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Particle Swarm Optimization (PSO) And Evolutionary Programming (EP) Technique for Optimal Placement and Sizing DG for Minimizing Loss in IEEE-30 Bus System

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Abstract: In recent years, most growing nations worldwide have experienced an unavoidably rising demand for electricity, which may result in a dropping of the voltage profile and a reduction in system stability, both of which have the potential to overload the power generation system significantly. One of the ways to reduce loss system network in this study is by distributed generation (DG) allocation, which the DG optimal location and sizing are the two most significant considerations for integration of DG. Improper placement and DG sizing in the power system not only result in increased total power losses but also affect the electrical system's capability to be function properly. This paper provides a comparative analysis of two meta- heuristic optimization techniques, that is, Particle Swarm Optimization (PSO) and Evolutionary Programming (EP), to examine the optimal placement and sizing of distributed-generation (DG) for photovoltaic systems with the aim of minimizing the losses in interconnected distributed generation, IEEE-30 bus system. The objective function of this study is minimization the power loss with considered some constraints which are voltage limits and DG sizing limits are being covers in this study. The optimization issue has been solved by working with MATLAB/m-files software. The outcomes derived from the simulation results in this study demonstrated that PSO performance of two units of DG is better compared to EP algorithm. The voltage profile was improved drastically, and the power loss was reduced as lowest as 17.4486MW in the first case, 17.4368MW in the second case, and 17.4179MW in the third case.

Keywords: Active power loss, Distributed generation, Evolutionary Programming, Particle Swarm Optimization

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1. INTRODUCTION

Renewable energy has become one of the alternatives for generating electricity to meet the rising energy demand due to the increased interest in green technologies. A decision to use this technology could maintain the sustainability of the environment and substantially impact the reduction of carbon[1]. Furthermore, its ability to be integrated in near to the load center offers a valuable solution for addressing location limiting factors resulting from power generation and reducing losses during transmission over long distances. Additionally, by incorporating renewable energy sources, the power system's losses and stability can be increased[2]. Although there have been more studies on how to incorporate renewable energy into DG properly, fewer studies have been conducted on the advantages of DG when considering the issue from the perspective of the transmission system.

The term 'Distributed Generation' (DG) refers to small power production technologies like photovoltaic and wind turbines which they generate power in either direct current (DC) or alternating current (AC) formats, with a range of frequencies. DG makes direct connections to customers, distribution systems, or transmission networks possible[3]. Given the rising global temperature, solar energy offers a clean alternative energy source. Because it is more effective and affordable, solar energy has the potential to serve as the next generation energy[4]. DG has helped the electrical power system get better in recent years. Due to rising of pollution to the environment and increasing growth in green energy sources, DG is a beneficial additional energy source for conventional fossil fuel power plants. The design and enhancement of power systems for increased reliability depend on the quantity, size, and kind of DG[5]. Power losses on the network have led to a system imbalance. Losses in storage and transmission or distribution contribute to most of the balance. DG is one of the solutions that must be carefully planned to effectively reduce transmission and distribution losses.

Recent advancements in smart grid technology and operating system integrity have led to an importance for environmental effects, stability, and cost reduction in network operations. Also, these advancements have contributed to the availability of high-quality energy supply[6].

To maximize the DG's contribution to the distribution system, utilization and DG capacity is required to controlled appropriately. Investors in DG installations require conditions of climate, the dimensions of a unit, and the accessibility of resources from nature[7]. The distribution network operating system can directly be impacted by DG installation. If the DG installation is done incorrectly, system losses, rising capital and operational expenses, and system instability may occur[8].

2. METHODOLOGY

This paper aims to implement Evolutionary Programming (EP) and Particle Swarm Optimization (PSO) algorithm by using MATLAB to determine the optimal location and sizing of distributed generation (DG) for photovoltaic system in an interconnected IEEE-30 bus power system, and minimize the active power loss and improve the voltage profile, then perform comparative studies in terms of active power loss and voltage profile of EP and PSO algorithm.

2.1 Objective Function

The objective function of this study is to minimize the active power losses by optimal placement and sizing of DG. The total active power loss is calculated as the summation of the active power loss of each problem formulation which expresses as in Eq (1) [9]:

$$F = \min \Sigma P_{LOSSES} \quad (1)$$

Where F is the objective function and P_{LOSSES} is the total active power losses in the proposed system.

