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Siting & Sizing of Dg for Power Loss & Thd Reduction, Voltage Improvement Using Pso & Sensitivity Analysis

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Abstract:- Integration of renewable energy based distributed generation (DG) units provides potential benefits to the conventional distribution systems. DG sources are becoming more prominent due the incremental demands of electrical energy. Location and capacities of DG sources have profoundly impact on the system losses in the distribution network. In this paper, Sensitivity Analysis is used for determining the location of DG and Particle Swarm Optimization (PSO) algorithm is used as the optimization technique for determining the size of DG in the distribution networks in order to reduce the real power losses of the system. To include the presence of harmonics, PSO was integrated with a harmonic power flow algorithm (HPF). The proposed PSO-HPF based approach is implemented on standard IEEE 15 bus test system to demonstrate effectiveness of the proposed methodology.

Keywords:- Distributed generation, Optimal placement, Power losses, Sensitivity analysis, Particle swarm optimization, harmonics, Total harmonic distortion.

I. INTRODUCTION

Due to limitation on fossil fuel resources, alternative solutions to traditional large power stations are under high priority in recent years to meet growing energy demand of the future. Also large power stations are discouraged due to many environmental concerns. On the other hand, renewable energy resources have been considered as the best alternative to traditional fossil fuels. The sizes of renewable energy based electricity generators would be very small as compared to large fossil fuel based power plant. Technically, they are suitable for installation at low voltage distribution system, near loads centres [1].

Distributed Generation (DG) is a small generator spotted throughout a power system network, providing the electricity locally to load customers [2]. DG can be an alternative for industrial, commercial and residential applications. DG makes use of the latest modern technology which is efficient, reliable, and simple enough so that it can compete with traditional large generators in some areas [3].

The problem of DG location and sizing is of great importance. The installation of DG units at non-optimal places and with non-optimal sizing can result in an increase in system losses, damaging voltage state, voltage flicker, protection, harmonic, stability etc.

Naresh Acharya et al suggested a heuristic method in [4] to select appropriate location and to calculate DG size for minimum real power losses. Though the method is effective in selecting location, it requires more computational efforts. The optimal value of DG for minimum system losses is calculated at each bus. Placing the calculated DG size for the buses one by one, corresponding system losses are calculated and compared to decide the appropriate location. More over the heuristic search requires exhaustive search for all possible locations which may not be applicable to more than one DG. This method is used to calculate DG size based on approximate loss formula may lead to an inappropriate solution.

In this paper, the optimal location of DG are identified based on sensitivity analysis PSO based technique which takes the number and location of DGs as input has been developed to determine the optimal size(s) of DG to minimize real power losses in distribution systems. The advantages of relieving PSO from determination of locations of DGs are improved convergence characteristics and less computation time.

The increasing use of harmonic polluting loads causes harmonic current and voltage distortion that may propagate throughout the distribution system. It is well known that both voltage and current waveform distortion may adversely affect the equipment connected to the power system. In particular, harmonic resonance phenomena in power systems are known to cause severe distortion levels [5], and even failure of power system components. Several governments worldwide promote distributed power generation using renewable energy sources. Therefore, the reduction of harmonic distortion is an important aspect of the power quality issue. Restricting the harmonic voltage and current distortion to ac minimum is a prerequisite for trouble-free exploitation of the electric power system and the connected loads.

The proposed (PSO-HPF) based approach is tested on an IEEE 15-bus radial distribution system and the scenarios yields efficiency in improvement of voltage profile and reduction of THD and power losses; it also permits an increase in power transfer capacity and maximum loading.

II. PROBLEM FORMULATION

The real power loss reduction in a distribution system is required for efficient power system operation. The loss in the system can be calculated by equation (1) [6], given the system operating condition,

$$P_L = \sum_{i=1}^{n}\sum_{j=1}^{n}\left(\alpha_{ij}\left(P_iP_j + Q_iQ_j\right) + \beta_{ij}\left(Q_iP_j - P_iQ_j\right)\right) \quad (1)$$

Where,

$$\alpha_{ij}=\frac{r_{ij}}{|V_i||V_j|}\cos\left(\delta_i - \delta_j\right) \quad (2)$$

$$\beta_{ij} = \frac{r_{ij}}{|V_i||V_j|}\sin\left(\delta_i - \delta_j\right) \quad (3)$$

where, P_i and Q_i are net real and reactive power injection in bus *'i'* respectively, r_{ij} is the line resistance between bus 'i' and 'j', $r_{ij}+jx_{ij}=Z_{ij}$ are the ij^{th} elements of $[Z_{bus}]$ matrix, V_i and δ_i are the voltage and angle at bus 'i' respectively.

