Investigating the Impact of Distributed Generators Power Factor to Simultaneous Optimization Analysis

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Abstract. In this paper, the Particle Swarm Optimization (PSO) technique is used to determine the optimal coordination for Distributed Generator (DG). The DG output and location is determined simultaneously. Furthermore, this study covers both single and multiple DGs analyses. Five different Power Factor (PF) values are also assigned to the DG units, which are 0.8, 0.85, 0.9, 0.95 and 1.0. Thus, the impacts of DG power factor to the optimal placement and output are investigated. From the result, the optimal DG placement is similar, regardless of the PF condition. For the single DG unit, the optimal location is bus 6 and for three DGs analysis, the optimal locations are at buses 14, 24, 30. However, the PF significantly influences the optimal DG output, power loss reduction and voltage profile improvement. Three DGs with PF 0.8 is the best option to reduce the power loss in the distribution network to the lowest value.

Introduction

Distribution network is one of the main components in electric power system that supplies power to the end user, either to industrial areas or residential areas. Originally, the distribution network is operated passively. This means that power supplied by the network totally depended on transmission/distribution substation. However, the introduction of Distribution Generator (DG) has transformed the behavior of the distribution network into an active system [1,2,3,4]. With the DG implementation, some of the load will be supplied by DG and remaining loads are supplied by existing substations.

However, it is very important to ensure that the DG location and their generated power are configured properly. Without proper placements, the DG will not be able to reduce the power loss to the lowest value [5,6]. Moreover, the non-optimal DG output can cause higher power loss than the initial condition and in the worst case, it could cause the distribution system to collapse. Therefore, many studies on optimal DG output and placement have been done [7,8,9].

Murthy et. al. [10], for example, have proposed the optimal DG based on sensitivity approach. The proposed sensitivity technique has given better DG placement and size compared to other existing indices, such as combined loss sensitivity, index vector, and voltage sensitivity index. Furthermore, the power loss in the system is also reduced. On the other hand, other approaches on optimal DG placement have been proposed by Lee et. al. [11]. The authors used power loss sensitivities or known as optimal locator index as a guidance to determine suitable DG location. The Kalman Filter technique is used for determining the suitable size of DG with the step increment of 10 kW.

In this research, the location and output of DG is determined using the optimization technique, which is Particle Swarm Optimization (PSO). The optimization process (for location and output) is done simultaneously in order to avoid the solution from being trapped in the local optimal result. Furthermore, two different case studies (single and multiple DG units) are considered with five

Power Factor (PF) condition, which are PF = 0.8, PF = 0.85, PF = 0.90, PF = 0.95 and PF = 1.0. Thus, the investigation on the impact of PF as well as number of DG will be discussed in detail. The 33-bus radial distribution system is selected as the test case system.

Problem Formulation

The installation of DG in the distribution network is capable of reducing the existing power loss and improving the voltage profile. However, the improvement depends on the appropriate DG coordination. In this paper, the PSO algorithm is used to solve the single and multiple DG coordination problems. The power loss value could be in the minimum value by finding the optimal DG location and output. The power loss, which is set as the objective function is calculated using (1).

$$P_{Loss} = \sum_{j=1}^{\max\ line} I_j^2 R_j \tag{1}$$

Besides that, several constraints are considered in the analysis in order to make the solution feasible and close to actual practical system. The lists of constraints are:

i. DG output power:

$$P_i^{\min} \leq P_{DGi} \leq P_i^{\max} \tag{2}$$

$$Q_{DGi} = P_{DGi} \tan\left(\cos^{-1}(PF)\right) \tag{3}$$

The randomization and updating value for DG output, which is given by PSO algorithm, must be within the DG capability limit. The DG output should not be lower than the minimum DG rated or higher than the maximum DG rated as shown in (2). Besides that, since the DG operates at a specific PF value, the reactive power supplied by the DG is equal to (3).

ii. Power Injected Constraint:

$$\sum_{h=1}^{no.of\ DG} P_{DG_h} < P_{Load} + P_{Losses} \tag{4}$$

The total power supplied by DGs to the system must be less than the total amount of demand and total power loss value. The purpose of this restriction is to avoid any power injection to the grid side.

iii. Power balance constraint:

$$\sum_{h=1}^{no.of\ DG} P_{DG_h} + P_{Substation} = P_{Load} + P_{Losses} \tag{5}$$

The summation of total power generated by DGs and the power supplied by substation must be equal to the result of total demand and power loss as shown in (5). With this concept, the frequency of the system is not changed even after the DG installation.

iv. Voltage Constraint:

$$V_{\min} \leq V_{bus} \leq V_{\max} \tag{6}$$

The voltage value at any bus in the system should be better than initial condition after the DG installation, either for single or multiple DG cases. Besides that, the voltage value should not exceed the maximum allowable limit (V_{max}), which is 1.05p.u and should be higher than the minimum allowable limit (V_{min}), which is 0.95p.u.

