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Capacitor placement in Power Distribution Networks using Particle Swarm Optimization: Case Study Savannakhet Province

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Abstract

This research presents the optimal capacitor placement on medium voltage (MV) distribution system with distributed generator (DG) connection applied particle swarm optimization (PSO) algorithm. This paper proposes the simulated collaboration between DIgSILENT PowerFactory and MATLAB software which are developed to solve the problem of capacitor placement in the power distribution system, which purpose to reduce the power losses and minimize the expense of the installation shunt capacitor. To obtain the optimal capacitor placement, the process is carried out by searching the probable candidate location given by the loss sensitivity factor (LSF) for reducing the search space of problem, and the optimal size would be determined with the proposed PSO algorithm. The study is taken into account the daily load variation to specify type of capacitor bank, and the case study is also considered with/without of distributed generator (DG) connected to the distribution grid. The PSO algorithm is validated the effectiveness as against the other algorithms reported on the literature under the IEEE 33-bus test system that conducts in the developed tool. The real power distribution system of Electricite du Lao (EDL) in Savannakhet province is also investigated. The study results demonstrate that the proposed methodology can provide the optimal location and capacity, which can reduce power losses and improve the bus voltage magnitude. The PSO algorithm can be achieved the satisfied annual net saving after capacitor placement as compared with genetic algorithm (GA).

Keywords: Capacitor Placement, Power Distribution System, Distributed Generator (DG), Active Power Loss Reduction, Particle Swarm Optimization (PSO).

1. INTRODUCTION

Presently, many countries worldwide have developed technology to support electric power for enhancement each system become high efficiency. Due to electricity demand growth and aged components have been increased each year, by these issues will be leading to a high loss of revenue and the system will become non-stable. Power loss is a weak point of the power system which affect to electricity response and economic development. For instance, World Bank Group (2018) was carried out the results of an international survey on T&D energy losses in 2018, most of the electricity loss appears in the power distribution network and the portion occurs 13% of the electricity generation. These highly consumed reactive power is the significant effect to the power distribution system losses that leads to decreasing the capability for supply the electric power as much as possible. Some of these losses can be reduced by reactive power compensation as installing shunt capacitors (capacitor banks). Also, this approach provides several advantages as well as improved power factor, improving the voltage level and obvious saving for supplying the electric power, this will lead to increase the existing capacity of the power system. Generally, the optimal capacitor placement in the power distribution system has to determine the quantity, capacity, type, and location of capacitor banks, which are particular importance to gain the maximum economic benefits without constraints violation.

Ever since, the optimum capacitor allocation is a complexity optimization problem, in the past there are many different optimization techniques are commonly solved the problem. According to Ng et al. (2000) classified the techniques of installation shunt capacitor in four kinds as analytical, numerical programming, heuristics, and artificial intelligence. As known on previous works extensively used analytical methods to explain the capacitor placement optimization problem as presented by Cook (1961). However, these methods were built based on their usually assumption operating conditions and giving the uncertainty result. Cho and Chen (1997) described the current analytical methods as more accurate and useful in the practical distribution system. The numerical programming techniques had implemented to solve the problem consist of a nonlinear optimization problem presented by Baran and Wu (1989).

The mixed integer non-linear programming (MINLP) method introduced for the optimum capacitor location for reduction the electric loss cost and minimization the capital cost of capacitors as shown in the research of Nojavan et al. (2014) and Baran and Wu (1989). These techniques also had some inconvenient for solving problem as higher computation time. From viewpoint of optimization problem, Aman et al. (2014) explained the optimal capacitor placement that is rather complicated cause of their high multi structure and size, nonlinear and discontinuous. These problem attributes make a challenging for solving via applying standardize optimization methods of Ng et al. (2000).

Recently, the various computation methods have been developed as well as metaheuristics approaches that can solve many problems on the power system. Singh and Rao (2012) presented particle swarm optimization (PSO) algorithm based-on artificial intelligent. This application also used for the capacitor placement problem, the objectives aimed to maximize cost saving by reduction the power loss and the reactive compensator costs. The research demonstrated that PSO had greater solution and giving the better voltage profile. In the same way, Shuaib et al. (2015) presented gravitational search algorithm (GSA), which purposed to maximize net saving by providing reduction active power losses and operation capacitors costs by considering capacity and location that most suitable to allocation in the distribution system. Díaz et al. (2018) presented a swarm approach known as locust search algorithm, they showed the effectiveness of the algorithm to determine the amount, location, and capacity of shunt capacitor for minimalizing the total capital cost, that purposes to reduce energy losses and improve the voltage profile in the radial distribution systems. Then, Jafari et al. (2020) presented a two-layer hybrid using a few combinations heuristic algorithm for the optimum place and operating times of switched capacitors, and the results indicated that had more effect on the distribution feeder with voltage-dependent loads and more advantages over other optimization algorithms. However, most of the mentioned research focused on developing the optimization algorithms and investigated in the test system. In contrast to the real system, which is the large scale of the power distribution system, that might not lead to the most optimal solution due to some restriction of the different algorithms.

