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Hybrid swarm evolutionary programming for optimal distributed generation in distribution system

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Abstract

This paper discusses the incorporation of the Hybrid Swarm Evolutionary Programming (SEP) for optimal distributed generation (DG) in the distribution system. High load demand will result in unstable control power distribution due to power transmission loss. The compensation process can be implemented by installing a compensation device to prevent this from happening. It is required the optimal sizing and location for the devices to achieve the objective and this can be done by using an optimization technique. Thus, this project aims to develop a hybrid computational intelligence technique is called hybrid SEP for loss minimization. The proposed method embedded the element of Particle Swarm Optimization (PSO) into traditional Evolutionary Programming (EP) to improve precision of traditional EP algorithm. The purpose of this study is to investigate the maximum benefits of DG integration to be gained. The proposed techniques are validated on IEEE-69 bus radial system with multiple units of DG. The results showed that the most effective type of DG inject to IEEE-69 bus radial system is with DG Type III, with 95% of active power loss reduction and the best on voltage profile improvement. Hybrid SEP shows superior to EP in term of loss minimization.

Keywords: Distributed generation, Evolutionary programming, Hybrid Swarm evolutionary programming

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1. Introduction

The power distribution system is one of the parts in power system, which is used to connect the user and power transmission system to meet the required demand and good quality of power. Distributed Generation (DG) is used for encounter most of the distribution system challenges, it is an effective tool. DG refers to different of technologies for electricity generation, such as renewable energy and non-renewable energy which can be either off-grid or on-grid mode. In recent years, the global electrical energy demand is continually increasing due to economic growth and higher standard of living. Thus, the increasingly stress condition of power generation and transmission system is facing several financial, environmental and technical obstacles due to experiencing increasing power loss. High voltage overhead transmission lines and those active and reactive elements in transmission system during transmission may cause loss of energy and indirect emissions cause indirect carbon emissions that will cause air pollution in power generation plant which are fossil fuel type due to lower efficiency cause by losses during transmission [14, 19, 12].

DG provide both active and reactive power support and alternative dispatch option of real power to delivered both voltage and line flow limits violations, minimize system losses, improve system stability and power quality. By reducing energy loss in transmission and distribution lines, power can be maximized on the demand side. Nowadays, the most attractive research area for power system is DG sizing and allocation for power loss minimization. These include topics such as enhancement of distribution system voltage stability, improvement of loadability, improvement of reliability and reduction of economic costs. The resistive and reactive element in distribution lines will cause the losses of real and imaginary power. Active power loss will reduce the efficiency of electrical energy transmission and loss of profit. There are different approaches are proposed to minimize the real power loss minimization by extensive body of literature. Furthermore, the improvement of electrical energy transmission efficiency is with only reducing active power losses, also optimize the reactive power losses for improving the voltage profile of the distribution network. Improvement of reactive power loss will be enhancing the loadability, decreasing voltage drops and ensure the stability of active power flow through the transmission lines [16, 2].

Many techniques are adopted to achieve loss minimization such as Particle Swarm Optimization (PSO), Mixed-Integer Nonlinear Programming, Modified Teaching- Learning-Based Optimization, and Gravitational Search Algorithm (GSA) was used to determine DG optimal capacity and site [1, 21, 5]. In this project, Evolutionary Programming (EP) is proposed to use for solving the problem for optimal DG placement, sizing and energy loss minimizing as a fitness function with network constraint. EP is a stochastic optimization technique that focuses on the behavior correlation between correlation parents and their offspring rather than attempting to replicate specific genetic operators found in nature. EP can be used to develop artificial intelligence and its optimization has been shown to be more efficient and successful than traditional methods since it does not rely on mathematical assumptions and provides a powerful global search across the control variable space. Nowadays, there are many hybrid types of optimization method used, the hybrid method combine of advantages of two method is resulted to have better efficiency on loss minimization and computation time [17]. There is also hybrid method of EP base proposed to use in this project.

2. Distributed generation

The power distribution system is the final stage of electric power transmission, it delivers the electricity from the transmission system to consumers. Distributed generations (DG) are small generating units, they are primarily built close the load center and at strategic points of the distribution system. DG able to fulfill the extra demand during peak hour when the centralized power plant insufficient to fulfill the whole demand. DG consists of two types, which are inverter-based and non-inverter-based DG [18]. DG is connected to meet local customer demand or to provide electricity to the rest of the electrical system. To maintain the benefits of DG, there are several factors must be considered and study well during the design stage, which are location, type, number and capacity [9].

Since the trend of deregulation has changed electricity per generation globally and can still not solve the electricity problem alone, the new generation technologies development in distribution system can change the ways of producing power.