The objective of the placement technique is to minimize the total real power loss. Mathematically, the objective function can be written as:

Minimize $P_L= \sum_{k=1}^{n} Loss_k$ (4)

Subject to constraints

Voltage constraints: $|V_i|^{min} \le |V_i| \le |V_i|^{max}$ (5)

Current limits: $|I_{ij}| \le |I_{ij}|^{max}$ (6)

where: $Loss_k$ is distribution loss at section k, n is total number of sections, P_L is the real power loss in the system.

III. SENSITIVITY ANALYSIS

Sensitivity factor method is based on the principle of linearization of original nonlinear equation around the initial operating point, which helps to reduce number of solution space. Loss sensitivity factor method is mainly used to solve the capacitor allocation problem [7]. Its application in Dg location is new in this field and has been reported in [8].

The real power loss in the system is given by equation (1), which is termed as "exact loss" formula. The sensitivity factor of real power loss with respect to real power injection is obtained by differentiating equation (1) with respect to real power injection at bus 'i' which is given by

$$\alpha_i=\frac{\partial P_L}{\partial P_i}=2\sum_{j=1}^{N}\left(\alpha_{ij}P_j-\beta_{ij}Q_j\right) \quad (7)$$

Sensitivity factors are evaluated at each bus, firstly by using the values obtained at base case load flows. The buses are ranked in descending order of the values of sensitivity factors to form a priority list. The total power loss against injected power is a parabolic function and at minimum of losses, the rate of change of real power loss with respect to real power injection becomes zero.

$$\alpha_i=\frac{\partial P_L}{\partial P_i}=2\sum_{j=1}^{N}\left(\alpha_{ij}P_j-\beta_{ij}Q_j\right)=0 \quad (8)$$

which follows the

$$P_i= \frac{1}{\alpha_{ii}}\left[\beta_{ii}Q_i+\sum_{j=1,\, j\neq i}^{N}\left(\alpha_{ij}P_j- \beta_{ij}Q_j\right)\right] \quad (9)$$

where P_i represents the real power injection at node i, which is the difference between real power generation and real power demand at that node.

$P_i = P_{DGi} - P_{Di}$ (10)

where P_{DGi} is the real power injection from DG placed at node i, P_{Di} is the load demand at node i, combining (9) &(10) we get

$$P_{DGi}= P_{Di} + \frac{1}{\alpha_{ii}}\left[\beta_{ii}Q_i- \sum_{j=1,\, j\neq i}^{N}\left(\alpha_{ij}P_j- \beta_{ij}Q_j\right)\right] \quad (11)$$

The above equation determines the size of the DG at which the losses are said to be minimum. By arranging the list in ascending order, the bus stood in the top is ranked as the first location of DG and further the process is repeated by placing the concerned size of DG at that particular location which generates the next location of DG. The process is said to be terminated when it determines the same location.

IV. PARTICLE SWARM OPTIMIZATION (PSO)

4.1 Introduction

Particle swarm optimization (PSO) is a population-based optimization method first proposed by Kennedy and Eberhart in 1995, inspired by social behavior of bird flocking or fish schooling [9]. The PSO as an optimization tool provides a population-based search procedure in which individuals called particles change their position (state) with time. In a PSO system, particles fly around in a multidimensional search space. During flight, each particle adjusts its position according to its own experience (This value is called Pbest), and according to the experience of a neighboring particle (This value is called Gbest),made use of the best position encountered by itself and its neighbor (Figure 1).

