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Optimization of the Thyristor Controlled Phase Shifting Transformer Using PSO Algorithm

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Article Info	ABSTRACT
	The increase of power system demand leads to the change in voltage profile, reliability requirement and system robustness against disturbance. The voltage profile can be improved by providing a source of reactive power through the addition of new power plants, capacitor banks, or implementation of Flexible AC Transmission System (FACTS) devices such as Static VAR Compensator (SVC), Unified Power Flow Control (UPFC), Thyristor Controlled Series Capacitor (TCSC), Thyristor Controlled Phase Shifting Transformer (TCPST), and many others. Determination of optimal location and sizing of device injection is paramount to produce the best improvement of voltage profile and power losses reduction. In this paper, optimization of the combined advantages of TCPST and TCSC has been investigated using Particle Swarm Optimization (PSO) algorithm, being applied to the 30-bus system IEEE standard. The effectiveness of the placement and sizing of TCPST-TCSC combination has been compared to the implementation of capacitor banks. The result showed that the combination of TCPST-TCSC resulted in more effective improvement of system power losses condition than the implementation of capacitor banks. The power losses reduction of 46.47% and 42.03% have been obtained using of TCPST-TCSC combination and capacitor banks respectively. The TCPST-TCSC and Capacitor Bank implementations by using PSO algorithm have also been compared with the implementation of Static VAR Compensator (SVC) using Artificial Bee Colony (ABC) Algorithm. The implementation of the TCSC-TCPST compensation with PSO algorithm have gave a better result than using the capacitor bank with PSO algorithm and SVC with the ABC algorithm.

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1. INTRODUCTION

The increase in electric power demand is in general proportional to the population growth of a country. The load increase usually requires the addition of new power plants, both in terms of the number of units and the generated power capacity. Consequently, further addition and expansion of transmission and distribution systems infrastructure are required. The system becomes more complex and susceptible to interference. Continuity of service must also satisfy technical and economical requirements. Load changes, composition of generating units in operation as well as the changes in network configuration have a great impact on the overall variation of voltage levels and power losses in the system. Voltage profile improvement to fulfill the assigned operation standard of the entire system has some impacts to decrease power losses in

the system [1]-[2]. Voltage fluctuation can also be controlled through power system compensation. The compensation both in transmission and distribution systems can be performed using either conventional capacitor banks or Flexible Alternating Current Transmission Systems (FACTS) devices [3]-[6]. The FACTS devices implementations include Static VAR Compensator (SVC) [7]-[9], Thyristor Controlled Series Capacitor (TCSC) [10], Thyristor Controlled Phase Shifting Transformer (TCPST) [11], Unified Power Flow Control (UPFC) [12], Dynamic Voltage Restorer (DVR) [13] and many others [14]. Some research results also showed that the use of distributed generation could overcome the voltage profile problem and power losses in distribution system, and also claimed to improve the distribution system performances in terms of power quality [13], reliability [15-16], and stability [17]-[18].

This paper presents the investigation results on the use of combination of two FACTS devices, which are a TCPST and a TCSC, to overcome the voltage profile problem. The TCSC is specifically used to compensate the reactance of the transmission line and commonly used on long transmission line. The main issues explored in the study were the optimal location and sizing for the placement of TCPST-TCSC combination. Comparison to the use of conventional capacitor banks has been performed to justify. There have been many methods proposed to solve the optimization problem, including the heuristic probabilistic and artificial intelligent methods. Genetic Algorithm (AG) method was explored to determine the optimal location of multi-type FACTS [19] and to control the voltage and reactive power [20]-[21]. There were many other artificial intelligent methods such as Artificial Bee Colony algorithm [8], [22], Simulated Annealing [23], Fuzzy EP algorithm [24], and others population algorithm [25], being studied. In this paper, Particle Swarm Optimization (PSO) algorithm is used to solve the optimization problem. However, the PSO algorithm has been used in many applications including the SVC location optimization [26]. PSO algorithm is a method adopting the social behavior of birds when flying together in search of food. Performance of the PSO algorithm to control the voltage profile and power losses have been tested on the 30-bus system IEEE standard data.