2.2 Constraint

The objective function of this study is subject to the constraint where there is +/- 5% tolerance of per unit voltage in the IEEE-30 bus system. The formula used for voltage is shown in Eq (2):

$$v_i = V_m[cos\theta + j\ sin\theta] \quad (2)$$

Inequality constraint of voltage

$$Vmin < Vi < Vmax \quad (3)$$
$$0.95\ pu < Vi < 1.05\ pu \quad (4)$$

Where V_i is the voltage in each bus. Vmin and Vmax is the minimum and maximum voltages.

DG capacity constraint

$$Pmin < Picap < Pmax \quad (5)$$
$$0\ MW < P_i^{cap} < 100\ MW \quad (6)$$

Where P_i^{cap} is the active power generation capacity of DG on certain bus. Pmax is the maximum power while Pmin is the minimum power.

2.3 Problem formulation

To form bus admittance matrix (*Ybus*) for power flow analysis

Branch admittance, $Z = r_{ij} + jX_{ij}$ (7)

Line impedance, $y = 1/Z$ (8)

Where:
Ij = the element of impedance matrix [Z_{bus}]
Z = branch admittance
R = *resistance*
j = imaginary unit
X = imaginary component for complex number
y = line impedance

2.4 Research Implementation

The proposed algorithm is applied on IEEE-30 bus interconnected distributed system in three different cases. In case 1, the power system is working with an additional reactive power, MVAR at bus 7 for single and two units of DG. Case 2, power system is working with an additional reactive power, MVAR at bus 15 for single and two units of DG. In case 3, the power system is working with an additional reactive power, MVAR at bus 21 for single and two units of DG. Besides, the reactive power load was varied to 40,60,80 and 100MVAR. Since adding the consideration of reactive power demand in IEEE-30 bus system can be an important factor in finding the optimal placement and sizing of DG. The result obtained by the proposed algorithm is compared in terms of placement and sizing of DG, active power loss and voltage profile. The overall project process has been discussed in the flowchart shown in Figure 1.

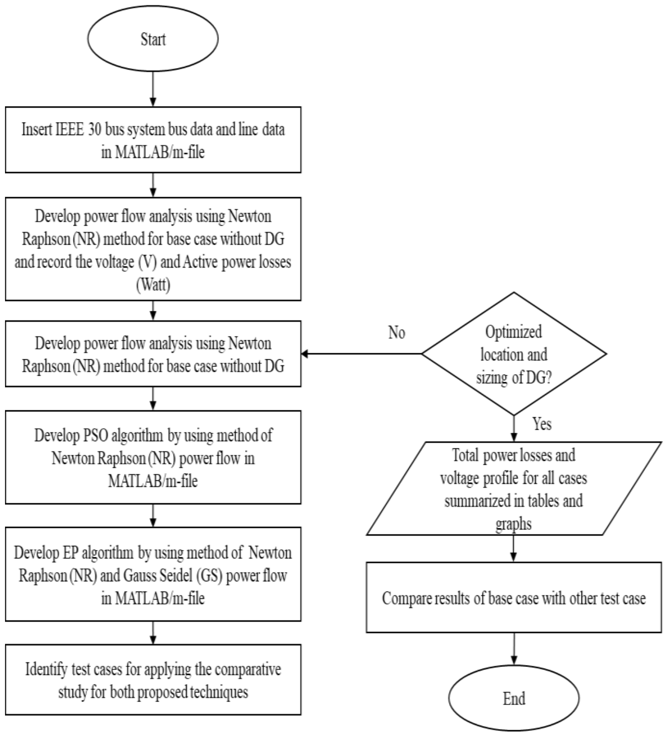

Figure 1. Flowchart of overall project

2.5 Modelling of IEEE-30 bus system

Figure 2 shows the IEEE-30 bus interconnected distribution system that will be used as a test distribution system in this project. This system consists of 30 buses, 1 generator, 21 load and 41 line (branches).