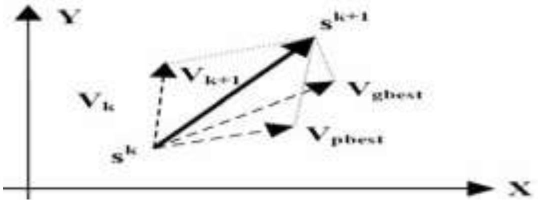

Figure 1: Concept of a searching point by PSO

This modification can be represented by the concept of velocity. Velocity of each agent can be modified by the following equation:

$$v_{id}^{k+1} = \omega v_{id}^{k} + c_1 \text{ rand}^* \left(pbest_{id} - s_{id}^{k}\right) + c_2 \text{ rand}^* \left(gbest_d - s_{id}^{k}\right) \quad (12)$$

Using the above equation, a certain velocity, which gradually gets close to pbest and gbest can be calculated. The current position (searching point in the solution space) can be modified by the following equation:

$$s_{id}^{k+1} = s_{id}^{k} + v_{id}^{k+1} \quad (13)$$

where s^k is current searching point, s^{k+1} is modified searching point, $v^k$is current velocity, $v^{k+1}$is modified velocity of agent i, v_{pbest} is velocity based on pbest, , v_{gbest} is velocity based on gbest, n is number of particles in a group, m is number of members in a particle, $pbest_i$ is pbest of agent i, $gbest_i$ is gbest of the group, ω_i is weight function for velocity of agent i, C_i is weight coefficients for each term. Appropriate value ranges for C1 and C2 are 1 to 2, ω_i is taken as 1.

4.2 Objective function

The main objective is to minimize the total power loss as given in Equation (1) while meeting the network constraints.

4.3 Algorithm for finding optimal DG sizing using PSO

The PSO-based approach for solving the optimal placement of DG (OPDG) problem to minimize the loss takes the following steps [10]:

Step 1: Input line and bus data.

Step 2: Calculate the loss using distribution load flow based on backward sweep-forward sweep method.

Step 3: Randomly generates an initial population (array) of particles with random positions and velocities on dimensions (Size of DG and Location of DG) in the solution space. Set the iteration counter k = 0.

Step 4: For each particle if the bus voltage is within the limits, calculate the total loss in equation (1). Otherwise, that particle is infeasible.

Step 5: For each particle, compare its objective value with the individual best. If the objective value is lower than Pbest, set this value as the current Pbest, and record the corresponding particle position.

Step 6: Choose the particle associated with the minimum individual best Pbest of all particles, and set the value of this Pbest as the current overall best Gbest.

Step 7: Update the velocity and position of particle using (12) and (13) respectively.

Step 8: If the iteration number reaches the maximum limit, go to Step 9. Otherwise, set iteration index k = k + 1, and go back to Step 4.

Step 9: Print out the optimal solution to the target problem. The best position includes the optimal locations and sizes of DG and the corresponding fitness value representing the minimum total real power loss.

V. HARMONIC POWER FLOW (HPF)

To solve the DG placement problem with harmonic distortion consideration, it is necessary to perform harmonic power flow calculations under different harmonic orders such that harmonic rms voltages and THD of bus voltages can be obtained as follows:

Step 1: Calculate V for fundamental case from general load flow.

Step 2: Calculate the harmonic load impedance Z_L^h

where $Z_L^h = R_L + jh\, X_L$ for h^{th} order harmonic

Step 3: Calculate the harmonic injection current I_{Li}^h

$I_{Li}^h = \%\ of\ Harmonic\ injection * I_{Li}$, where i=1,2,……n

Step 4: Calculate the line impedance Z^h=R+jh X

Step 5: Calculate the Z_{bus}^h matrix

Step 6: Calculate the harmonic voltages V^h

$V^h = [Z_{bus}^h][I^h]$ where $I^h = I_{Li} + I_{Li}^h$

Step 7: Calculate the Total Harmonic Distortion (THD)

$$THD(\%) = \frac{100}{|V_i^1|}\sqrt{\sum_{h=2}^{nh}|V_i^h|^2}$$

where V_i^1 = fundamental voltage

V_i^h = h^{th} order of harmonic voltage

VI. TEST SYSTEM & ANALYTICAL TOOLS

The system under study is a typical 15 bus test system, contains 15 buses and 14 branches as shown in the figure3. A computer program is written in MATLAB2009a to find the optimal location of DG's by using sensitivity analysis and also the optimal size of each Dg were determined by using PSO.