2.   POWER SYSTEM COMPENSATION
2.1.   Thyristor Controlled Phase Shifting Transformer (TCPST)

TCPST is a device with characteristics similar to conventional Phase Angle Regulators (PAR), being connected in series to network. The main difference lies in the fact that the tap changer is controlled using thyristor to achieve faster operation [14]. The voltage on the primary side is injected thus the phase shifted, and therefore the transmission angle can be controlled. The modeling of power injection at the ith and j[th] buses is shown in Figure 1.
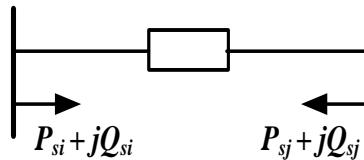

$$P_{si} + jQ_{si} \qquad\qquad P_{sj} + jQ_{sj}$$

Figure 1. Modeling of TCPST injection

The P_{si}, Q_{si}, P_{sj}, and Q_{sj} parameters can be determined as follows:

$$P_{Si} = \tau bs V_i V_j \sin(\theta_{ij} + \gamma) \tag{1}$$

$$Q_{Si} = \tau^2 bs V_i^2 - \tau bs V_i V_j \cos(\theta_{ij} + \gamma) \tag{2}$$

$$P_{Sj} = -\tau bs V_i V_j \sin(\theta_{ij} + \gamma) \tag{3}$$

$$Q_{Sj} = -\tau bs V_i V_j \cos(\theta_{ij} + \gamma) \tag{4}$$

where $\tau = \frac{|V_s|}{|V_i|}$, $bs = \frac{1}{X_s}$, and γ is the angle to be controlled by TCPST. The voltage phase-angle which can be controlled by TCPST is in the range between -5° and 5°. Figure 2 indicates the modeling of TCPST in the transmission line [14].
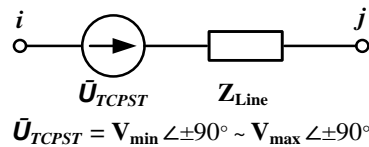
$$\bar{U}_{TCPST} = V_{min} \angle \pm 90° \sim V_{max} \angle \pm 90°$$

Figure 2. The TCSC model in transmission line

2.2. Thyristor Controlled Series Capacitor (TCSC)

TCSC is one type of FACTS devices which combines a Thyristor Controlled Reactor (TCR) with capacitor [14]. The TCR consists of inductor being connected in series with thyristor. TCSC is capable to adjust reactance of transmission line by controlling the thyristor firing-angle. Figure 3 represents a simple modeling of series TCSC. To avoid over compensation, the injection of TCSC is set on 20% inductive $(0.2X_{line})$ up to 70% capacitive $(-0.7X_{line})$ of the line reactance [28], such that:

$$r_{TCSCmin} = -0.7 \text{ and } r_{TCSCmax} = 0.2 \tag{5}$$
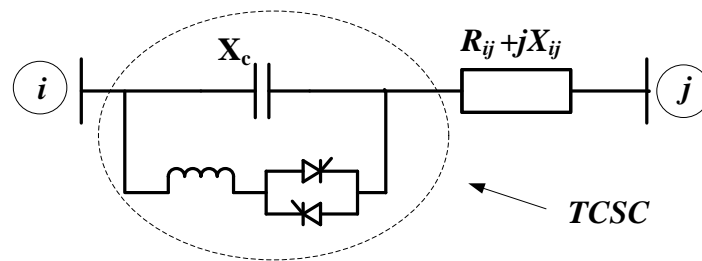

Figure 3. The modeling of TCSC

The TCSC modeling which enables the reactance control of the transmission line is shown in Figure 4 [28]. The relationship between the TCSC rating to the transmission line reactance is expressed as follows:

$$X_{total} = X_{line} + X_{TCSC} \tag{6}$$

$$X_{TCSC} = r_{TCSC} \times X_{line} \tag{7}$$

where X_{line} is the line reactance and r_{TCSC} is the compensation rating of TCSC.

$$X_{TCSC} = X_{min} \text{ - } X_{max}$$
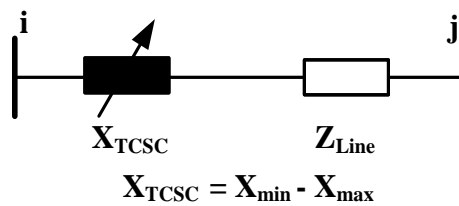
Figure 4. The TCSC modeling in the transmission system

3. PARTICLE SWARM OPTIMIZATION (PSO)

Particle Swarm Optimization (PSO) algorithm is an optimization technique within a problem space which adopts the behavior of birds or fishes in finding food. In general, the PSO algorithm process to solve an optimization problem can be represented using a flowchart shown in Figure 5. The steps to find the optimum value using the PSO algorithm can be described as follows:
1. Initialize the particle positions randomly within a problem space.

$$Particle\_position = Minimum\_Limit + (Maximum\_Limit - Minimum\_Limit) \times$$
$$rand\,(1, Particle\_Number) \tag{8}$$

2. Initialize the velocity of each particle:

$$V_{\max} = \frac{(Max\_limit - Minimum\_limit)}{N} \tag{9}$$

$$Particle\_Velocity = (V_{\max} - V_{\min}) \times rand(1, Particle\_Number) + V_{\min} \tag{10}$$