In this paper, the developed tool for solving the optimal capacitor placement problem for the real power distribution system is presented. To clarify, the number, size, type, and location of capacitor banks is taken into account for meet along the profile characteristic of load demand. This research adopts LSF to decrease search space of the capacitor bank solutions. The PSO algorithm is implemented due to its advantages and uncomplexity of the optimization process. According to the proposed consideration of capacitor banks allocation, the experimental is simulated in DIgSILENT PowerFactory and applies the proposed algorithm via MATLAB, which collaborates by the communication the data interchange between two software. Therefore, the study results demonstrate that the proposed tool can be determined the optimal capacitor placement which aims to minimize the total cost of power losses and capital cost of capacitors which are related to the acquired revenue on annual net savings. Additionally, the proposed approach can contribute to implementation with the real distribution system, which can specifically solve the optimization problem for power system. As Shaheen and El-Sehiemy (2020) presented the installed capacitor banks can consider for the coordinated volt/var control due to the integration of DG to manage the reactive power application for the modern distribution grid.

The remaining of the research is ordered as follow: in section 2 discusses concept of power loss calculation and Loss Sensitivity Factor (LSF); In section 3 details the proposed objective optimization process for capacitor placement using (PSO) algorithm; Section 4 presents the study results and discussion of the capacitor placement; The conclusion is summarized in section 5.

2. Analysis of Power Loss in The Power Distribution System

This section describes a method of power loss calculation, which analyzes by compensating the reactive power into the nodes rather than drawing from the grid. To find the selection bus for placing shunt capacitors apply Loss Sensitivity Factor.

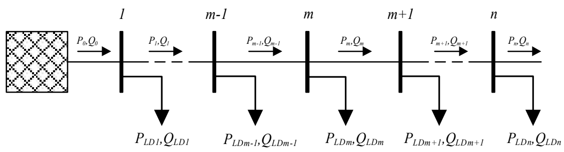

Figure 1 Schematic of radial distribution system diagram

2.1 Power loss calculation

The calculation power loss had been developed to simplified method by Su and Tsai (1996). A set of basic line flow equations is provided as a choice for computing the power line flow analysis based on this method, which completely avoids the iteration process. From Figure 1 demonstrates all connection points connected to the node *m* the power at node *m* can be determined the equations as follows:

$$P_m = P_{m+1} + P_{LDm} + \left(\frac{P_m^2 + Q_m^2}{|V_m|^2}\right) R_{m,m+1}$$
$$\cong P_{m+1} + P_{LDm} + \left((P_{m+1}+P_{Lm})^2 + (Q_{m+1}+Q_{Lm})^2\right) R_{m,m+1} \quad (1)$$

$$Q_m = Q_{m+1} + Q_{LDm} + \left(\frac{P_m^2 + Q_m^2}{|V_m|^2}\right) X_{m,m+1}$$
$$\cong Q_{m+1} + Q_{LDm} + \left((P_{m+1}+P_{Lm})^2 + (Q_{m+1}+Q_{Lm})^2\right) X_{m,m+1} \quad (2)$$

$$|V_{m+1}|^2 = |V_m|^2 - 2\left(\left(R_{m,m+1} \times P_{LDm}\right) + \left(X_{m,m+1} \times Q_{LDm}\right)\right) + \left(\frac{P_m^2 + Q_m^2}{|V_m|^2}\right) \quad (3)$$

Where: P_m is the active power sent out from bus m, Q_m means the reactive power released from bus m, P_{LDm} denotes the active power load at bus m, Q_{LDm} is a required load of reactive power at bus m, and where $R_{m,m+1}$ is the resistance between bus m and $m+1$ and $X_{m,m+1}$ means the reactance between bus m and $m+1$. Moreover, $|V_m|$ is the voltage level at bus m.

2.2 Loss sensitivity factor

To conduct for power loss reduction there are much research had used Loss sensitivity factor. Due to this technique is useful for estimation which bus has highly probability to install shunt capacitors. The Loss sensitivity factor is commonly applied for evaluation the applicant buses. Prakash and Sydulu (2006) presented a technique that mostly assists to reduce of the exploration area for the optimization work, it can be formulated as follows:

$$\frac{\partial P_{Loss}}{\partial Q_{m-1,m}} = \frac{2 \times Q_{m-1,m}}{|V_m|^2} \times R_{m-1,m} \quad (4)$$

$$\frac{\partial Q_{Loss}}{\partial Q_{m-1,m}} = \frac{2 \times Q_{m-1,m}}{|V_m|^2} \times X_{m-1,m} \quad (5)$$

This LSF implementation lists to arrange capacitor positions in descending order from their indicators. The greater indicator value is the most possibility for capacitor placement.