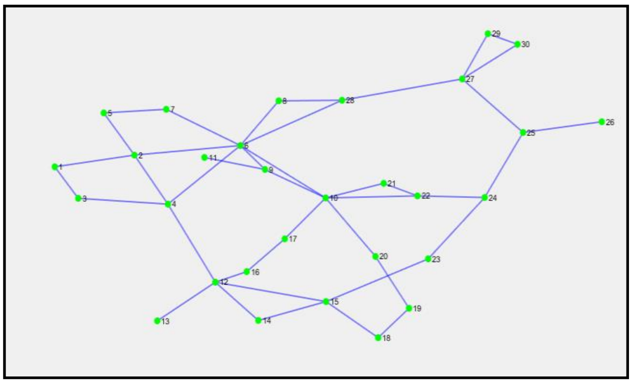

Figure 2. IEEE-30 bus interconnected distribution system

2.6 Newton Raphson power flow analysis

Figure 3 shows the process of Newton Raphson power flow analysis that has been used in this study.

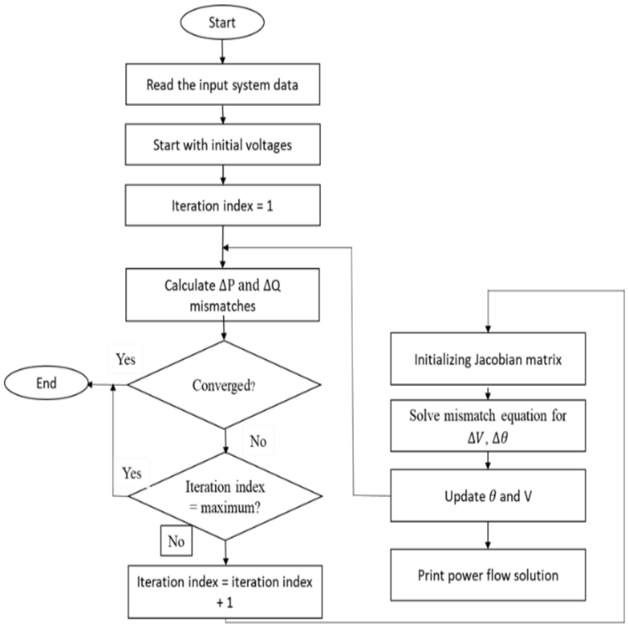

Figure 3. Flowchart of Newton Raphson (NR) analysis [3]

3. OPTIMIZATION PROCEDURE

This section explains the important procedure used in EP algorithm.

3.1 Evolutionary Programming (EP) algorithm

EP is the first techniques used in this study. The main EP process are Initialization, Fitness 1, Mutation, Fitness 2, Combination and Selection as shown in Figure 4. Besides, the detail parameter inserted in the EP optimization is shown in Table 1.

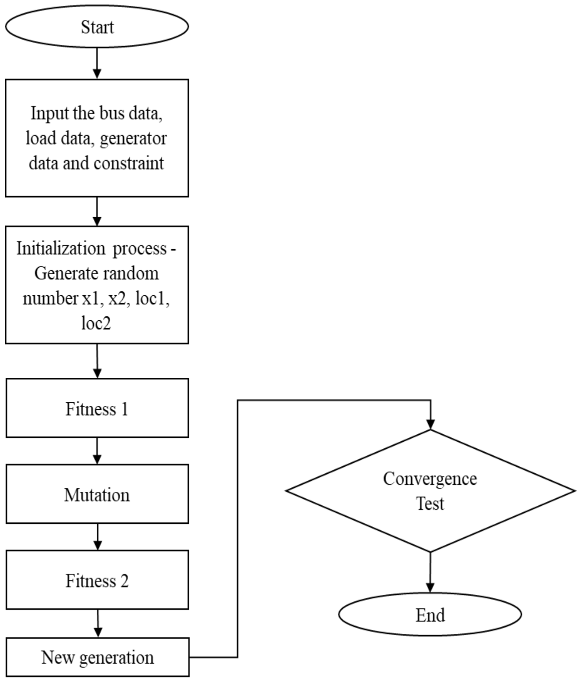

Figure 4. Overall process of EP technique for optimization

Table 1. Parameter of EP optimization

Parameters	**Values**
Bus no	3-30
Bus value	10-100
Base MVA	100
Maximum iteration, *MaxIt*	100
Number of DG	2
Population size, *kira*	20
Voltage constraint, *Vm*	0.95 – 1.05 p.u[10]
Power flow Solution	Newton Raphson & Gauss-Seidel
Location boundary	2 -30 bus
Size boundary, *Qdg*	0 – 100 MVAR
Output	loc1, loc2, x1, x2