3. Evaluate the objective function of each particle.
4. Calculate the best position/location (P_{best}) and the best global position (G_{best}).
5. Update velocity and position of a particle, as shown in Equation (13) and (14). In this stage, the acceleration coefficient c_1 and c_2 being used are generally within the values of 0 to 4. A weight function (w), in the range of 0.4 to 0.9, is also used to control the exploration of global and local particles. The improvement of the weight function can be done using Equation (11).
6.

$$w(\text{t}) = (w_{\max} - w_{\min}) \times \left(\frac{iter_{\max} - iter\,(\text{t})}{iter_{\max}}\right) + w_{\min} \tag{11}$$

$$V_{\text{id}}(\text{t}+1) = w(\text{t}) \times V_{\text{id}}(\text{t}) + c_1 \times T_{1\text{d}}(\text{t}) \times \left(P_{\text{best id}}(\text{t}) - X_{\text{id}}(\text{t})\right) + c_2 \times T_{2\text{d}}(\text{t}) \times (G_{\text{bestd}}(\text{t}) - X_{\text{id}}(\text{t})) \tag{12}$$

$$X_{\text{id}}(\text{t}+1) = X_{\text{id}}(\text{t}) + V_{\text{id}}(\text{t}) \tag{13}$$

where t is the iteration step, V_{id} (t) is the current velocity of the particle i in the dimension d at iteration step t, V_{id} (t + 1) is the velocity of the particle i in the dimension d at iteration step $t + 1$, X_{ID} (t) is the current position of particle i in the dimension d at the iteration step t, X_{ID} (t + 1) is the position of particle i in dimension d at iteration $t + 1$, c_1 is the acceleration constant 1 (cognitive constant), c_2 is the acceleration constant 2 (social constant) , T_{ID} (t) and T_{2D} (t) are random numbers uniformly distributed between 0 and 1, P_{bestid} (t) is the local best position of particle i in dimension d at iteration t, and G_{bestid}(t) is the local best position of the global at iteration t.

7. Evaluate the objective function value on the next iteration.
8. Determine the final of P_{best} and G_{best}
9. Evaluate whether the solution is optimal, if a convergence has been achieved then it comes to end, otherwise going back to step 3.
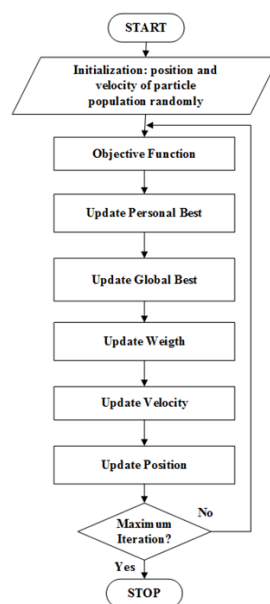

Figure 5. Steps to follow using the PSO algorithm

The flowchart of the PSO algorithm implementation is shown in Figure 6, whereas the control parameters used is given Table 1.
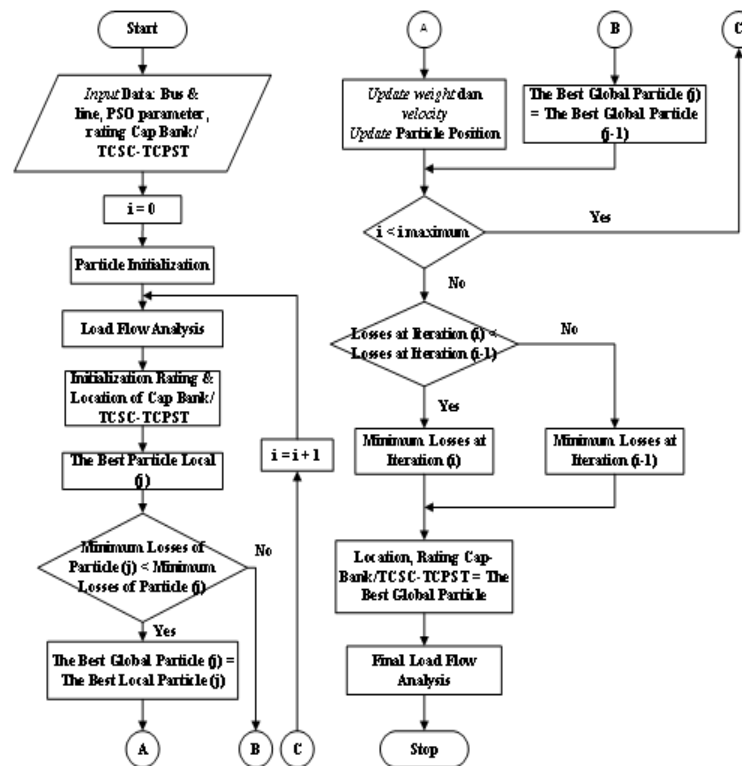