3. CAPACITOR PLACEMENT USING PSO ALGORITHM

In this research, the purpose of the capacitor allocation issue is to enhance the power distribution system via reducing power losses and sustained the bus voltages under the permissible limit. The objective function is described as below.

3.1 Objective function

To accomplish the reactive power compensation optimization problem, the quantity, place, type, and capacity of shunt capacitors are considered. It can be described as the equation below:

$$min\,F = C_e \times \sum P_{Loss} \times t + \sum_{i=1}^{N_c} (C_{cr} \times Q_c) + C_{cI} \times N_c \quad (6)$$

where: C_e is the price of electricity, t is the time period, C_{cr} is cost per unit of capacitor bank, Q_c is rating of capacitor bank, C_{cI} is cost of capacitor installation, and N_c is the quantity of capacitors to install.

From the objective function above, the proposed approach must be subjected the constraints including the grid voltage and total released of reactive power by capacitor banks as follows:

$$V_{min} < V_j < V_{max} \quad (7)$$

$$\sum Q_C \leq \sum Q_{C,max} \quad (8)$$

Where: Q_C is reactive power compensated to the power line, $Q_{C,max}$ is the maximum allowable compensation reactive power into the network, and $Vmin$, $Vmax$ are the lowest and highest voltage limit at network bus j.

3.2 Particle swarm optimization algorithm

Refer to the purpose and restriction conditions in the proposed optimization algorithm, this research adopts swarm intelligence approach, which is the particle swarm optimization algorithm and widely applied in this field works. The mathematic details of the PSO algorithm describes as below:

$$\begin{cases} V_i^{t+1} = \omega V_i^t + c_1 \cdot r_1 \cdot \left(P_{bi}^t - Q_{ci}^t\right) + c_2 \cdot r_2 \cdot \left(G_{bi}^t - Q_{ci}^t\right) \\ Q_{ci}^{t+1} = X_i^t + \left(V_i^{t+1} \times C\right) \end{cases} \quad (9)$$

Where: c_1 and c_2 are the acceleration factors, V_i means velocity of individual i in repetition t, Q_c is reactive power compensated of individual i in iteration t, P_{bi} is individual best of the i^{th} loop, G_{bi} is global best of all populations, r_1 and r_2 are random variables in the extent of [0,1], and ω is the weight of inertia.

Singh and Yadagiri (2009) described the perception of time-varying inertial weight (TVIM), when initial exploration started with large inertia weight factor and its value would be slowly decreased from the exploring procedure as well. It is expressed as:

$$\omega = (\omega_{max} - \omega_{min}) \times \frac{iter_{max} - iter}{iter_{max}} + \omega_{min} \quad (10)$$

Where: ω_{max} and ω_{min} are the max and min weight of inertia value, $iter_{max}$ is the maximum number setting of iteration, and it defines as $\omega_{max} = 0.9$ and $\omega_{min} = 0.4$.

Moondee and Srirattanawichaikul (2019) introduced the constriction factor to upgrade the convergence of the proposed algorithm.

$$C = \frac{2}{\left|2 - \phi - \sqrt{\phi^2 - 4}\right|} \text{ where } 4.1 \leq \phi \leq 4.2 \quad (11)$$

When the factor C reduces, a convergence turns into gradual due to the variety population is decreased. To have a fast convergence, this paper determines $C = 0.352$.

3.3 Solving process

This work focuses on designing the developed tool by DIgSILENT PowerFactory and MATLAB as shown in

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Figure 2 that applies the proposed algorithm, which implements to find the optimal capacitor placement in terms of minimization cost function containing power losses and capacitor installation. As shown, DIgSILENT PowerFactory is applied for built a distribution network modeling and analyzed power flow. The optimization process carries out with MATLAB software because it can develop to provide very flexible research for implementing the algorithms. The two software exchange information data and communicated with CSV file and there is an excel file called Flag that is applied to avoid the conflicted working of both software. Based on this approach, the developed tool is examined in the real distribution feeder of Savannakhet, and the proposed algorithm is verified the effectiveness which compares