Furthermore, the detailed process of the proposed EP optimization, which has been implemented in the MATLAB/m-file, was discussed as follows:

Step 1: Run base case load flow (without DG)

- Initialize power loss vector and iteration count.
- Specify the bus number and value of DG.
- Form the bus admittance matrix, then performed the power flow solution by using NR method. Next, print the power solution and calculate the line flow and transmission loss in the system.

Step 2: Store the voltage and loss values before EP Optimization

Step 3: EP Optimization begins- Initialization process

- Generate random loc1, loc2, x1, and x2.
- Insert DG into system by define the size DG and bus location.
- Perform power flow calculation and calculate the transmission loss. (calculated Loss>=initial loss), the loops will iterate.
- Stored x1, x2, loc1, loc2 I '*keluaran*' array if vice versa.

Step 4: Fitness 1

- Inner loop finishes – then, code enters an outer loop, fitness calculation is performed for the 20 sets of DG locations and sizes in each iteration stored in the `*keluaran*` array.
- Power flow analysis is performed and calculate the transmission loss
- Fitness values (loc, x, and loss) stored in fit1 array

Step 5: Mutation

- Generate new candidate solutions for optimization process.
- Gaussian-distributed random number is generated (`Z1`, `Z2`, `Z3`, `Z4`) based on the fitness values and max/min ranges of DG x and loc.
- Mutation applied to DG (`x1`, `x2`, `loc1`, and `loc2`), - `x1_new`, `x2_new`, `loc1_new`, and `loc2_new`

Step 6: Fitness 2

- Fitness calculation process is repeated with the new generation of DG sizes and locations.
- Power flow analysis is performed for each set, x, loc, loss and then stored in `fit2` array.

Step 7: New generation

- Fitness values (`fit1` and `fit2`) combined =`Fit_all` array.
- `Fit_all` array is sorted based on the fitness values, and the top 20 individuals with the lowest fitness values are selected (`Fit_low`).

Step 8: Convergence Test

- The code checks if the difference between the max & min fit values in `Fit_low` is below a threshold (0.0001).
- Below threshold, it will proceed next iteration and then it will convergence.
- If exceed threshold, the itercount incremented.
- If exceed 100 times, Optimization will stop

Step 9: Output produced

- Convergence graph, voltage profile

3.2 Particle Swarm Optimization (PSO) algorithm

PSO is the second techniques used in this study. In PSO, the state of each particle is defined by two fundamental variables, namely velocity and position. In PSO, the state of each particle is defined by two fundamental variables, namely velocity and position. The equation utilized for the updating of particle velocity and position is as in Eq (9) and Eq (10) [11][12]:

$$v_{ij}(t+1) = wv(t) + c_1 r_1(pbest_{ij}(t) - x_{ij}(t) + c_2 r_2(gbest_j(t) - x_{ij}(t)) \quad (9)$$

$$x_{ij}(t+1) = x_{ij}(t) + v_{ij}(t+1) \quad (10)$$

Where *Xij* and *Vij* are the parameter used in the algorithm.

The main PSO process is shown as Figure 5, and the parameter inserted in the PSO optimization is shown in Table 2.