Figure 6. PSO solution

Table 1. The PSO control parameters

Parameter	Value
Number of Particle	50
Maximum Iteration	20
Number of Variable	3
c_1 and c_2	4
weight (w)	0,4
r_{TCSC} maximum	0,2 X_{line}
r_{TCSC} minimum	- 0,7 X_{line}
δ_{TCPST} maximum	5°
δ_{TCPST} minimum	- 5°
Objective Function	Min F=min P_{loss}

4. RESULTS AND DISCUSSION

In this study, the proposed solution has been simulated and tested using 30-bus system IEEE standard data. The results of the power flow analysis have been obtained from some scenarios including the conditions without any injection of compensation, the condition with injection of optimum capacitor bank compensation, and the condition with injection of optimum TCPST-TCSC compensation. The PSO algorithm implementation to determine the optimum location and sizing of the compensation using the TCPST-TCSC combination has been compared to that using capacitor bank. In addition, the PSO algorithm performance has also been compared with the implementation of Artificial Bee Colony (ABC) Algorithm [8].

4.1. IEEE 30 Bus System Data

The performance of the PSO algorithm has been tested using the 30-bus system IEEE standard data as follows: Bus Number: 30, Slack bus: Bus no#1, Generator: Bus no# 2, 5, 8, 11, and 13, Total demand: 201.43 MW and 137.80 MVAR. The PSO algorithm will determine the best location and sizing of the reactive power required in the system by performing the load flow analysis for each iteration. There are four

(4) cases of the system that will be performed to show the performance of the PSO algorithm and the implemented of the compensator devices i.e.:
- Case#1: without any injection of compensation,
- Case#2: with injection of capacitor bank compensation
- Case#3: with injection TCPST-TCSC compensation
- Case#4: with injection SVC compensation by using another optimization method i.e. Artificial Bee Colony (ABC) Algorithm [8].

For Case#2 and #3, the load flow analyses have been performed after the determination of optimum location and capacity of reactive power compensation required in the system using the PSO algorithm. In addition, the PSO Algorithm is also compared with ABC algorithm as given in Case#4.

4.2. Results of Case#1: without any injection of compensation

In this analysis, the 30-bus IEEE system has been tested under the condition without any compensating device. Based on the load flow analysis, the power flow as well as power losses on each branch, and the voltage on each system bus could be determined. Newton Raphson algorithm has been adopted to solve the load flow problem based on the following parameters: base power=100 MVA, accuracy=0.00001, and maximum iteration number=20. The results of load flow analysis for this case is shown in Table 2.

Based on Table 2, total active and reactive power generated were around 205.489 MW and 118.401 MVAR respectively. In addition, the total active and reactive power losses in the system were approximately 4.061 MW and -19.399 MVAR. There were three buses experiencing under voltage problem, being lower than the allowable minimum voltage, i.e. 0.95 p.u. The buses with voltage level beyond the limits occurred on bus# 18, bus#19, and bus#20. The percentage of the active power losses is about 2.02% with respect to the active power load.

Table 2. Load flow results Case#1

Bus#	Voltage		Load		Generation	
	|V| (pu)	◻	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
1	1	0	0	0	24.819	-1.742
2	1	-0.334	21.7	12.7	60.97	30.371
3	0.983	-1.353	2.4	1.2	0	0
4	0.979	-1.597	7.6	1.6	0	0
5	0.983	-1.767	0	0	0	0
6	0.971	-2.05	0	0	0	0
7	0.967	-2.494	22.8	10.9	0	0
8	0.958	-2.531	30	30	0	0
9	0.963	-2.531	0	0	0	0
10	0.96	-2.789	5.9	2	0	0
11	0.963	-2.531	0	0	0	0
12	0.975	-1.346	11.2	7.5	0	0
13	1	1.7	0	0	37	18.855
14	0.962	-2.055	6.2	1.6	0	0
15	0.962	-1.898	8.2	2.5	0	0
16	0.96	-2.263	3.5	1.8	0	0
17	0.954	-2.882	9	5.8	0	0
18	0.914	-2.133	3.2	0.9	0	0
19	0.889	-2.027	9.5	34	0	0
20	0.905	-2.33	2.2	0.7	0	0
21	0.971	-2.877	19.669	11.2	0	0
22	0.98	-2.708	0	0	31.59	36.954
23	1	-1.603	3.2	1.6	22.2	20.463
24	0.975	-2.752	15	6.7	0	0
25	0.984	-2.015	1	0	0	0
26	0.966	-2.464	3.5	2.3	0	0
27	1	-1.154	0	0	28.91	13.5
28	0.973	-2.122	0	0	0	0
29	0.976	-2.808	3.659	0.9	0	0
30	0.964	-3.803	12	1.9	0	0
	Total		201.428	137.8	205.489	118.401
	Total Losses		4.061	MW	-19.399	MVAR
	% of Losses		2.02%	MW	-16.4%	MVAR