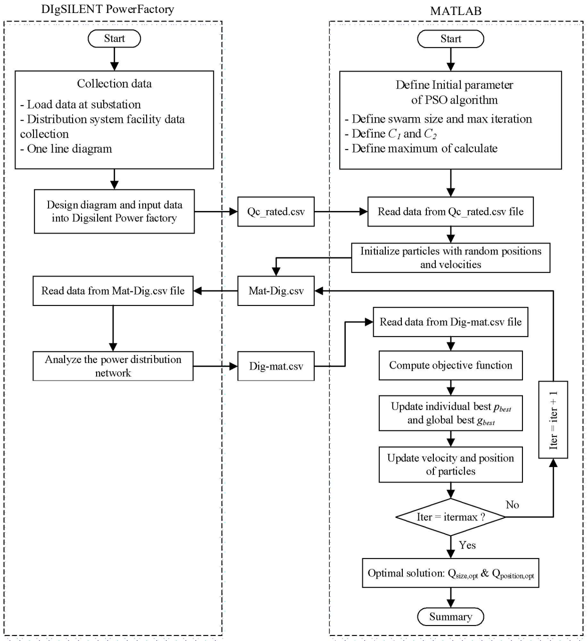

Figure 2 The process of the proposed approach by adopting particle swarm optimization algorithm

with genetic algorithm (GA). The proposed process describes as below:

Step 1: Model the distribution network, input data into DIgSILENT, and send the standard reactive power compensator size to MATLAB.

Step 2: Input PSO parameters include population sizes, weight of inertia, acceleration coefficients, maximum number of iterations.

Step 3: Initialize particle parameters with random the position and velocity.

Step 4: Send the random variables through Mat2Dig.csv file to DIgSILENT.

Step 5: Read the random variables and perform power flow analysis.

Step 6: Send the power flow results of each variable through Dig2Mat.csv file to MATLAB.

Step 7: Read the power flow results and evaluate the optimal values according to an objective function equation (8) and within the restricted conditions.

Step 8: Compare particles objective functions and update $P_{best,i}$ for each particle during the cycle and $G_{best,i}$ through all the particles.

Step 9: Following equation (11) is taking for updating velocity and position

Step 10: Repeat the loop until the maximum iteration.

Step 11: Report the optimal place of capacitor banks.

4. CASE STUDY AND DISCUSSION

In this section, the proposed technique to locate capacitor banks in power distribution system was explained above. The network model was simulated in DIgSILENT PowerFactory. MATLAB was implemented to perform optimization algorithm for achieving the optimum placed and sized of capacitors solution. The results of the study were presented and discussed.

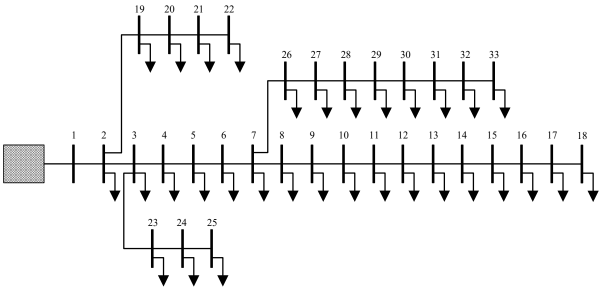

Figure 3 The schematic of IEEE 33-bus test system

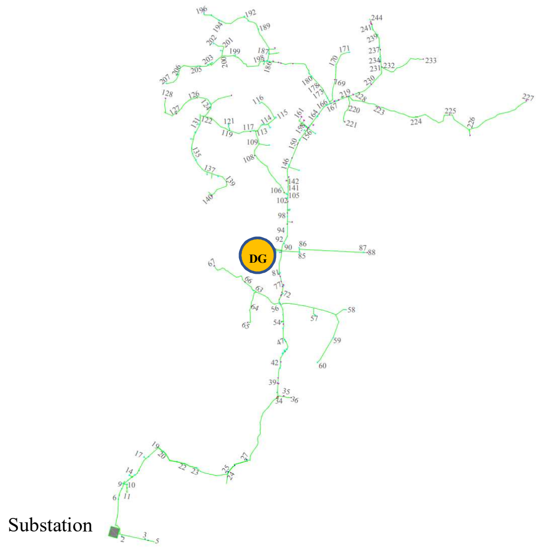

Figure 4 The topology of distribution feeder of Savannakhet province

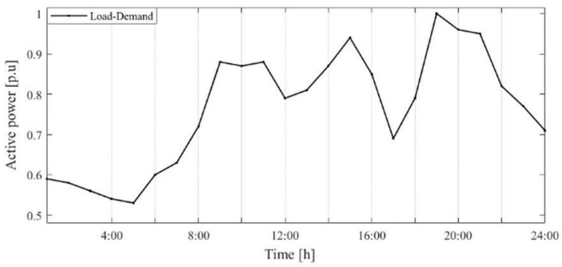

Figure 5 Daily load demand of Savannakhet distribution feeder

Table 1 Parameter of Savannakhet's power distribution feeder and sizes of capacitor bank for placement