Therefore, all these constraints will be checked every time the updating process is done in the PSO algorithm. If the result of placement and DG output caused violation in any of the constraints, the PSO will add the penalty value to the objective function. The test system and PSO algorithm were conducted using MATLAB programming language in MATLAB 7.8 with 2GB RAM.

Particle Swarm Optimization Implementation

Particle Swarm Optimization (PSO) algorithm is a technique proposed by Ebehart and Kennedy [12] and has been widely used in many applications such as in engineering field and financial problem. The idea of PSO is adapted from the food searching behavior of birds or fish. In optimization process, the birds or fish is known as particles. These particles will move with a specific guidance and change their position and speed until they arrive at the destination, which is known as food source location.

Furthermore, the changes in new position and new speed of each particle depend on their own information (local best - P_{best}) and others (global best - G_{best}). In general, the updated formulae to find the new velocity and new position for the particles proposed by Yuhui and Ebehart [13] are:

$$v_i^{k+1} = \omega_i^{\,k} v_i^k + c_1 r_{1i} (P_{best-i}^k - x_i^k) + c_2 r_{2i} (G_{best}^k - x_i^k) \tag{7}$$

$$x_i^{k+1} = v_i^{k+1} + x_i^k \tag{8}$$

where:

ω	= Inertia weight of particle
υ	= Velocity of particle
c_1, c_2	= Acceleration constant (cognitive and social)
r_1, r_2	= Random number between ‘0’ to ‘1’
P_{best}	= The best fitness that given by particle until current iteration
G_{best}	= The best fitness that given by any particles in the population at current iteration

The inertia weight (ω_i) value is different in each iteration and based on the following equation:

$$\omega_i = \omega_{\max} - \frac{(\omega_{\max} - \omega_{\min})}{k_{\max}} \, (k) \tag{9}$$

where:

k	= Iteration number

In order to implement the simultaneous analysis for the DG coordination problem, the position in the PSO will be used to represent the DG location and output. For example, the particle (xi) on single DG analysis consists of the DG location and the DG output parameters as shown below:

$$x_i = \left| rand\left(DG_{output}\right)_i \quad ceil\left(rand\left(DG_{bus}\right)_i\right) \right| \tag{10}$$

Thus, the location and output will be updated simultaneously in the PSO process until the maximum iteration is reached. Fig. 1 shows the flow chart of PSO algorithm in solving the simultaneous DG placement and output problem based on PF condition.