4.3. Results of Case#2: with injection of capacitor bank compensation

IEEE standard system has been tested for the condition with the placement of capacitor bank. The number of capacitor banks required in the system was 3 locations with capacity values between 0 up to 50 MVAR. The optimum location and capacity of capacitor bank used are shown in Table 3. From the table it can be seen that the resulted location and capacity of capacitor bank after optimization using the PSO algorithm were 12.5433 MVAR (0.2502 p.u.) located at bus#17, 25.5432 MVAR (0.5105 p.u.) located at bus#7, and 28.2801 MVAR (0.5664 p.u.) located at bus#31.

Table 3. Capacitor bank optimization results for Case#2 using the PSO algorithm

Compensation	Bus No# Location	Rating (p.u.)	Rating (MVAR)
Capacitor Bank	17	0.2502	12.5433
Capacitor Bank	7	0.5105	25.5432
Capacitor Bank	31	0.5664	28.2801

Table 4 shows the simulation result of the system after the optimum placement of the capacitor banks with the minimum power losses. It can be seen that the total power generated were around 213.83MW for active power and 149.91 MVAR for reactive power. The total active and reactive power losses for Case#2 were 9.901 MW and 16.009 MVAR respectively. There is no voltage violation for the Case#2 since all of bus voltage values were in the range of 0.95 p.u. to 1.05 p.u. The voltage profile for each bus is depicted in Figure 8. The voltage level of buses which experienced under voltage condition in Case # 1 has been rising to meet the allowable voltage level.

Table 4. Load flow results for Case#2

Bus#	Voltage		Load		Generation	
	|V| (pu)	α	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
1	1	0	0	0	23.112	-10.156
2	1	-0.288	21.7	12.7	60.97	6.641
3	0.998	-1.52	2.4	1.2	0	0
4	0.997	-1.813	7.6	1.6	0	0
5	0.991	-1.796	0	0	0	0
6	0.987	-2.224	0	0	0	0
7	0.98	-2.602	22.8	10.9	0	0
8	0.974	-2.68	30	30	0	0
9	0.997	-2.743	0	0	0	0
10	0.989	-3.018	5.9	2	0	0
11	0.997	-2.743	0	0	0	0
12	0.989	-1.373	11.2	7.5	0	0
13	1	1.628	0	0	37	8.645
14	0.979	-2.077	6.2	1.6	0	0
15	0.982	-2.015	8.2	2.5	0	0
16	0.981	-2.401	3.5	1.8	0	0
17	0.981	-3.059	9	5.8	0	0
18	0.969	-3.08	3.2	0.9	0	0
19	0.965	-3.503	9.5	34	0	0
20	0.97	-3.45	2.2	0.7	0	0
21	0.994	-2.944	19.669	11.2	0	0
22	1	-2.73	0	0	31.59	26.998
23	1	-1.134	3.2	1.6	22.2	6.703
24	0.985	-2.548	15	6.7	0	0
25	0.988	-1.87	1	0	0	0
26	0.97	-2.315	3.5	2.3	0	0
27	1	-1.051	0	0	28.91	8.488
28	0.988	-2.236	0	0	0	0
29	0.976	-2.705	3.659	0.9	0	0
30	0.964	-3.7	12	1.9	0	0
	Total		201.428	137.8	203.782	47.319
	Total Losses		2.354	MW	-24.114	MVAR
	% of Losses		1.17%		-17.5%	

The process in achieving the minimum power losses using the PSO algorithm is shown in Figure 7. The minimum power loss on each iteration as the objective function has been recorded. It is only after reaching the convergence criteria that the PSO algorithm steps could be ended. The maximum iterations