Name	Unit	Variable
Peak load	MW	4.50
Power factor		0.85
Rate of distributed generator (DG)	MW	2.50
Capacitor size	kVAR / Unit	150 300 450 600 750 900 1050 1200

To achievement the objective and maximize profit there are some parameters that would be considered to calculate investment criteria including the capital cost of capacitor and distributed generator (DG) operation cost, which assumed as table below:

Table 2 Parameter cost for investment calculation

Descriptions	Price
Fixed capacitor ($/kVAR)	7
Switched capacitor ($/kVAR)	25
Installation capacitor bank ($/Unit)	750
The electricity price ($/kWh)	0.0937
Distributed generator (DG) operation cost ($/kWh)	0.06

4.1 Comparison results for the IEEE 33-Bus radial distribution network

Figure 3 illustrates the schematic of the test system, it comprises 33 buses and 32 lines, the first bus considers the substation bus which is retrieved from Díaz et al. (2018). The total active and reactive power demand connected to the system is 3.72 MW and 2.3 MVAR, respectively. The specification of capacitor bank includes the limit size and different capital cost which is applied from Jafari et al. (2020). Also, the consideration criteria include the constant load model and the objective function regarded only cost of loss and cost of capacitors. The proposed method conducts the simulation in the developed tool.

Table 3 shows the comparison results between the proposed PSO algorithm and some of the other algorithm for the optimal capacitor placement on IEEE 33-bus distribution network. The approach in literature consists of gravitational search algorithm (GSA), locust search algorithm (LS), and Hybrid algorithm (GA-GA), which has been brought up to consider in order to validate the effectiveness of the proposed PSO algorithm. As a result, before reactive power compensation, the power loss of the system is about 210.97 kW, and the annual cost is 35,443 $. Corresponding to the minimization problem the proposed approach can be determined the capacitor placement, which has been chosen allocation at bus 8, 14, 23, and 30, that determines the size as 300, 300, 300 and 1,050 kVAR, respectively. The reactive power compensation served by capacitors can be decreased the total power loss to 131.45 kW, which produces the net savings of about 12,804 $ or 36.16% compared with the uncompensated case. From Table 3, it can be seen that the PSO algorithm is greater effective than the other approach, including the proposed GA. Therefore, this approach would be applied to study the capacitor placement problem with the real power distribution system of Savannakhet in the next subsection.

4.2 Practical distribution system of Savannakhet modelling

To present the capacitor placement in the power distribution network, the network model in Figure 4 is used to examine the proposed method. The network model and load profile were received from the real 22 kV distribution feeder of Savannakhet province. The feeder comprises 244-bus and supplied to the rural area including a several type of consumers such as residential, industrial, and economic, etc. The distribution network parameter was listed in Table 1, defining that the peak load demand is 4.5 MW and power factor (PF) equals 0.85. It should be noted that the distributed generator (DG) rating 2.5 MW is taking into account in cases of with/without DG connected to the feeder and operate at unity power factor (PF). In addition, the standard size of capacitor banks for allocation were also defined. The load demand profile was obtained from real distribution feeder, it is shown in Figure 5.

4.3. Case study and Results

According to the network data and the permissible voltage of distribution system must be under ±5% of nominal voltage at 22kV as applying the capacitor bank for compensation the reactive power as described above. To obtain the condition of fixed and switched type of capacitor, this study applies 24 hours load data time day for model load variation in the distribution network in Figure 5. The case study divides in two cases, i.e., capacitor banks allocation without DG dispatched and capacitor placement with DG connected.

Table 3 The comparison of the different algorithm results for the IEEE 33-bus radial distribution network

	Base case	GSA	LS	Hybrid (GA-GA)	Proposed GA	Proposed PSO
Peak Loss [kW]	210.97	134.50	136.10	135.87	138.59	131.45
Reduction [%]	-	36.25	35.49	35.60	34.31	37.69
Optimum location	-	26, 13, 15	5, 8,11, 6, 24, 26, 30, 32	13, 29, 25	10, 30, 32	8, 14, 25, 30
Optimum size [kVAR]	-	350, 450, 800	150, 150,150,150, 450, 150,750, 150	350, 1200, 350	750, 300, 600	300, 300, 300, 1050
Total capacity of capacitor [kVAR]	-	1,600	2,100	1,900	1,650	1,950
Total cost of capacitor [$]	-	457	771	449	444	554
Cost Energy Loss [$/year]	35,443	22,596	22,865	22,826	23,283	22,085
Total annual cost [$/year]	35,443	23,053	23,636	23,275	23,727	22,639
Net Saving [$/year]	-	12,390	11,807	12,168	11,716	12,804
Net Saving [%]	-	34.96	33.31	34.33	33.06	36.16

4.3.1 The candidate bus by LSF

Firstly, the candidate bus for allocation reactive compensator devices were applied loss sensitivity factor (LSF), this analysis helps to decrease the exploration of the optimization problem. Corresponding to LSF performed the 15 buses in descending order which are possibility to install capacitors including {142, 159, 189, 132, 90, 122, 198, 24, 94, 220, 35, 114, 56, 241and 1}. Following the standard size of capacitor in Table 1, the optimal size would be determined by the optimization algorithms that indicates in the next sub-section.