The latest trend in the penetration of utilise source located within the distribution system is a very promising choice in the context of deregulation. DG units will have a significant impact on whole distribution systems operation. For example, on-load tap changing transformers at substations or switched capacitors on feeders are used to regulate in radial distribution feeders.

The distribution power flow changed is due to the existence of DG units call for comprehensive study and creation of instruments that can measure their increase/reduction of feeder losses and feeder loadability contributions. The most substantial advantages are gained from deferral when installation of DG at the end of long feeders and near the load.

The voltage profile of the system would be affected by the installation of DG units. In certain situations, this effect may be positive, such as voltage support, but it can be negative such as over-voltage or under-voltage, based on the relative size of the DG and their allocation, distribution line and load characteristic, and method of voltage regulation [5], [7, 15, 10, 8].

The integration of DG into distribution systems has been known for decades. Distribution planning and operational practises would become substantially complicated and require significantly higher effort in data collection and analysis. There are many benefits with implementing DG in distribution system, but at the same time there are many constraints and limitations and DG also raise the system planning problem complexity. Thus, to ensure the efficiency ad profit of the utility, DG's size and location is crucial for the loss reduction [11].

3. Optimal allocation and DG planning

EP and proposed hybrid SEP are techniques for determining the optimal active and reactive power to be dispatched by the generator buses that are participating. Both programs were written in the MATLAB programming language. The random number indicated the number of generator buses injected into the system as Type 1 DGs with active power, Type 2 DGs with reactive power, or Type 3 DGs with active and reactive power. There are several variables, namely x-1., x-2, up to x-n, that are dependent on the n number of randomly generated DG units. These variables determine the amount of power to be injected into the generator bus at random locations. These values will be stored in the load flow program's system data.

The load flow program's output is then used to calculate the total loss, which is used to determine fitness. To begin, inequality constraints must be defined to ensure that the methods generate random numbers that satisfy the predetermined requirements. During initialization, the total loss value must be less than the loss set value, and the bus voltage limit must be within the voltage set range. The constraints set's purpose is to ensure that the total loss calculated by the generated random numbers is less than the loss set, thereby improving the fitness of the system. Otherwise, the system's total loss may not be improved. Additionally, the inequality constraint of the voltage limit is used to ensure that the system voltage is not violated during the fitness calculation. Both methods are used to accomplish the desired results.

3.1. Evolutionary programming

EP is an optimization method of artificial intelligence (AI) hierarchy falls under the Evolutionary Computation (EC). After Fogel's exposure, EP has been used in detailed project analysis and optimization [20]. This method has been reported as a quick search method that has usually used to ease the analysis method and to fine-tune the results. In recent years, this method was extensively used to solve power system optimization challenges.

EP is a method of stochastic optimization focused on the mechanics of the natural selections-mutation, competition and evolution. The behavioural relation between parents and their offspring was emphasised in this method. EP finds the optimal solution by constructing a population of multiple generations of individual solutions [20, 4, 13]. A new population is created from the existing population by realizing the mutation operator. By disrupting each component of the current solution, the operator generates a new solution by a random quantity. Each candidate's strength is determined by its fitness, which measured by the optimization problem's objective function. Every individual from the population will compete by the selection process which carry out through the tournament system. For the new generation, the individuals which have gained the most wins will be chosen, the weaker individuals will eliminated. Random number generation, mutation and selection tournament involved in the execution of the EP. Figure 1 showed the general flowchart for basic Evolutionary Programming. In Figure 2 shows the flowchart for the DG allocation and sizing optimization to minimize the losses and improve voltage profile.

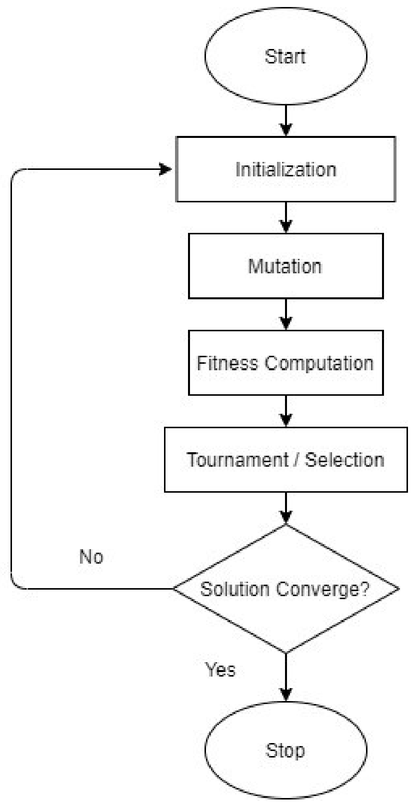

Figure 1: Flowchart for basic evolutionary programming

3.2. Proposed hybrid swarm evolutionary programming

PSO is a problem-solving algorithm that can solve problems of any sequence and with any set of constraints. PSO involves placing multiple simple entity particles in the search space of a problem