performed for the test were 20 iterations. Based on the figure, it also showed that the minimum active power losses can be reached on the 5th iteration with the value of 2.354 MW.
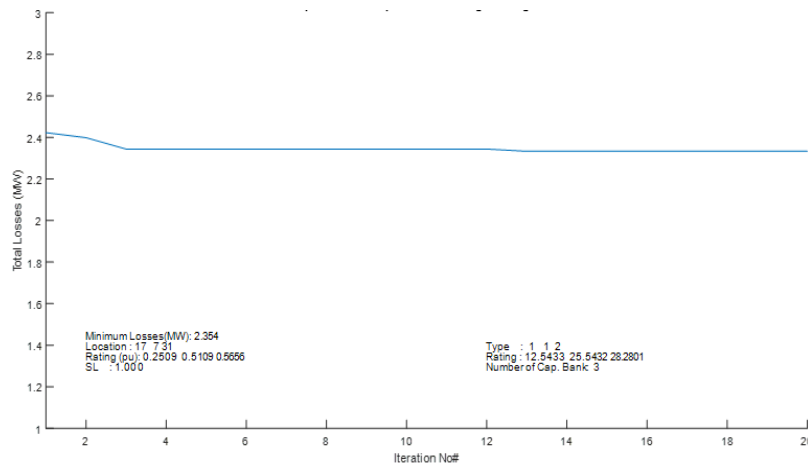

Figure 7. The convergence criteria for Case#2

4.4. Result of Case#3: with injection TCSC-TCPST compensation

In this part, the standard IEEE 30-bus system has been tested in a condition with TCSC-TCPST being implemented in the system. Based on the results, the optimum location and size of the TCSC-TCPST is are shown in Table 5. The optimum place of TCSC was on the line#15 which was connected to bus#27 and bus#29 with a rating of -0,5535X_{line} and line#31 which was connected to bus#27 and bus#30 with the rating of -0,5343Xline. In addition, the TCPST has also been implemented in the line#26 which was connected to bus#10 and bus#20 with the injected phase-angle of -2.6839°.

The simulation results of the system after the placement of TCSC and TCPST for the most minimum power loss is shown in Table 6. It can be seen that the total power generated by the generator was equal to 203.602 MW and 40.891 MVAR for active power and reactive power respectively. The total active and reactive power losses for Case#3 were 2.174 MW and -25.041 MVAR respectively. There was no voltage violation for the Case#3 since the voltage of all buses were in the range of 0.95 p.u. – 1.05 p.u. The percentage of the power losses is about 1.07% with respect to the active power load.

The process in achieving the minimum power losses for Case#3 with TCSC-TCPST compensation using the PSO algorithm is given in Figure 8. The minimum active power losses could be reached on the 14th iteration with the value of 2.174 MW.
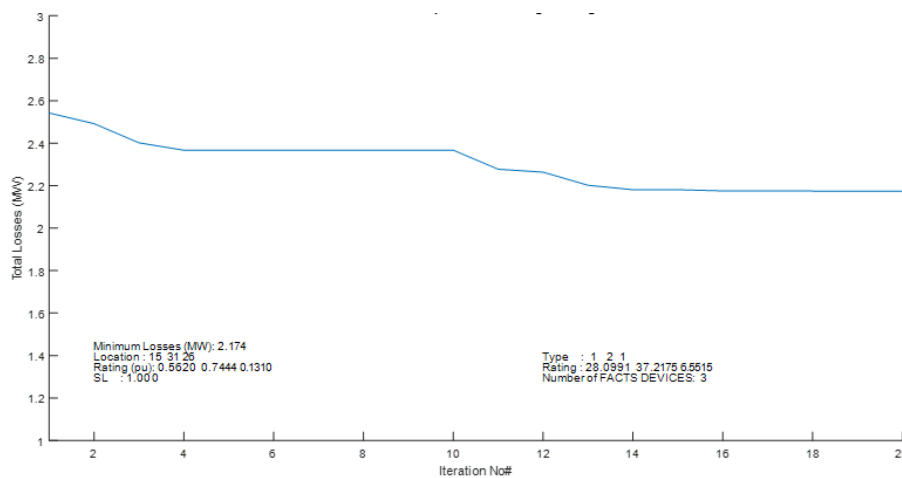

Figure 8. The convergence criteria for Case#3

Table 5. TCSC & TCPST optimization results using the PSO algorithm for Case#3

Compensation	Location (Line)	From Bus	To Bus	Rating
TCSC	15	27	29	$-0{,}5535X_{line}$
TCSC	31	27	30	$-0{,}5343X_{line}$
TCPST	26	10	20	$-2{,}6839°$