4.3.2 Case installing OCP without DG connected

Table 4 presents the results of the distribution system before and after allocated the reactive power compensator in case of DG disconnected. The simulation results were validated comparing with genetic algorithm (GA). This table clarifies that the capacity of reactive power compensator of a total 3,900 kVAR is required in the GA method compared to 3,750 kVAR in the PSO algorithm. However, the power losses are least in the case of PSO algorithm, and it provides a reduction power loss at all load levels against base case 540.97 kW, 303.83 kW and 94.43 kW become 359.22kW, 226.72 kW and 128.60 kW, respectively. The proposed PSO algorithm shows better effectiveness than the genetic algorithm (GA) in terms of loss reduction and voltage improvement.

Figure 6 shows the simulation results of power losses reduction during daily period, which compared between base case, GA and proposed PSO algorithm. According to base case before compensation, it can be observed that the shunt capacitors can be reduced significantly power losses. Also, the power losses reduction is decreased slightly low in light load period, but it can reduce more during peak load demand especially in case of the proposed PSO method.

Figure 7 demonstrates the voltage profile of the distribution feeder at light load and peak load time, which is indicates the comparison between the uncompensated and the compensated reactive power by capacitor banks with the optimization algorithm. It can be observed that the bus voltage of base case is lower than the voltage permission limitation of all load level period and the worst bus voltage during peak load which is 0.80 p.u at bus 207. The capacitor placement with the proposed process can regulate the voltage profile during light load to peak load period that can be maintained under grid code and the worst bus voltage was 0.95 p.u at bus 244. Furthermore, the improved voltage profile of GA method is better than the PSO algorithm due to the high injected reactive power from capacitor banks.

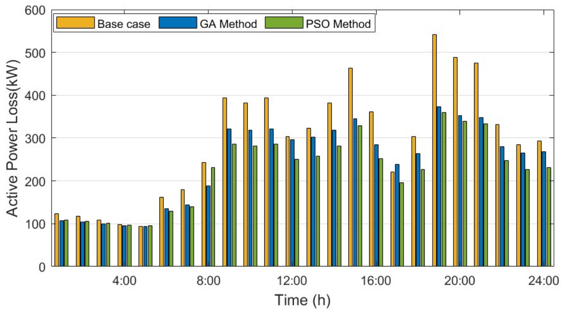

Figure 6 The comparison power losses in case without DG connected

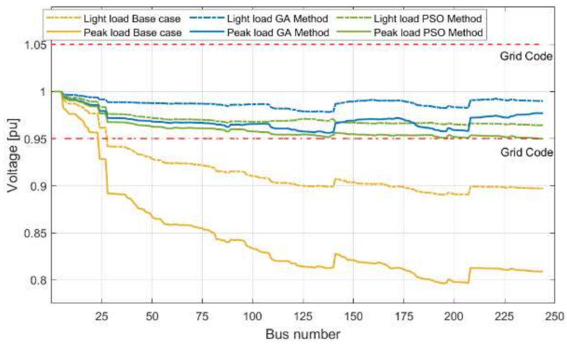

Figure 7 The comparison improved voltage profile of the power distribution system in case without DG connected

Table 4 The performance of power distribution feeder after compensated reactive power on each load level without DG connected

	Load level	S_{HV} (kVA)	Q_{HV} (kVAR)	Optimal capacitor placement Location	Size (kVAR)	Total capacity (kVAR)	Ploss (kW)	Bus/ V_{max} (p.u)	Bus/ V_{min} (p.u)
Base case	Peak (1 p.u)	6,245	3,570	-	-	-	540.97	1.00/1	0.80/207
	Normal (0.75 p.u)	4,559	2,508	-	-	-	284.08	1.00/1	0.85/196
	Light (0.55 p.u)	3,450	1,854	-	-	-	161.33	1.00/1	0.89/196
Proposed GA	Peak (1 p.u)	4,972	-410.75	[56 122 159 220 241]	[450 450 900 1050 1050]	3,900	372.68	1.00/1	0.96/140
	Normal (0.75 p.u)	3,933	-1,034.50	[122 159 220 241]	[450 900 1050 1050]	3,450	265.70	1.02/241	0.99/36
	Light (0.55 p.u)	2,937	-551.73	[56 159 220]	[450 900 1050]	2,400	135.28	1.00/1	0.98/140
Proposed PSO	Peak (1 p.u)	4,946	-192.39	[90 94 132 189 198]	[900 450 900 900 600]	3,750	359.67	1.00/1	0.95/244
	Normal (0.75 p.u)	3,769	-316.25	[94 132 189 198]	[450 900 900 600]	2,850	226.72	1.00/1	0.97/244
	Light (0.55 p.u)	2,880	94.58	[132 189]	[900 900]	1,800	128.60	1.00/1	0.96/244