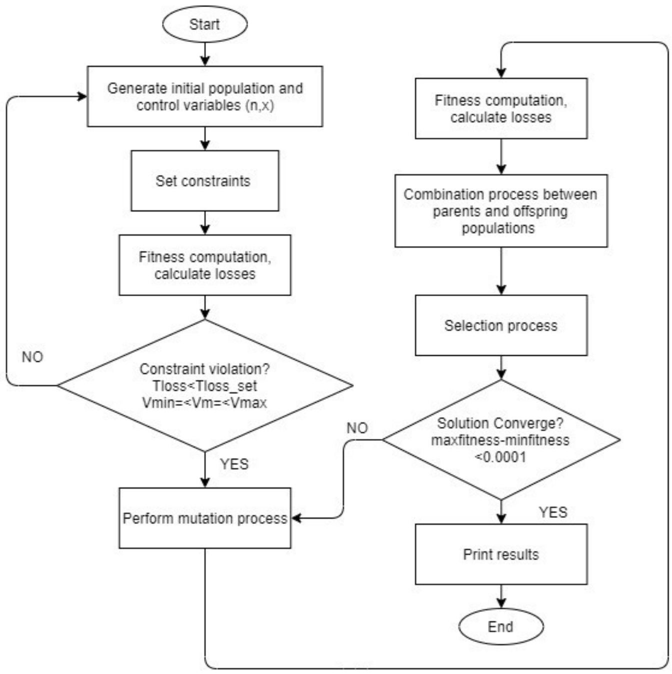

Figure 2: Flowchart for the DG allocation sizing

or function, and each particle evaluates the objective function at its current position. Each particle's path throughout the search space is then calculated by combining some elements of its current and optimal locations with those of one or more swarm members, along with certain random disturbance. After all particles have been moved, the next iteration is beginning. It is like a flock of bird looking for food, the swarm is likely approaching the fitness function's optimum. Particles is flying around in an n-dimensional search space in a PSO system. Each particle is adjusting its own position with its own experience (known as P_{best}) as well as the experience of a neighbouring particle (known as G_{best}) [9, 3, 6].

The advantage of Particle Swarm Optimization (PSO) method is providing the precise solution, while its flaw is required longer time for the computational process due to the slow convergence. The advantage of Evolutionary Programming optimization (EP) is the solution have fast convergence characteristic and its flaw is the solution is not precise for every computation. Thus, the hybrid SEP method will combine of both PSO and EP advantage to encounter their flaw. The hybrid method will provide precise solution compared to traditional EP and fast computation compared to PSO. Figure 3 shows the flowchart for the DG allocation and sizing optimization to minimize the losses and improve voltage profile.

The proposed hybrid SEP method for optimal size, loss minimization, and voltage profile improvement of multiple DG of various types consists of the following steps:

Step 1. Set population number.

Step 2. Set number of DG to be install (2, 3, to n number of DGs).

Step 3. Generate random number, x1, x2, x. . . ... (different type of DG: Type 1, Type 2, or Type 3).

Step 4. Set constraints, i.e. total loss $\leq loss_{set}$ and $V_{min} \leq V_m \leq V_{max}$.

Step 5. Calculate fitness by running load flow program to identify total loss.

Step 6. Assign particle personal best and global best, P_{best} and G_{best}.

Step 7. Particle update position and velocity.

Step 8. Calculate fitness by running load flow program to identify total loss
Step 9. Compare P_{best} with G_{best}.
Step 10. Perform mutation process and calculate fitness
Step 11. Combine data and selection process
Step 12. Convergence test
Step 13. End program