Table 6. Load flow results for Case#3

Bus#	Voltage		Load		Generation	
	|V| (pu)	α	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
1	1	0	0	0	22.932	-8.16
2	1	-0.284	21.7	12.7	60.97	5.876
3	0.995	-1.467	2.4	1.2	0	0
4	0.993	-1.746	7.6	1.6	0	0
5	0.993	-1.81	0	0	0	0
6	0.991	-2.269	0	0	0	0
7	0.983	-2.633	22.8	10.9	0	0
8	0.988	-2.887	30	30	0	0
9	0.99	-2.753	0	0	0	0
10	0.989	-3.009	5.9	2	0	0
11	0.99	-2.753	0	0	0	0
12	0.993	-1.393	11.2	7.5	0	0
13	1	1.597	0	0	37	5.978
14	0.993	-2.445	6.2	1.6	0	0
15	0.989	-2.109	8.2	2.5	0	0
16	0.983	-2.398	3.5	1.8	0	0
17	0.982	-3.054	9	5.8	0	0
18	0.983	-3.366	3.2	0.9	0	0
19	0.983	-3.904	9.5	34	0	0
20	0.983	-3.739	2.2	0.7	0	0
21	0.994	-2.93	19.669	11.2	0	0
22	1	-2.714	0	0	31.59	26.712
23	1	-1.068	3.2	1.6	22.2	3.302
24	0.985	-2.524	15	6.7	0	0
25	0.988	-1.884	1	0	0	0
26	0.97	-2.329	3.5	2.3	0	0
27	1	-1.088	0	0	28.91	7.183
28	0.993	-2.303	0	0	0	0
29	0.976	-2.743	3.659	0.9	0	0
30	0.964	-3.738	12	1.9	0	0
Total			201.428	137.8	203.602	40.891
Total Losses			2.174	MW	-25.041	MVAR
% of Losses			1.07%		-18.2%	

4.5. Result of Case#4: with injection SVC using Artificial Bee Colony (ABC) Algorithm [8]

To show the performance of the PSO algorithm, the comparison with Artificial Bee Colony (ABC) Algorithm [8] result has been made. The same simulation using IEEE 30-bus system as a base-case data have been made and compared in terms of voltage profile and the best active power loss reached. Based on the ABC algorithm result shows that the number of SVCs required in the system was two (2) locations with capacity values 36.996 MVAR at bus#5 and 36.971 MVAR at bus#19 respectively.

The simulation results of the system after the placement of SVC for the most minimum power loss is shown in Table 7. It can be seen that the total power generated by the generator was equal to 204.21 MW and 48.40 MVAR for active power and reactive power. The total active and reactive power losses obtained for this case were 2.7927 MW and -15.2076 MVAR respectively. There was no voltage violation in this case since the voltage of all buses were in the acceptable range. The percentage of the power losses is about 1.37% with respect to the active power load.

Table 7. Load flow results for Case#4: with injection SVC using ABC Algorithm [8]

Bus#	Voltage		Load		Generation	
	|V| (pu)	α	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
1	1	0	0	0.00	23.54	-5.64
2	1	-0.369	21.7	12.70	60.97	1.60
3	0.9883	-1.535	2.4	1.20	0.00	0.00
4	0.986	-1.786	7.6	1.60	0.00	0.00

Table 7. Load flow results for Case#4: with injection SVC using ABC Algorithm [8]

Bus#	Voltage		Load		Generation	
	|V| (pu)	α	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
5	1.0223	-2.472	0	0.00	0.00	0.00
6	0.9815	-2.246	0	0.00	0.00	0.00
7	0.9885	-2.846	22.8	10.90	0.00	0.00
8	0.9694	-2.709	30	30.00	0.00	0.00
9	0.979	-2.825	0	0.00	0.00	0.00
10	0.9776	-3.129	5.9	2.00	0.00	0.00
11	0.979	-2.825	0	0.00	0.00	0.00
12	0.986	-1.415	11.2	7.50	0.00	0.00
13	1	1.5966	0	0.00	37.00	10.95
14	0.9775	-2.14	6.2	1.60	0.00	0.00
15	0.9815	-2.106	8.2	2.50	0.00	0.00
16	0.9745	-2.472	3.5	1.80	0.00	0.00
17	0.9708	-3.181	9	5.80	0.00	0.00
18	0.9733	-3.426	3.2	0.90	0.00	0.00
19	0.9727	-3.99	9.5	34.00	0.00	0.00
20	0.9727	-3.834	2.2	0.70	0.00	0.00
21	0.9746	-3.507	19.669	11.20	0.00	0.00
22	1	-2.072	0	0.00	31.59	24.64
23	1	-0.962	3.2	1.60	22.20	6.94
24	0.9848	-2.159	15	6.70	0.00	0.00
25	0.988	-1.648	1	0.00	0.00	0.00
26	0.97	-2.1	3.5	2.30	0.00	0.00
27	1	-0.928	0	0.00	28.91	9.92
28	0.9831	-2.291	0	0.00	0.00	0.00
29	0.9762	-2.531	3.659	0.90	0.00	0.00
30	0.9637	-3.538	12	1.90	0.00	0.00
	Total		201.428	137.80	204.21	48.40
	Total Losses		2.7927	MW	-15.2076	MVAR
	% of Losses		1.37%		-31.42%	

4.6. Comparison results between cases

The results of system simulation on IEEE 30-bus system with four cases have been compared in terms of voltage profile and the best active power loss reached for each case by using the PSO algorithm and ABC algorithm [8]. Figure 8 shows the voltage profiles comparison. The worst voltage profile has been experienced in Case#1 where the availability of the reactive power was very limited depending on the generating unit. There are three buses were below the allowable minimum voltage of 0.95 p.u.