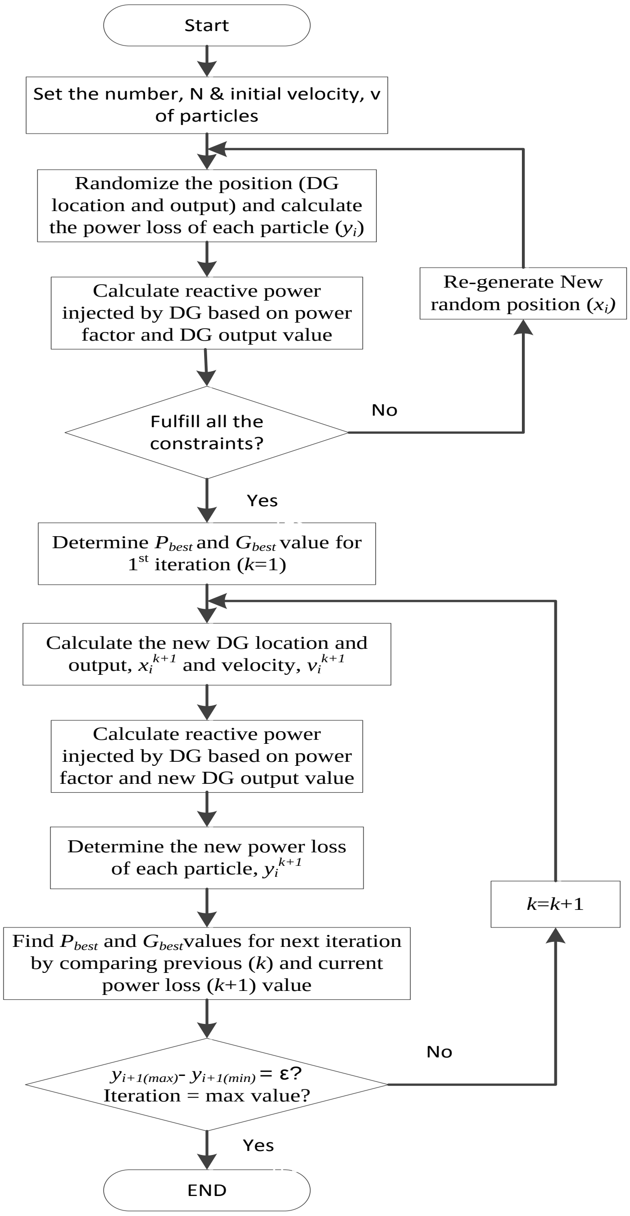

Fig.1: The process to find the optimal DG placement and output

Particle Swarm Optimization Implementation

The original 33 bus system, as shown in Fig. 2, is a radial distribution system with total load of 3.715 MW, 2.3 MVar and the real loss in the system is 203.18 kW. Besides that, the PSO parameters that being set in this study are:

- $c_1 = c_2 = 1.4$;
- $\omega_{min} = 0.9$;
- $\omega_{max} = 0.4$;
- N = 20;
- $iteration_{max} = 200$;

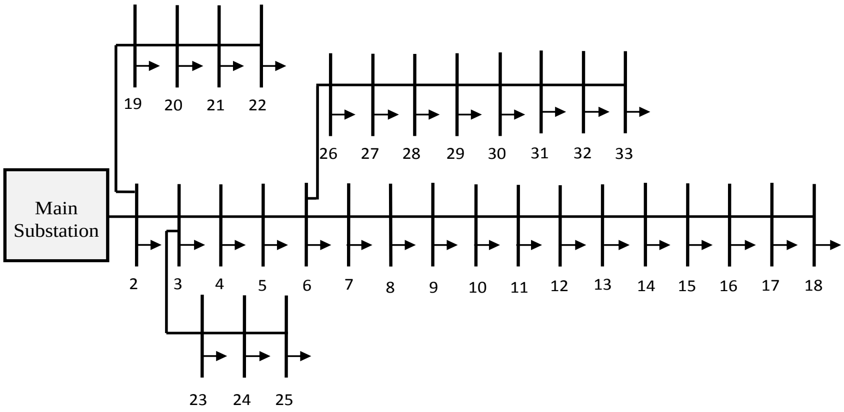

Fig. 2: The case study network: 33-bus radial distribution system

Table 1 shows the optimal DG location and output based on the PF value for single DG analysis. From the results, the optimal location for DG is similar regardless of the PF condition, which is at bus 6. However, the PF affects the power loss and total optimal DG output results. From the analysis, the power loss value is between 60 kW to 72 kW when the DG is operated at 0.8 to 0.95 PF and double up to 104.38 kW when the DG is operated at PF 1.0. In term of optimal DG operation, the amount of output is increasing when the DG is operated from 0.8 (PF) to 0.95 (PF). The increment can be presented as a linear equation as shown in Fig. 3. In a nutshell, the PF does not only affect the power loss value, it also affects the DG output.

Table 1: Optimal DG Location and Output for Single DG Unit

	Single DG unit		
DG Power Factor	Optimal DG location	Optimal DG output	Power Loss
w/o DG	-	-	203.1854 kW
0.80	Bus 6	2.4719 MW	61.6523 kW
0.85	Bus 6	2.6257 MW	61.7661 kW
0.90	Bus 6	2.7534 MW	64.4667 kW
0.95	Bus 6	2.8269 MW	71.8595 kW
1.00	Bus 6	2.5762 MW	104.3802 kW