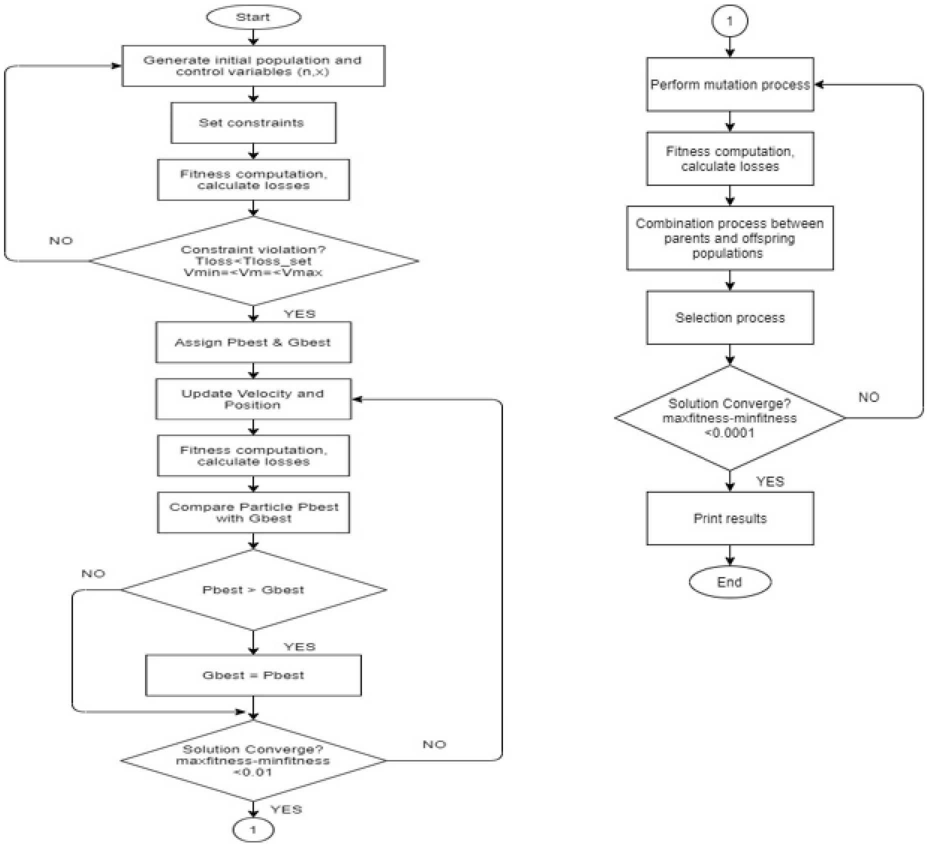

Figure 3: Flowchart of HSEP process for DG allocation and sizing

3.3. Objective function

The objective function in this project is real power losses, it is the sum of the entire electrical load of all nodes in the power distribution test system. in the pre optimization, the initial losses on the system are required to identify. Hence, by studying the power injected through the load buses, the type of DG used will affect the system. Thus, the optimization of the objective function of the system is using the algorithm technique. The objective function f is given by:

$$minf = \sum_{i=1}^{a} P_i \qquad (1)$$

Where:
i represented as location of DG unit;
P_i represented as power loss at bus i;
a represented as test system total number of bus.

The generator voltage will be the load/bus plus some value relating to the line impedance and power flows along the line. The larger of impedance and power flow, the voltage rise will be larger. In general, the assumption of stability for all node voltages is within 0.90 and 1.05p.u. the voltage must be maintained within the limits on each bus. The given inequality constraint on voltage at each bus is:

$$|Vi|min \leq Vi \leq |Vi|max \tag{2}$$

Where: $|Vi|$min represented as minimum node voltage;
$|Vi|$max represented as maximum node voltage.

The power loss constraint set is depending to the design losses and the optimization technique whether to set in active loss or reactive power loss. But the power loss constraint must set below the total power loss in the system without DG added to have loss minimization.

$$Tloss < Tloss\_set \tag{3}$$

Where:
Tloss represented as system losses.
Tloss_set represented as pre-set system losses.

Integration of DGs can help improve the efficiency of active power losses. Equation showing the effect of DG integration on active power loss reduction, P_{Loss}^{Index} as defined (4).

$$\%P_{Loss}^{Index} = \frac{P_{Loss}^{DG}}{P_{DG}^{witoutDG}} \times 100\% \tag{4}$$

The reactive power losses vary depending on how many DGs are integrated. To determine the extent of DG integration's impact on reactive power losses, Q_{Loss}^{Index} is defined as:

$$\%Q_{Loss}^{Index} = \frac{Q_{Loss}^{DG}}{Q_{DG}^{witoutDG}} \times 100\% \tag{5}$$

4. Results and discussion

This section discusses the EP results and proposed HSEP for determining DG size and location to maximise DG benefits. The results of active and reactive losses, as well as the voltage profile after the addition of multiple DG of various types and sizes, are discussed throughout this section. All losses are calculated using the line loss programme. Real power loss and reactive power loss are the two types of losses that occur in the distribution system. The resistance in lines causes real power loss, while reactive power loss is caused by reactive elements in the distribution system. Higher loss and lower voltage magnitude will result for buses that are far from the power generation unit or slack bus. As a result, to minimize losses, the DG unit must inject active or reactive power into the distribution system. Depending on the type and total losses in the system, different types of DG insert into the system may result in different efficiency on loss minimization. There is total 3 case study conducted in this project, Case study 1 (without DG), Case study 2 (2 units of DG), Case study 3 (3 units of DG) and Case study 4 (4 units of DG) with different type of DG, Type 1 (only active power), Type 2 (only reactive power) and Type 3 (both active and reactive power). The best of five simulations is used to record and tabulate the results.