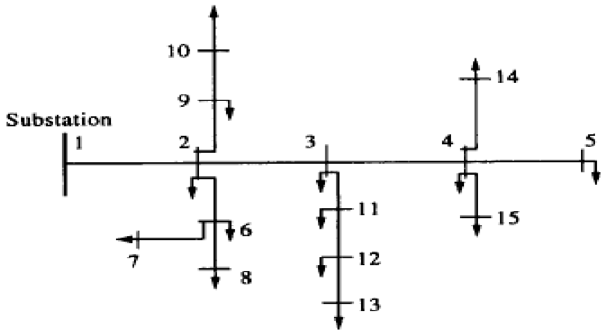

Figure 3: Single line diagram of IEEE 15 bus test system

The power factor of the load is treated as cos ∅ =0.70. The only supply source in the system is the substation at bus 1 as a slack bus with a constant voltage. All loads are treated as constant PQ spot loads. Tables 1,2&3 represents the input data of the test system.

Table 1: Line data of IEEE 15 bus test system

Branch number	Sending end node	Receiving end node	R (ohm)	X (ohm)
1	1	2	1.35309	1.32349
2	2	3	1.17024	1.14464
3	3	4	0.84111	0.82271
4	4	5	1.52348	1.02760
5	2	6	2.55727	1.72490
6	6	7	1.08820	0.73400
7	6	8	1.25143	0.84410
8	2	9	2.01317	1.35790
9	9	10	1.68671	1.13770
10	3	11	1.79553	1.21110
11	11	12	2.44845	1.65150
12	12	13	2.01317	1.35790
13	4	14	2.23081	1.50470
14	4	15	1.19702	0.80740

Table 2: Load data of IEEE 15 bus system

Node	KVA	Node	KVA
1	0	9	100
2	63	10	63
3	100	11	200
4	200	12	100
5	63	13	63
6	200	14	100
7	200	15	200
8	100		

Table 3: Load compensation in terms of harmonic sources

Bus number	Harmonic injection current	Order of injected harmonic
2	15%	3
5	15%	3
8	17%	3
10	15%	3
12	17%	3
14	17%	3
15	20%	3

VII. RESULTS AND DISCUSSIONS

Firstly Radial Distribution Load Flow (RDLF) [11] is conducted on the standard IEEE 15 bus test system which consists of the formation of various matrices like Bus Injected Branch Current (BIBC) matrix, Branch Current to Bus Voltage (BCBCV) matrix etc. The product of BIBC matrix and BCBV matrix represents RDLF matrix which is clearly explained in [11].

The real power loss of the test system before introducing any DG in to the system is 51.1676KW. A program is written in MATLAB 2009a to calculate the loss saving, DG location and its corresponding size in MW. Now the sensitivity analysis program in written in MATLAB is made run to determine the DG location along with the loss savings. For the first iteration the maximum loss saving is occurring at bus 3. The candidate location for DG is bus 3 with a loss saving of 17.2928 kW. The optimum size of DG at bus 3 is 0.7899 MW. By assuming 0.7899 MW DG is connected at bus 3 of base system and is considered as base case. Now the candidate location is bus 6 with 0.2309 MW size and the loss saving is 3.5866 KW. Now the candidate location is bus 2 with 0.0814 MW. The results are shown in table 4.

Table 4: Results for Sensitivity analysis

Iteration No	Bus num	DG size (MW)	Saving (KW)
1	3	0.7899	17.2928
2	6	0.2309	3.5866
3	2	0.0814	0.1612

The solution obtained above is local optimum solution but not global optimum solution. The DG sizes corresponding to global optimum solution are determined using PSO method. The candidate locations for DG placement are taken from Sensitivity analysis i.e., bus numbers 3, 6 and 2. With these locations, sizes of DGs are determined by using Particle swarm optimization (PSO) Algorithm described in section 4. The sizes of DGs are dependent on the number of DG locations. The number of DG's to be installed for the test system is limited to three and brief explanation to this is given in the following three cases. Case 1 represents installation of only one DG in to the system, case 2 with two DG's and case 3 followed by three DG's. DG sizes in the four optimal locations, total real power losses before and after DG installation for four cases are given in Table 5.