Table 5 The performance of power distribution feeder after compensated reactive power on each load level when distributed generator (DG) connected

	Load level	S_{HV} (kVA)	Q_{HV} (kVAR)	Optimal capacitor placement Location	Size (kVAR)	Total capacity (kVAR)	Ploss (kW)	Bus/ V_{max} (p.u)	Bus/ V_{min} (p.u)
Base case	Peak (1 p.u)	3,757	2,978	-	-	-	208.75	1.00/1	0.86/196
	Normal (0.75 p.u)	2,454	2,181	-	-	-	96.20	1.00/1	0.91/196
	Light (0.55 p.u)	1,691	1,664	-	-	-	53.43	1.00/1	0.94/196
Proposed GA	Peak (1 p.u)	2,180	170	[35 142 198 220]	[450 900 450 900]	2,700	91.76	1.00/1	0.97/140
	Normal (0.75 p.u)	1,102	-203	[142 198 220]	[900 450 900]	2,250	54.32	1.01/208	0.99/140
	Light (0.55 p.u)	378	-244	[142 220]	[900 900]	1,800	38.16	1.02/208	1.00/1
Proposed PSO	Peak (1 p.u)	2,171	161	[90 94 189 198]	[900 900 450 450]	2,700	83.42	1.00/1	0.96/140
	Normal (0.75 p.u)	1,083	-192	[90 94 189]	[900 900 450]	2,250	36.93	1.01/90	0.99/207
	Light (0.55 p.u)	371	-247	[94 189 198]	[900 450 450]	1,800	26.90	1.02/94	1.00/1

4.3.3 Case installing OCP with DG connected

This case study considers the distributed generator (DG) synchronized to the power distribution and applied the optimization algorithms to allocate capacitor banks. In the same way as the previous case study, the proposed PSO algorithm has investigated the effectiveness compared with the genetic algorithm as shown in Table 5. The obtained results give that each method suggests installing the capacitor bank with the same capacity of 2,700 kVAR but the proposed algorithm performs better than GA, where the power losses at each load level period from peak load to light load can highly reduce that is 83.42 kW, 36.93 kW and 26.90 kW, respectively.

Figure 8 demonstrates a significant reduction in power loss, it can be observed that the PSO algorithm is highly capable of reducing power loss up to twice as compared to the base case. The reason is that the distributed generator and shunt capacitor placed along the feeder can respond the power near the load, which is helpful to assist substation to reduce drawing the power from the power grid and improving efficiency of power distribution system.

Figure 9 shows the voltage profile of the real distribution feeder with a distributed generator connected. As the base case that is only DG connected, it can be seen that cannot improve bus voltage within grid code, because of the topology of the distribution feeder that the load is far from the substation. Contrast, the reactive power compensation using proposed optimization algorithm provided the optimal location and size of shunt capacitor which can regulate the voltage profile maintained under permission limits.

4.2.4 Results and discussion

This study is implemented a real power distribution system to find out the optimal reactive power compensation, which purpose to evaluate the proposed PSO algorithm that compares effectiveness with the widely referred optimization technique as genetic algorithm (GA). Refer to Table 2 listed the capital cost for installing capacitor and the reduction power loss and total annual cost were obtained and listed in Table 6. In the case without DG connected, under uncompensated