4.1. DG in the distribution system

Before evaluating the efficiency of the optimization method in terms of loss minimization and voltage profile improvement, it is necessary to determine the total loss of the distribution system, as well as the voltage profile of the distribution system without DG. The results for Case 1 exhibit the total losses are 0.225MW and 0.102 MVar respectively. According to Tables 1, 2, and 3, adding DG Type 3 to the test system results in the greatest reduction in loss for loss minimization, whereas adding DG Type 2 shows the least reduction in loss minimization. However, when three DG units are installed, the loss reduction percentage is similar to that of four DG units, which is 95%. According to Table 2, the optimal locations for a three-unit DG installation utilising hybrid SEP are buses 7, 22, and 62. Additionally, the result also recorded the suitable location, DG sizing, active and reactive power loss and the percentage of loss reduction in order to monitor the performance.

Table 1: Case Study 2 with different type of DG.

Type	Method	Bus Location	DG Size (MW)	DG Size (MVar)	Active Power Loss (MW)	P_{Loss}^{Index} (%)	Reactive Power Loss (MVar)	Q_{Loss}^{Index} (%)
No DG					0.225		0.102	
P	EP	17	0.670		0.084	63%	0.042	59%
		64	1.503					
	SEP	17	0.577		0.083	63%	0.042	59%
		64	1.556					
Q	EP	17		0.234	0.155	31%	0.072	29%
		64		1.117				
	SEP	17		0.376	0.154	32%	0.072	30%
		64		1.110				
PQ	EP	17	0.579	0.304	0.026	89%	0.017	83%
		64	1.677	0.882				
	SEP	17	0.658	0.346	0.026	89%	0.017	83%
		64	1.634	0.859				

The results of multiple units of DG Type 1 are shown in Tables 4. The percentage of P_{Loss}^{Index} indicates that the maximum reduction in loss is 68 percent. The results indicate that three units of DG can achieve the same level of loss reduction as four units of DG. It has the potential to reduce the cost of DG installation. According to the results in Table 5, the hybrid SEP produces the best results in terms of loss reduction percentage. The optimal reactive power size can only reduce losses by 35%. When the DG type 3 is installed in the system, the result indicates a 95% reduction in loss as tabulated in Table 6. This type of DG has the highest loss reduction compared to the others. According to all simulation results, hybrid SEP performed slightly better than EP at minimising loss.

Table 2: Case Study 3 with different type of DG.

Type	Method	Bus Location	DG Size (MW)	DG Size (MVar)	Active Power Loss (MW)	P_{Loss}^{Index} (%)	Reactive Power Loss (MVar)	Q_{Loss}^{Index} (%)
No DG					0.225		0.102	
P	EP	7	1.195		0.073	68%	0.036	64%
		22	0.418					
		62	1.625					
	SEP	7	0.790		0.072	68%	0.036	65%
		22	0.444					
		62	1.677					
Q	EP	7		0.468	0.148	34%	0.069	33%
		22	0.159					
		62	1.125					
	SEP	7		0.561	0.146	35%	0.068	33%
		22	0.276					
		62	1.194					
PQ	EP	7	0.948	0.498	0.013	94%	0.010	90%
		22	0.346	0.182				
		62	1.558	0.819				
	SEP	7	0.632	0.332	0.011	95%	0.009	91%
		22	0.445	0.234				
		62	1.804	0.948				

4.2. Voltage profile improvement

This section discusses the effect on the voltage profile of the distribution system when various types and units of DG are added using EP optimization and hybrid SEP. Figures 4 to 6 depict the voltage profiles of comparison between hybrid SEP, EP, and without DG for DG type 1. The results shows that when DG is added to the system, the voltage profile can be improved. The findings also revealed that as the number of units of DG added to the distribution system increases, the voltage profile increases as well. When DG is added to the system, the voltage profile for buses 60 through 66 improves significantly.