Table 5: Results for PSO algorithm

<table>
<tr><th>Case</th><th>Bus location</th><th>DG size (MW)</th><th>Total size (MW)</th><th>Losses before DG installation (KW)</th><th>Losses after DG installation</th><th>Saving (KW)</th></tr>
<tr><td>1</td><td>3</td><td>0.902</td><td>0.902</td><td rowspan="3">51.1676</td><td>32.789</td><td>18.396</td></tr>
<tr><td rowspan="2">2</td><td>3</td><td>0.708</td><td rowspan="2">1.068</td><td rowspan="2">29.130</td><td rowspan="2">22.055</td></tr>
<tr><td>6</td><td>0.360</td></tr>
</table>

3	3	0.639	1.130		29.014	22.171
	6	0.328				
	2	0.163				

Due to the installation of the three DG's at the determined locations with the corresponding determined at sizes, the total real power loss of the system is reduced from 51.1860KW to 29.1368KW with a maximum saving of 29.1368KW.

Table 6: Results for real power loss before and after DG placement

	Before DG installation (KW)	After DG installation (KW)
Real power loss	51.1676	29.0145

Similarly due to the introduction of DG in to the system the voltage profile as been improved which is represented in the below table.

Table 7: Results for voltage profile before and after DG placement

Bus num	Voltages before DG installation	Voltages after DG installation
1	1.0000	1.0000
2	0.9746	0.9878
3	0.9620	0.9834
4	0.9573	0.9833
5	0.9542	0.9802
6	0.9626	0.9831
7	0.9604	0.9839
8	0.9601	0.9806
9	0.9706	0.9838
10	0.9689	0.9822
11	0.9553	0.9768
12	0.9477	0.9694
13	0.9457	0.9674
14	0.9559	0.9819
15	0.9561	0.9821

The introduction of DG results in the following benefits like improvement of voltage profile, reduction of current through the branches, maximum loading point is also achieved, reduction of power losses, increase of power transfer capability. But the major drawback due to the introduction of DG is the production of harmonics in to the test system. In order to reduce this harmonics, the capacitors are to be placed in to the test system. Firstly the Harmonic Power Flow (HPF) algorithm is said to be run in order to determine the amount of harmonics present at each and every bus in the test system. Thus the HPF algorithm is initially made run on the test system before any installation of DG and the corresponding results obtained are represented in case I. Soon after the installation of DG in to the system, the same algorithm is repeated which in turn results in the increment of harmonics that are already present in the system and is represented clearly in the case II. From the results obtained in the case II, the location of capacitor is chosen as bus5 followed by bus 14, then bus 15 and finally with bus 4 since the values of harmonics are more at these locations while compared to the remaining locations. The sizes of the capacitors to be installed at these candidate bus locations are determined by using PSO algorithm which is seen in section 4 [12].

Table 8: Capacitor Location and its Sizes

Case	Capacitor Location	Capacitor Size
1	5	0.573
2	5	0.413
	14	0.230
3	5	0.291
	14	0.146
	15	0.260
4	5	0.175
	14	0.079
	15	0.221
	4	0.270

By installation of capacitors at particular buses with the correct determined sizes results in the decrease of the harmonics when compared to the previous cases. The result of this one is represented in case III as follows.

Table 9: Results for Total Harmonic Distortion (THD)

Bus num	Case I	Case II	Case III
1	0	0	0
2	25.2186	29.3833	13.1230
3	33.9036	38.1593	19.6288
4	45.0831	43.7909	35.4777
5	47.6297	46.5234	37.0694
6	26.3988	32.0191	12.6660
7	27.8917	35.7221	11.5781
8	28.3858	34.1763	14.0330
9	26.2511	30.4959	13.8013
10	27.5337	31.8514	14.7109
11	34.6747	39.0409	20.0738
12	37.2819	41.9129	21.7213
13	38.7744	43.5410	22.7215
14	46.2696	45.0633	36.1623
15	46.1159	44.8985	36.0981

Case I represents THD values before the installation of DG in to the test system, Case II represents THD values after the installation of DG in to the test system, Case III represents THD values after the installation of capacitors in to the test system.

VIII. CONCLUSION

Size and location of DG are the crucial factors in the application of DG for loss minimization. This paper presents an algorithm for the identification of bus location using Sensitivity analysis and also an algorithm for the determination of size of the DG using PSO. This methodology is tested on IEEE 15 bus system. By installing DGs at all the potential locations, the total power loss of the system has been reduced drastically and the voltage profile of the system is also improved. The harmonics that are present in the system due to the installation of DG are reduced by placing capacitors at the locations determined by using PSO-HPF based algorithm.

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