However, the supply of the reactive power depended on the output of the active power loading for each unit. On the other hand, the voltage profiles have been improved in Case#2 and Case#3 by using PSO algorithm and Case#4 by using ABC algorithm, since the reactive power sources have been implemented to support the deficiency of the reactive power. All of the buses voltage was above 0.95 p.u., since the reactive power compensations required in the system were satisfied using capacitor bank for Case#2, TCSC-TCPST for Case#3, and SVC for Case#4. The Case#3 showed a better voltage profile compared to the other cases.
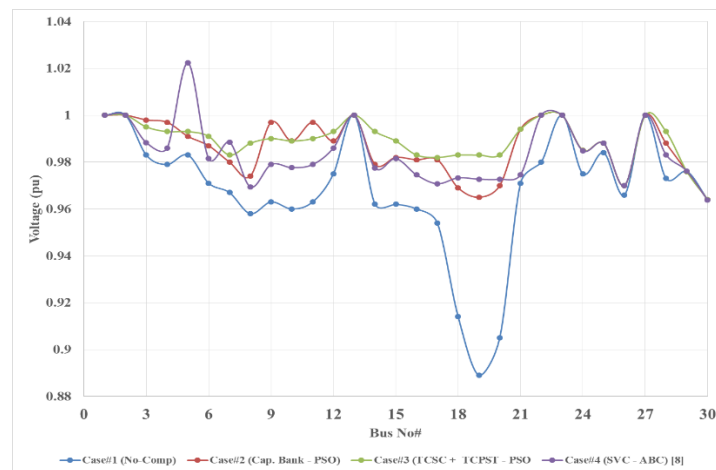

Figure 8. Voltage profile comparison for each case

Table 7. Comparison of active power losses between cases

Simulation	Case#1 (No-Comp)	Case#2 (Cap. Bank - PSO)	Case#3 (TCSC + TCPST – PSO)	Case#4 (SVC - ABC) [8]
Active Power Losses (MW) (a)	4.061	2.354	2.174	2.793
% of (a) respect to active power load	2.02%	1.17%	1.07%	1.37%
Active power losses improvement respect to Case#1 (MW)	0.000	1.707	1.887	1.268
Percentage of active power losses improvement respect to Case#1 (%)	0.00%	42.03%	46.47%	31.23%

Table 7 shows the comparison of active power losses for the four cases. The percentage of active power losses referred to the total active power load is given in the table. The implementation of the capacitor banks and the TCSC-TCPST combination which had been optimized using the PSO algorithm could reduce the active power losses as much as 1.707 MW (42.03%) and 1.887 MW (46.47%) respectively, being compared to the condition without any injection of the compensation (Case#1). In addition, the implementation of the SVC compensation by using the ABC algorithm could also reduce the active power losses as much as 1.887 MW (31.23%) with respect to the Case#1. However, the implementation of the TCSC-TCPST compensation with PSO algorithm gave a slightly better result than using the capacitor bank with PSO algorithm and SVC with ABC algorithm [8].

5.   CONCLUSION

The Particle Swarm Optimization (PSO) algorithm has been explored to determine the optimum location and sizing of capacitor banks and TCPST-TCSC combination with the aim to improve the voltage profile and to reduce the power losses of the system. It has been proven that the algorithm performed well and required small iterations number, i.e. 5-14 iterations, in determining the optimum values. The 30-bus system IEEE standard was tested to show the performance of the PSO algorithm. The optimum placement and sizing of capacitor bank and TCPST-TCSC combination on the transmission lines using the PSO algorithm have been proven to be able to improve the bus voltage bus values within the allowable voltage limits. The result also showed that the implementation of optimum TCPST-TCSC placement was more effective than the optimum placement of capacitor banks in reducing power losses of the system, giving a reduction of 46.47% and 42.03% using TCPST-TCSC combination and capacitor bank respectively. The performance of PSO algorithm also have been compared with the ABC algorithm. The implementation of the TCSC-TCPST compensation with PSO algorithm gave a slightly better result than using the capacitor bank with PSO algorithm and SVC with the ABC algorithm.

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