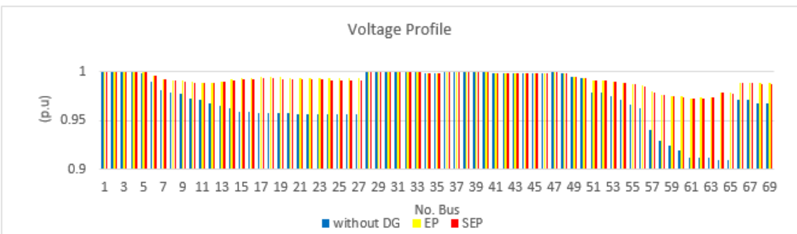

Figure 4: Voltage profile of Case Study 2 with Type 1 of DG.

Table 3: Case Study 4 with different type of DG.

Type	Method	Bus Location	DG Size (MW)	DG Size (MVar)	Active Power Loss (MW)	P_{Loss}^{Index} (%)	Reactive Power Loss (MVar)	Q_{Loss}^{Index} (%)
No DG					0.225		0.102	
P	EP	7	0.600		0.074	67%	0.037	64%
		22	0.656					
		58	0.166					
		62	1.452					
	SEP	7	0.573		0.071	68%	0.036	65%
		22	0.394					
		58	0.209					
		62	1.507					
Q	EP	7		1.445	0.156	31%	0.073	28%
		22	0.286					
		58	0.684					
		62	0.860					
	SEP	7		0.485	0.146	35%	0.068	33%
		22	0.286					
		58	0.172					
		62	0.128					
PQ	EP	7	0.969	0.510	0.012	95%	0.010	90%
		22	0.519	0.273				
		58	0.341	0.179				
		62	1.344	0.707				
	SEP	7	0.632	0.332	0.010	95%	0.009	91%
		22	0.460	0.242				
		58	0.222	0.117				
		62	1.598	0.840				

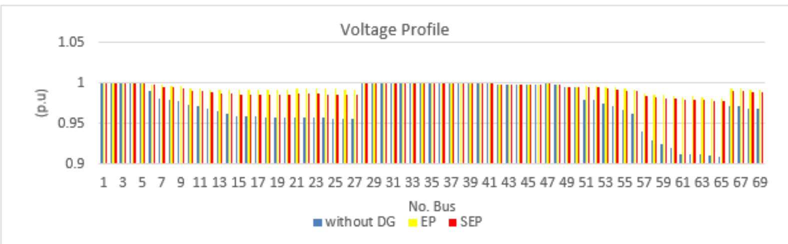

Figure 5: Voltage profile of Case Study 3 with Type 1 of DG.

Table 4: Multiple units of DG Type 1.

Case	Method	Bus Location	DG Size (MW)	Power Loss (MW)	P_{Loss}^{Index} (%)	Power Loss (kVar)	Q_{Loss}^{Index} (%)
No DG				0.225		0.102	
2 DG	EP	17	0.670	0.084	63%	0.042	59%
		64	1.503				
	SEP	17	0.577	0.083	63%	0.042	59%
		64	1.556				
3 DG	EP	7	1.195	0.073	68%	0.036	64%
		22	0.448				
		62	1.625				
	SEP	7	0.790	0.072	68%	0.036	65%
		22	0.444				
		62	1.677				
4 DG	EP	7	0.600	0.074	67%	0.037	64%
		22	0.656				
		58	0.166				
		62	1.452				
	SEP	7	0.573	0.071	68%	0.036	65%
		22	0.394				
		58	0.209				
		62	1.507				

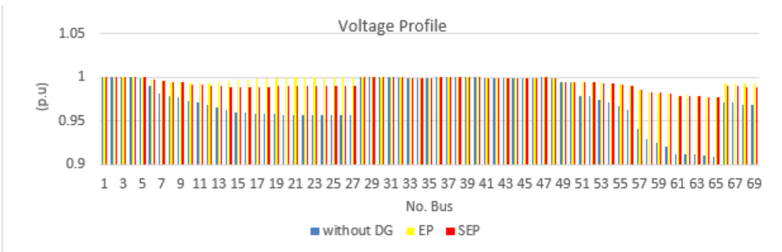

Figure 6: Voltage profile of Case Study 4 with Type 1 of DG.

When comparing Figures 7, 8 and 9, hybrid SEP outperforms EP in terms of voltage profile improvement. Aside from that, it appears that as the number of DG units added to the distribution system increases, the voltage profile improves most for Case Studies 2 and 3, particularly when DG type 2 is added. Type 2 DG is not efficient to maintain voltage profile within the nominal operating range, some node voltage is less than 0.95 p.u after 4 units of DG added.

The voltage profile for DG type 3 is shown in Figures 10, 11, and 12. The results indicate that the hybrid SEP outperforms the EP in terms of voltage profile improvement, especially at lower bus voltages when no DG is installed. Aside from that, it appears that as the number of DG units added to the distribution system increases, the voltage profile improves most for Case Studies 2 and 3, particularly when DG type 3 is added. The findings also revealed that as the number of units of DG added to the distribution system increases, the voltage profile increases as well. When DG is added to the system, the voltage profile for buses 60 through 66 improves significantly.