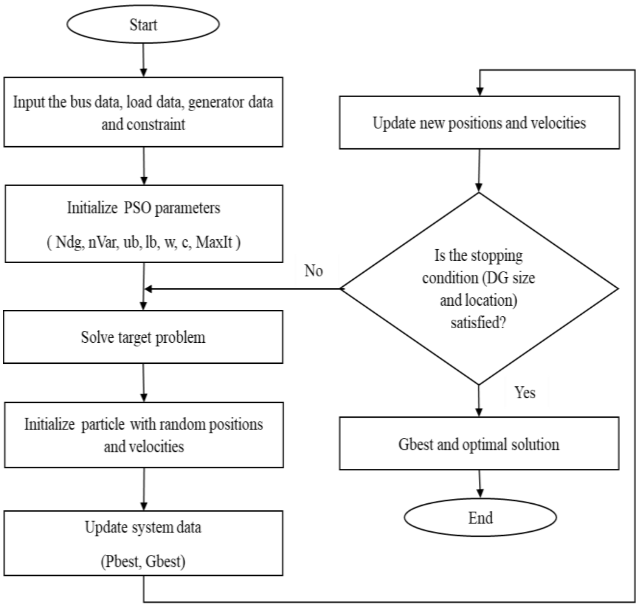

Figure 5. Overall process of PSO technique for optimization

Table 2. Parameter of PSO optimization

Parameters	Values
Bus no	3-30
Bus value	10-100
Base MVA	100
Maximum iteration, MaxIt	100
Number of DG	2
Population size, nPop	20
Cognitive weight, c	2
Inertia weight, w	Min-0.1 Max- 0.9
Voltage constraint, Vm	0.95 – 1.05 p.u
Location boundary	2 -30 bus

Size boundary , Qdg	0 – 100 MVAR
Power flow Solution	Newton Raphson
Output	Best cost: loss Location Size (MW)

Furthermore, the detailed process of the proposed PSO optimization, which has been implemented in the MATLAB/m-file, was discussed as follows:

Step 1: PSO optimization begins - Initialize the parameters

- Population size, maximum number of iterations, number of DG, upper and lower bounds for DG location and size, cognitive weight, c, inertia weight, w.

Step 2: Initialize particle with random position and velocities

- DG location randomly generated within the bounds specified by lb and ub, while the DG size is randomly generated within its own specific bounds.
- The position and velocity of each particle stored in the particle structure.

Step 3: Update system data

- Perform power flow analysis using the PSO, then, modified bus data, where DG are inserted into the system by updating the bus data and calculate the transmission loss
- Update *Pbest* and *Gbest*

Step 4: Particle position and velocity update (new)

- Velocity is updated by considering the inertia weight, cognitive component (c1), and social component (c2).
- Check either V within range values.
- Particle position then updated using the new velocity, & boundary check location and size within bounds.
- Perform power flow based on best position found.

Step 5: *Gbest* and optimal solution is produced

- Best solution (position and cost) found in the current iteration and store them in the record structure

Step 6: Output produced

- Convergence graph and voltage profile

4. RESULTS AND DISCUSSION

Three cases are studied to verify the effectiveness of PSO in DG placement. Case 1, where the power system is working with an additional reactive power, MVAR at bus 7 for single and two units of DG. Case 2, where the power system is working with an additional reactive power, MVAR at bus 15 for single and two units of DG. Case 3 where the power system is working with an additional reactive power, MVAR at bus 21 for single and two units of DG. The comparison of DG placement and sizing, active power losses and voltage profile between EP and PSO simulation results for all of cases has been analyzed. The example of voltage profile and convergence graph figure produced will be shown for case 1, single unit DG as shown in Figure 6 and Figure 7 and two units of DG as shown in Figure 8, and Figure 9. This pattern of results is being produced for all cases.

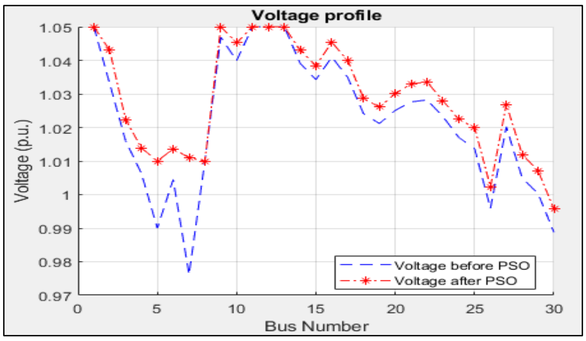

Figure 6. Voltage profile of PSO techniques for 40MVAR load variation at bus 7 for single unit DG