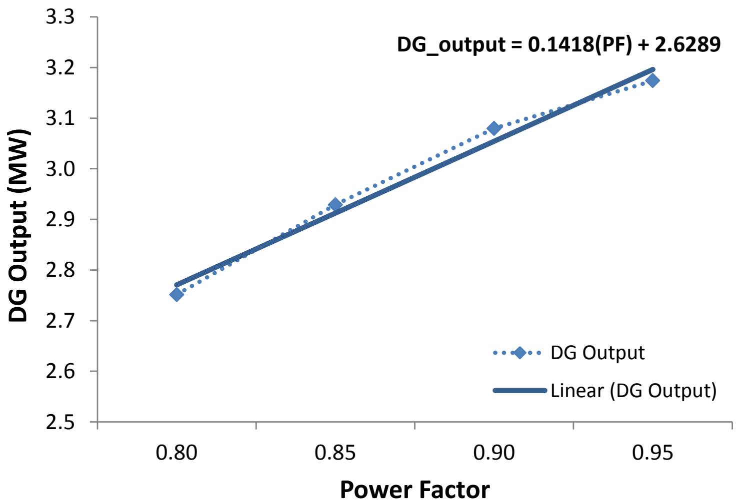

Fig. 3: The relationship between optimal DG output and PF value

Further power loss reduction can be obtained when multiple DGs are placed in the network. However, similar to the single DG analysis, the optimal locations for multiple DGs are the same and are not affected by the PF value as shown in Table 2. The DG must be located at buses 14, 24 and 30 in order to get the lower power loss and the PF 0.8 gives the lowest power loss in the system compared to the others.

Table 2: Optimal DG Location and Output for Multiple DG Units

	Three DG units			
DG Power Factor	Optimal DG location	Optimal DG output	Total DG Output	Power Loss
w/o DG	-	-	-	203.1854 kW
0.80	Bus 14 Bus 24 Bus 30	0.6478 MW 0.9409 MW 1.1627 MW	2.7514 MW	13.8829 kW
0.85	Bus 14 Bus 24 Bus 30	0.6982 MW 1.0131 MW 1.2176 MW	2.9289 MW	14.4063 kW
0.90	Bus 14 Bus 24 Bus 30	0.7447 MW 1.0798 MW 1.2552 MW	3.0797 MW	18.3041 kW
0.95	Bus 14 Bus 24 Bus 30	0.7815 MW 1.1333 MW 1.2592 MW	3.1739 MW	28.3433 kW
1.00	Bus 14 Bus 24 Bus 30	0.7542 MW 1.0993 MW 1.0714 MW	2.9249 MW	71.5486 kW

In terms of total output, the spreading of DG in the system causes the total optimal DG output to become larger than a single DG output. For example, the total DG output given by PF 0.85 is 2.6257 MW for single DG and 2.9289 MW for three DGs. There is an addition of 11.55% of active power provided by three DGs analysis. Therefore, the reactive power that will be supplied to the system is also increased as shown in Fig. 4.

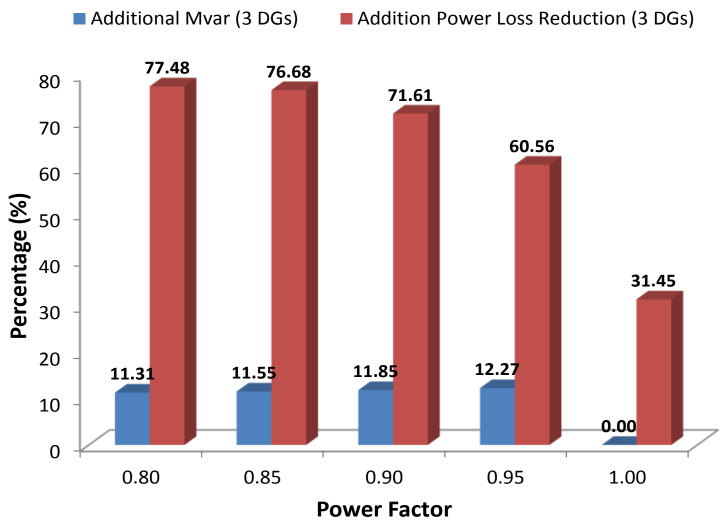

Fig. 4: The deviation between single and multiple DG performance

Although additional reactive power is required for 3 DGs case (except for PF 1.0), the reduction of power loss is very large compared to single DG configuration. From the figure, when the DG operates at PF 0.8, the power loss for 3 DGs configuration in the system is 77.48% lower than single DG configuration. The deviation between these two conditions is calculated based on the following equation:

$$\Delta result = \left| \frac{(DG_{3units} - DG_{1unit})}{DG_{1unit}} \right| (100\%) \tag{11}$$

Thus, from the bar chart, the distribution network performance is much better under multiple DG installation.