Table 5: Multiple units of DG Type 2.

Case	Method	Bus Location	DG Size (MW)	Power Loss (MW)	P_{Loss}^{Index} (%)	Power Loss (kVar)	Q_{Loss}^{Index} (%)
No DG				0.225		0.102	
2 DG	EP	17	0.234	0.155	31%	0.072	29%
		64	1.117				
	SEP	17	0.376	0.154	32%	0.072	30%
		64	1.110				
3 DG	EP	7	0.468	0.148	34%	0.069	33%
		22	0.159				
		62	1.125				
	SEP	7	0.561	0.146	35%	0.068	33%
		22	0.276				
		62	1.194				
4 DG	EP	7	1.445	0.156	31%	0.073	28%
		22	0.684				
		58	0.684				
		62	0.860				
	SEP	7	0.485	0.146	35%	0.068	33%
		22	0.263				
		58	0.172				
		62	1.128				

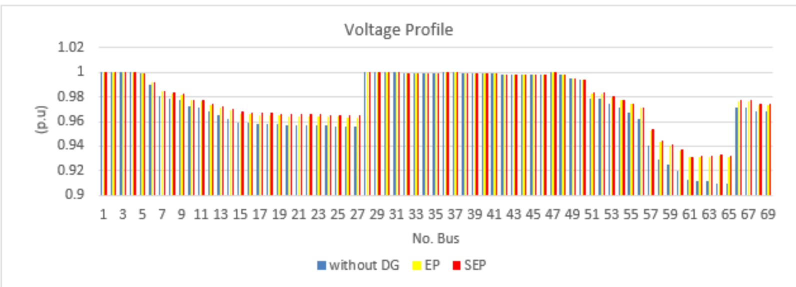

Figure 7: Voltage profile of Case Study 2 with Type 2 of DG.

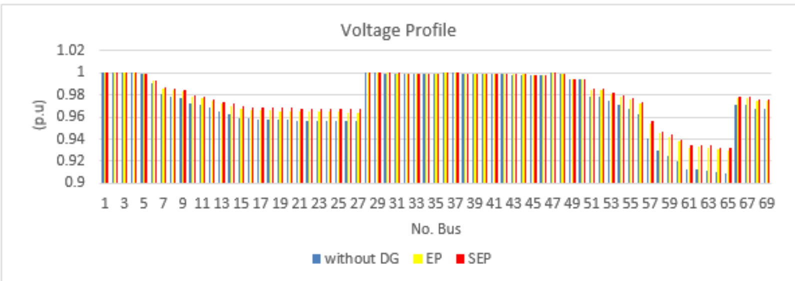

Figure 8: Voltage profile of Case Study 3 with Type 2 of DG.

Table 6: Multiple units of DG Type 3

Case	Method	Bus Location	DG Size (MW)	DG Size (MVar)	Power Loss (MW)	P_{Loss}^{Index} (%)	Power Loss (kVar)	Q_{Loss}^{Index} (%)
No DG					0.225		0.102	
2 DG	EP	17	0.579	0.304	0.026	89%	0.017	83%
		64	1.677	0.882				
	SEP	17	0.658	0.346	0.026	89%	0.017	83%
		64	1.634	0.859				
3 DG	EP	7	0.948	0.498	0.013	94%	0.010	90%
		22	0.346	0.182				
		62	1.558	0.819				
	SEP	7	0.632	0.332	0.011	95%	0.009	91%
		22	0.445	0.234				
		62	1.804	0.948				
4 DG	EP	7	0.969	0.510	0.012	95%	0.010	90%
		22	0.519	0.273				
		58	0.341	0.179				
		62	1.344	0.707				
	SEP	7	0.632	0.332	0.010	95%	0.009	91%
		22	0.460	0.242				
		58	0.222	0.117				
		62	1.598	0.840				

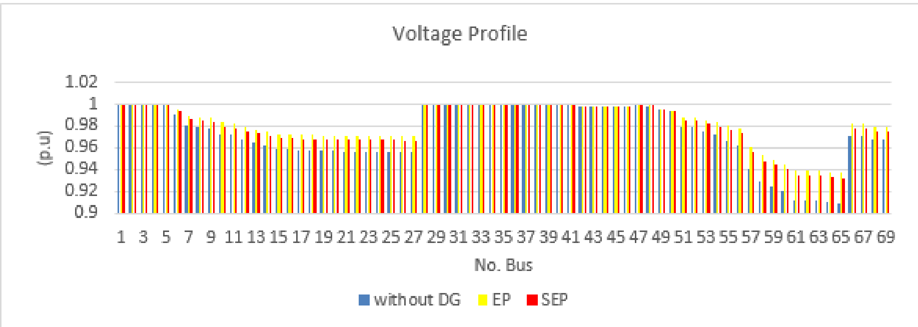

Figure 9: Voltage profile of Case Study 4 with Type 2 of DG.