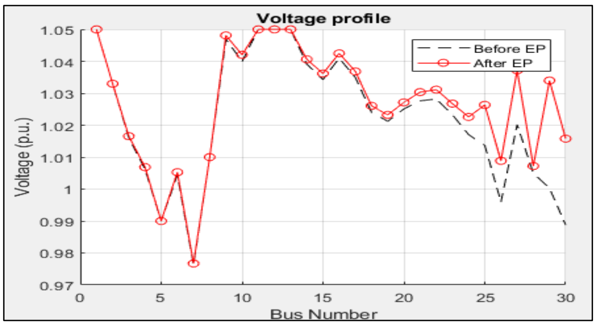

Figure 7. Voltage profile of EP techniques for 40MVAR load variation at bus 7 for single unit DG

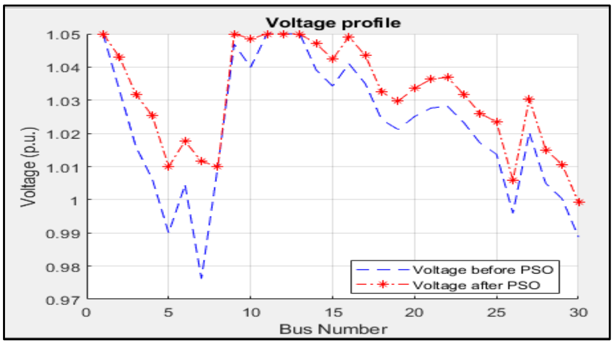

Figure 8. Voltage profile of PSO techniques for 40MVAR load variation at bus 7 for two units of DG

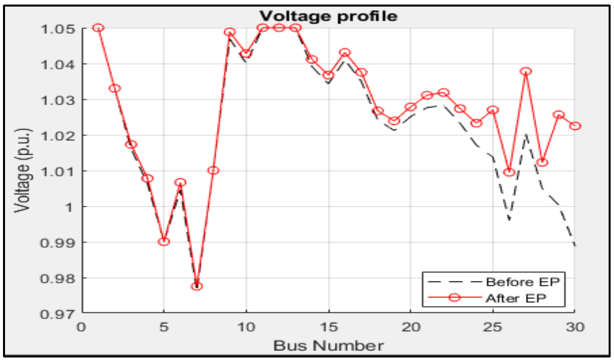

Figure 9. Voltage profile of EP techniques for 40MVAR load variation at bus 7 for two units of DG

4.1 Case 1: Load variation at Bus 7

Comparison between base case, single unit of DG and two units of DG for additional reactive power load at bus 7

As referring to Table 3, the selected location and sizing for EP techniques for single unit of DG would be at bus 29 with 5.6427MW size of DG, while for two units of DG is bus 28 with size DG of 9.9073MW and bus 30 with size of 4.4151MW. Next, the selected location and sizing for PSO techniques for one units of DG possible to be at bus 7 with a size of 42.84MW, 62.85MW, and 82.85MW. But, in this project, the cost analysis is not be focus on, so, considering the lower computational time will be chosen when the power losses are equal. Therefore, in this case, 82.85MW will be the best size since the computational time is much lower, 61.9677s compared to others. Lastly, for two units of DG, the best location is bus 4 with size of 33.72MW and bus 7, 39.05MW.

Table 3. Summarization of selected location and sizing of DG for case 1

Parameter	Load variation (MVAR)	Base case	EP		PSO	
			1 DG	2 DG	1 DG	2 DG
Total Active Power Loss (MW)	40	18.0810	18.0333	18.0175	17.5572	17.4486
	60	18.6670	18.6067	18.5829	17.5572	17.4877
	80	19.7960	19.4460	19.4062	17.5572	17.4877
	100	20.8670	20.5980	20.5670	17.5589	17.5059
Total Reactive Power Loss (MVAR)	40	24.8210	24.4340	24.8210	21.9960	24.8210
	60	25.89	26.6410	25.89	21.9860	25.89
	80	32.279	30.1040	32.279	21.9860	32.2790
	100	36.9570	33.4020	36.9570	22.0190	36.9570
Selected optimal location and sizing (DG location, DG size)			(Bus 29, 5.6427MW)	(Bus 28, 9.9073MW) & (Bus 30, 4.4151MW)	(Bus 7, **82.85MW**)	(Bus 4, 33.72MW) & (Bus 7, (39.05MW)

4.2 Case 1: Load variation at Bus 15

Comparison between base case, single unit of DG and two units of DG for additional reactive power load at bus 7