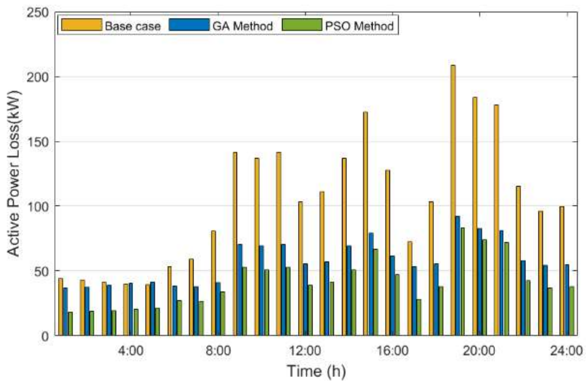

Figure 8 The comparison power losses in case DG connected

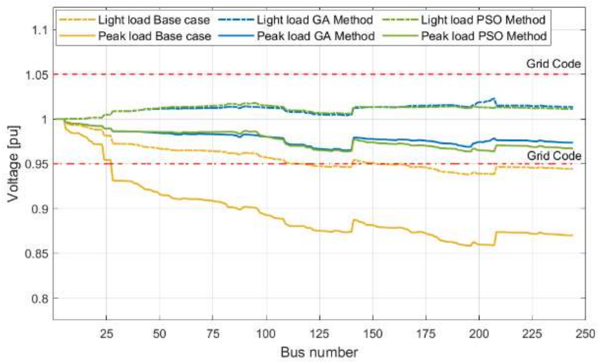

Figure 9 The comparison improved voltage profile of the power distribution system in case DG connected

reactive power the distribution system active loss was 540.97 kW, and a total annual cost was 241,799 $. The PSO algorithm provided the optimal capacity of the capacitor bank that reduced real power losses by 359.2 kW or 33.60% as compared to the base case, which leads to saving the cost of 7,350 $ per year of 3.04%. Moreover, in case DG connected the simulation result shows the base case carried power losses of 208.75 kW and the total annual cost in this case includes the annual cost of energy loss and the operation cost of DG which was approximately 175,039 $ per year. The proposed PSO algorithm shows the outcome that gave the greater net saving compared the genetic algorithm (GA) by reducing

Table 6 The comparison of experiment results for capacitor placement in the real distribution network 244-bus

		Case DG disconnected			Case DG connected		
		Base case	GA Method	PSO Method	Base case	GA Method	PSO Method
Peak Loss [kW]		540.97	377.36	359.22	208.75	91.761	83.421
Reduction [%]		-	30.24	33.60	-	56.04	60.04
Cost Energy Loss [$/year]		241,799	172,922	170,099	86,533	47,081	34,179
Optimum location of capacitor bank	**Fixed**	-	[159 220]	[132 189]	-	[142 220]	[94 189]
	Switched	-	[56 122 241]	[90 94 198]	-	[35 198]	[90 198]
Optimum size of capacitor bank [kVAR]	**Fixed**	-	[900 1050]	[900 900]	-	[900 900]	[900 450]
	Switched	-	[450 450 1050]	[900 450 600]	-	[450 450]	[900 450]
Total quantity of capacitor		-	5	5	-	4	4
Total capacity of capacitor [kVAR]		-	3,900	3,750	-	2,700	2,700
Total cost of capacitor [$]		-	65,400	64,350	-	36,600	46,200
Total cost of DG operation [$/year]		-	-	-	88,506	88,506	88,506
Total annual cost [$/year]		241,799	238,322	234,449	175,039	172,187	168,885
Net Saving [$/year]		-	3,477	7,350	-	2,852	6,155
Net Saving [%]		-	1.44	3.04	-	1.63	3.52

power losses and supporting the annual cost saving 6,155 $ or 3.52% as against the case of uncompensated reactive power as shown in Table 5. As a result, when DG connected to the distribution grid with capacitor operate simultaneously, it can be seen the potential of the distribution feeder improvement that can reduce power during on-peak, reduce line losses, and regulate voltage profile under allowable limitations. Even though the net saving of each case study was slightly low due to the capital cost of the capacitor bank being expensive, which relates to the number, capacity, and type of capacitor that would be required to support reactive power demand along the feeder. However, the reactive power compensation method provides the satisfied in terms of the power loss reduction and voltage profile. As well, the developed tool can be also accomplished implement the practical distribution system for conducting an installation capacitor following the planner.

5. CONCLUSION

This research presented the optimal capacitor placement in the power distribution system with DG connected to the Savannakhet area using the particle swarm optimization (PSO) algorithm. The developed tool implemented MATLAB software and DIgSILENT PowerFactory which purpose to verify the presented optimization algorithm. This tool has been examined with the real distribution system of Savannakhet province. The proposed algorithm was applied to determine the optimal capacitor allocation which the purpose to reduce power losses and minimize the installation cost of the capacitor. The loss sensitivity factor is adopted to decrease the dimension of the optimal results of the capacitor. Overall, the presented process has obtained the optimal location and size of the capacitor bank following the case study. The PSO algorithm has been provided most efficient in terms of the reduced power loss by up to 30% and it promoted increasing the annual net saving. The proposed PSO algorithm shows greater capabilities over the genetic algorithm (GA). This impact of the study will be implemented to improve the presented power system problem. Furthermore, the proposed optimization approach can develop the capability of the capacitor to study the coordinated volt/var control of the grid modernization application in the future.

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