The performance of EP versus hybrid SEP is compared using five samples or simulations of computational results. According to the collected data, hybrid SEP outperforms EP in some cases and in terms of loss reduction, as discussed in this section.

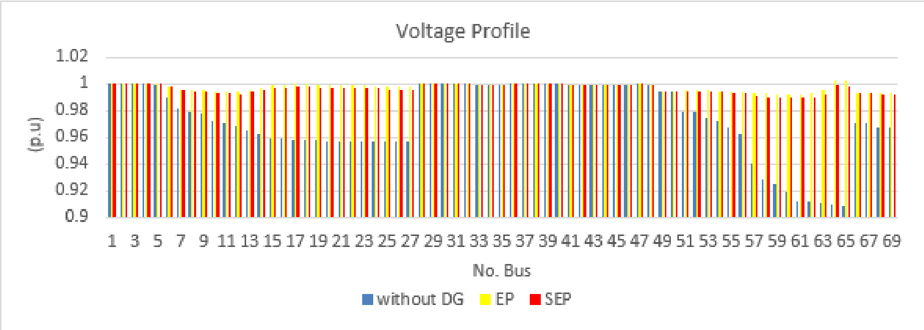

Figure 10: Voltage profile of Case Study 2 with Type 3 of DG.

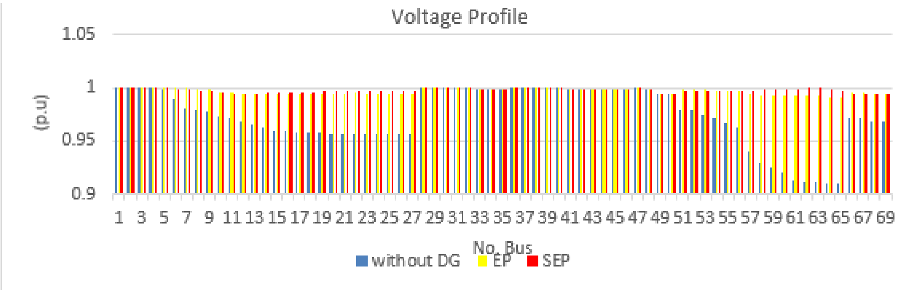

Figure 11: Voltage profile of Case Study 3 with Type 3 of DG.

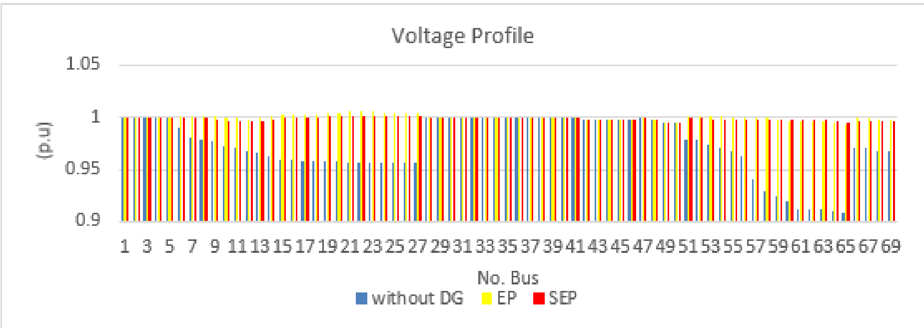

Figure 12: Voltage profile of Case Study 4 with Type 3 of DG.Voltage profile of Case Study 4 with Type 3 of DG.

5. Conclusion

In conclusion, this project successfully developed Evolutionary Programming (EP) and the proposed hybrid SEP optimization methods for determining the optimal placement and sizing of DG for minimising active and reactive losses and improving the voltage profile in the IEEE-69 bus radial distribution system. The performance of both methods is compared in terms of loss minimization and voltage profile improvement. The proposed hybrid SEP outperforms EP in terms of loss minimization, but EP outperforms hybrid SEP slightly in terms of voltage profile improvement. There are significant knowledges gained from completing this study, including the fact that a larger size and additional DG units are not required to minimise distribution losses and improve voltage profile. Thus, the optimal location must be determined to enhance the optimal benefit of DG.

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