As referred to Table 4, the selected location and sizing for EP techniques for single unit of DG would be at bus 28 with 19.4795MW size of DG, while for two units of DG is bus 29 with size DG of 4.1392MW and bus 28 with size of 15.3289MW. Next, the selected location and sizing for PSO techniques for one units of DG possible to be at bus 21 with a size of 43.03MW, 63.03MW and 83.03MW. But, in this project, the cost analysis is not be focus on. Therefore, considering the lower computational time will be chosen when the power losses are equal. Therefore, in this case, 83.03MW will be the best size since the computational time is much lower, 48.8205 seconds compared to others. Lastly, for two units of DG for PSO techniques, the best location is bus 21 with size of 40.72MW and bus 4, with DG size 33.05MW.

Table 4. Summarization of selected location and sizing of DG for case 2

Parameter	Load variation, (MVAR)	Base case	EP		PSO	
			1 DG	2 DG	1 DG	2 DG
Total Active Power Loss (MW)	40	18.8530	18.8060	18.7956	17.5420	17.4739
	60	20.5710	20.4100	20.3948	17.5420	17.4368
	80	22.8200	22.6790	22.6562	20.7485	17.4739
	100	26.2990	25.7924	25.7920	17.5759	17.4533
Total Reactive Power Loss (MVAR)	40	28.089	26.773	27.454	28.089	21.22
	60	35.915	34.74	34.262	35.915	21.113
	80	45.025	43.446	42.845	45.025	21.22
	100	58.787	54.545	54.642	58.787	21.351
Selected optimal location and sizing (DG location, DG size)			(Bus 28, 31.9209MW)	(Bus 30, 4.717MW), (Bus 28, 5.8336MW)	(Bus 15, 48.72MW, 68.72MW)	(Bus 15, 66.17MW), & (Bus 4, 33.16MW)

4.3 Case 1: Load variation at Bus 21

Comparison between base case, single unit of DG and two units of DG for additional reactive power load at bus 21

As referred to Table 5, the selected location and sizing for EP techniques for single unit of DG would be at bus 28 with 19.4795MW size of DG, while for two units of DG is bus 29 with size DG of 4.1392MW and bus 28 with size of 15.3289MW. Next, the selected location and sizing for PSO techniques for one units of DG possible to be at bus 21 with a size of 43.03MW, 63.03MW and 83.03MW. But, in this project, the cost analysis is not be focus on. Therefore, considering the lower computational time will be chosen when the power losses are equal. Therefore, in this case, 83.03MW will be the best size since the computational time is much lower, 48.8205 seconds compared to others. Lastly, for two units of DG for PSO techniques, the best location is bus 21 with size of 40.72MW and bus 4, with DG size 33.05MW.

Table 5. Summarization of selected location and sizing of DG for case 3

Parameter	Load variation (MVAR)	Base case	EP		PSO	
			1 DG	2 DG	1 DG	2 DG
Total Active Power Loss (MW)	40	18.3550	18.2460	18.2262	17.5232	17.4179
	60	19.3180	19.2650	19.2313	17.5232	17.4179
	80	20.8850	20.7050	20.6840	17.5232	17.4866
	100	23.5920	22.7934	22.8310	17.5265	17.4760
Total Reactive Power Loss (MVAR)	40	26.6410	25.3010	24.9850	21.6010	21.0180
	60	31.4680	30.6470	29.2400	21.6010	21.0180
	80	40.0600	36.8820	36.6680	21.6010	21.4810
	100	54.1510	45.5930	46.3950	21.6840	21.2610
Optimal location and sizing			28, (19.4795MW)	29, (4.1392MW), 28 (15.3289MW)	21, (43.03MW, 63.03MW, **83.03MW**)	4, (33.05MW), 21 (40.72MW)

4.4 Summarization for comparison of active power losses between all cases

4.4.1 Comparison active power loss when reactive power load is varied at bus 7

For case 1, which is the reactive load power is varied at bus 7, the active power losses (MW) when using PSO optimization is higher compared to EP optimization. Moreover, the active power losses of using two units of DG gives the lowest losses which is 17.4486MW as compared to one unit of DG as shown in Figure 10.

