	2560	P-69.54	69.09	-

The study shows that optimal placement of DG not only helps in reduction of power losses but also enhance the system voltage along with reduction in other factors such as voltage sag, total harmonic distortion etc. which can be harmful for system reliability and operation.

The ideal location for DG placement is observed by

- Selection of objective(s)
- Identifying system constraints
- Selection of optimization method
- Identifying the type of load
- Accordingly, identifying the type of DG required.
- Obtaining results and comparing

Various methods have been studied to identify the best location for placing DG in order to obtain maximum benefit from it. DG's scattered all over the system are more efficient as compared to those concentrated at one location.

8. CONCLUSION

This paper presents a brief review on optimal placement of DG for minimizing power losses in the distribution system. It is observed that there are various factors on the basis of which the distributed generators can be placed in the system. Also, there are different types of optimization techniques which are used to analyse the system performance and hence helps in finding an ideal location to site DG. Further, a comparative study shows the results of power loss minimization analysis performed on 33 and 69 bus test system. It can be concluded that DG improves the system performance when placed optimally and integrated up to a certain penetration limit. It helps in enhancing system voltage profile, reduce power losses, increase system reliability and reduce cost when sized properly

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