The voltage profile of the system was also improved tremendously by the reactive power injection. Fig. 5 shows the comparison of voltage profile after the DG installation for all PF conditions. From the results, there are certain bus voltages given by 3 DGs are lower than single DG, such as buses 4, 5 and 6. However, the placement of 3 DGs was able to ensure that all buses were operated above 0.98p.u. The small variation in voltage profile, indirectly, will reduce the amount of current flow in the line, which causes power loss reduction in the system (P=I2R). Therefore, it can be concluded that multiple DGs can provide better performance to the radial distribution system.

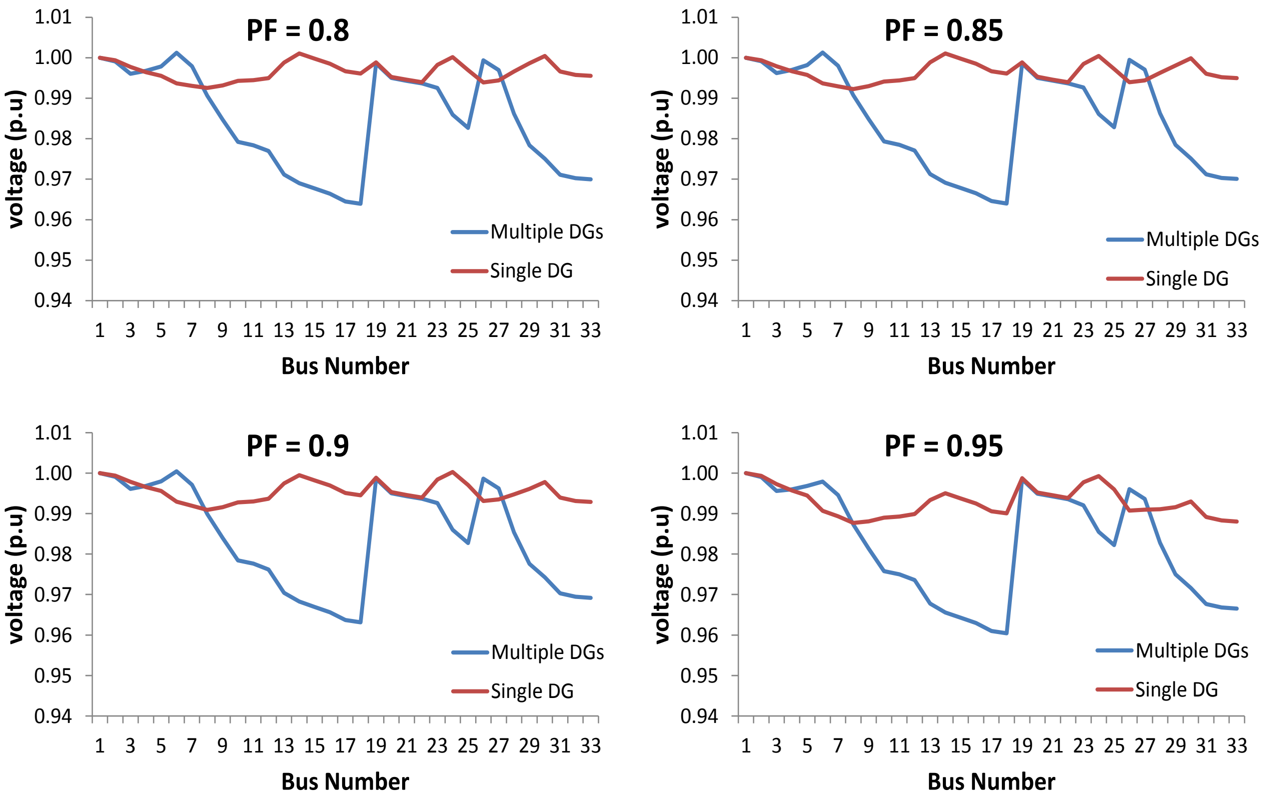

Fig. 5: The comparison of voltage profile provided by single and multiple DGs

Conclusion

The main idea of this research is to investigate the impact of DG Power Factor (PF) to the optimal DG placement and output. The analysis covered for single and multiple DG units. Overall, the optimal DG placement is not affected by the PF value, either for single or multiple DG units. However, the PF condition gives significant changes to the power loss value. Furthermore, although the total DG output for multiple DG unit is quite larger than single DG analysis, the spreading of DG help tremendously in improving the voltage profile. Thus, the particle swarm optimization has worked perfectly in finding the optimal DG placement and output, in order to improve the distribution system performance.

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