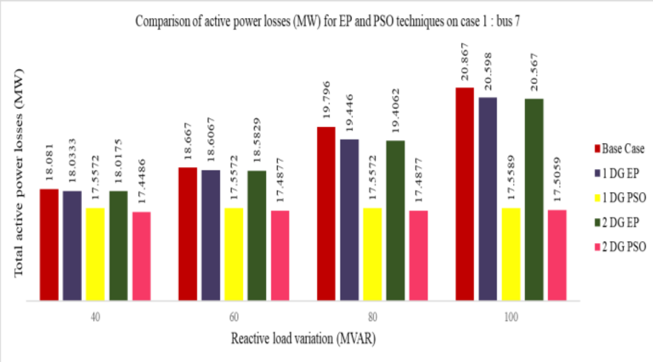

Figure 10. Comparison of active power losses for load variation at bus 7 for EP and PSO techniques

4.4.2 Comparison active power loss when reactive power load is varied at bus 15

In the case where the reactive load power is varied at bus 15, it is observed that the active power losses (expressed in megawatts) obtained through PSO optimization are comparatively greater than those obtained through EP optimization. Furthermore, it is observed that the employing of two units of distributed generation (DG) results in the lowest active power losses, amounting to 17.4368MW. This contrasts with the use of a single unit of DG, as illustrates in Figures 11.

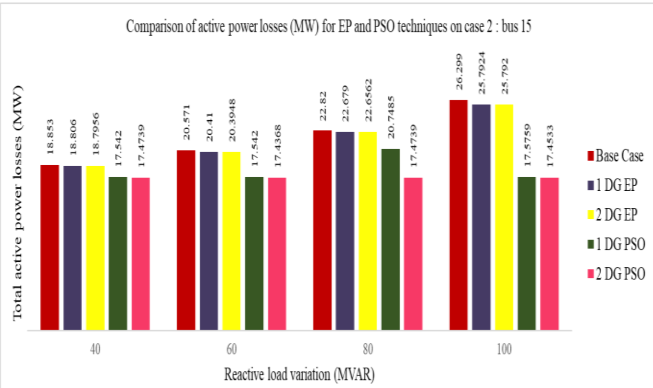

Figure 11. Comparison of active power losses for load variation at bus 15 for EP and PSO techniques

4.4.3 Comparison active power loss when reactive power load is varied at bus 21

In the case where the reactive load power is varied at bus 21 (referred to as case 3), it is observed that the utilization of PSO optimization results in higher active power losses (measured in MW) compared to the utilization of EP optimization. Furthermore, it can be observed from Figures 12 that applying two units of distributed generation (DG) results in the lowest active power losses, which is 17.4179 MW, in comparison to the application of a single unit of DG.

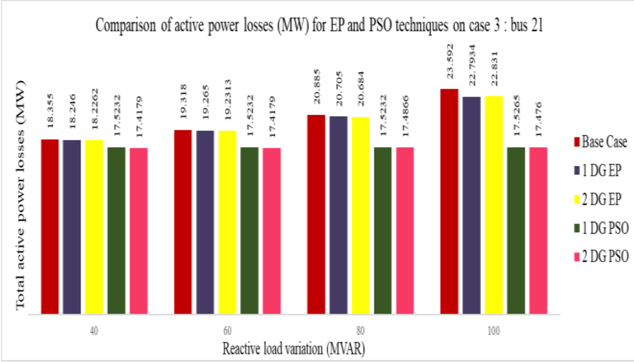

Figure 12. Comparison of active power losses for load variation at bus 21 for EP and PSO techniques

5. CONCLUSION

Based on the results of this research, it can be concluded that two different algorithms namely EP and PSO are systematically presented in this study by producing the graph of voltage profile, convergence graph, in order to fully the fitness function, the optimal placement and sizing of DG for minimizing the power losses. The result analysis provides comparison of two techniques algorithm which shows that PSO algorithm gives the best performance (outperformed the EP) in achieving significantly high Total active power losses (MW) reduction, its computational time is more faster, and two units of DG installation exhibit the most positive impact on power loss minimization. Since the economic analysis is not include in this study, the selection of optimal placement and sizing of DG will depend on the total active power loss (MW) and computational time (seconds).

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