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Optimal Location and Sizing of SVC Using Particle Swarm Optimization Technique.

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Abstract— **This paper describes optimal location and sizing of static var compensator (SVC) based on Particle Swarm Optimization for minimization of transmission losses considering cost function. Particle Swarm Optimization (PSO) is population-based stochastic search algorithms approaches as the potential techniques to solving such a problem. For this study, static var compensator (SVC) is chosen as the compensation device. Validation through the implementation on the IEEE 30-bus system indicated that PSO is feasible to achieve the task. The simulation results are compared with those obtained from Evolutionary Programming (EP) technique in the attempt to highlight its merit.**

Keywords-component; optimal location; optimal sizing; Particle Swarm Optimization; transmission loss minimization; static var compensator.

I. INTRODUCTION

The FACTS is a concept proposed by N.G. Hingorani [1] a well-known term for higher controllability in power systems by means of power electronics devices. FACTS devices can provide benefits in increasing system transmission capacity and power flow control flexibility and rapidity [2]. Population base, cooperative and competitive stochastic search algorithms are very popular in the recent year in the research area of computational intelligence. PSO algorithm was developed by Kennedy and Eberhart based on the social behaviors of animal swarms (e.g. bird blocks and fish schools) [17]. PSO is also applied for solving various optimization problems in electrical engineering [2, 3, 18-20]. Optimal locations of different types of FACTS devices in the power system has been attempted using different Evolutionary Programming (EP) techniques such as Hybrid Tabu Search and Simulated Annealing (TS/SA), GA, Repetitive Power Flow method (RPF), BA and Fuzzy decision making and PSO. The maximum increase in system loadability is achieved by GA and PSO techniques with an optimal numbers of five TCSCs devices in the system. In [9], GA and PSO are used to optimize the parameters of TCSC. However, PSO have more advantageous than that of GA. PSO gives a better balanced mechanism and better variation to the global and local exploration abilities. Moreover, it can be applied to solve various optimization problems in power system such as power system stability enhancement and capacitor placement problems [10].This paper presents PSO technique for loss minimization in power system by using SVC. PSO was adopted to optimize the SVCs location and sizing to be installed in power transmission network. The PSO and EP techniques were performed on the IEEE 30-bus system have indicated that the proposed methods are worth in loss minimization scheme.

II. FACTS DEVICE

Flexible AC Transmission Systems (FACTS) devices have several types namely: thyristor controlled static compensator (TCSC), static var compensator (SVC), unified power flow controller (UPFC), static compensator (STATCOM), and thyristor controlled phase shifter transformer (TCPST) [11-12]. The SVC is a shunt type FACTS device defined as a shunt connected static var generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of the power system, typically the bus voltage [13]. The SVC can inject or absorb its reactive power (Q_{SVC}) at a chosen bus. It injects reactive power into the system it $Q_{SVC} < 0$ and absorbs reactive power from the system if $Q_{SVC} > 0$ [14]. The working range of SVC is between 0MVar and +100MVar [21]. The SVC is modeled as a generator or absorber of reactive power as shown in Figure 1.a. It is modeled as an ideal reactive power injection at bus *i*, as shown in Figure 1.b. The injected

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power at bus *i* is: [15 - 16].

$$\Delta Q_{is} = Q_{SVC} \qquad (1)$$
$$Q_{\min} \le Q_{SVC} \le Q_{\max}$$

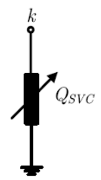

Figure 1.a Block diagram of SVC

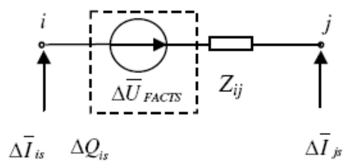

Figure 1.b Mathematical model of SVC

III. OPTIMIZATIONS TECHNIQUE

A. *Particle Swarm Optimization (PSO)*

The PSO provides a population-based search procedure in which individuals called particles and changes their positions. The position of each particle is presented in X-Y plane. Each particle moves to the new position using velocity according to its own experience, called as P_{best}. G_{best} is the overall best value obtained so far by any particle in the population. By time to time, the PSO consists of velocity changes of each particle towards its P_{best} and G_{best} [18-19]. Each particle tries to modify its current position and velocity according to the distance between its current position and P_{best}, and the current position and G_{best}. After finding the best values the particle updates its velocity and position. Velocity of each particle can be modified. [2,3, 20]. The flowchart of PSO is shown in Figure 2.

B. *Evolutionary Programming (EP)*

The Evolutionary Programming (EP) is one of the artificial intelligent method is introduction by David B. Fogel in 1960 [21] was inspired from natural selection process to find the global optimum of complex problem [22]. It is evolutionary algorithms are based on computational models of fundamental evolutionary processes such as initialization, mutation, selection and reproduction. In [50], proposed EP to define the optimal placement of FACTS device for maximization the total transfer capability (TTC) of power system. EP also searches for FACTS parameters, FACTS locations, and the real power generations except the slack bus in power system, the real power loads in sink area and generation bus voltages. In [22] proposed a loss sensitivity approach for placement of Phase Shifter Series Capacitors (PSSC) and Static VAR Compensators. In this research, EP technique was used to optimal the sizing of UPFCs with objective function to minimize the loss and improve the voltage profile. The flowchart of EP is shown in Figure 3.

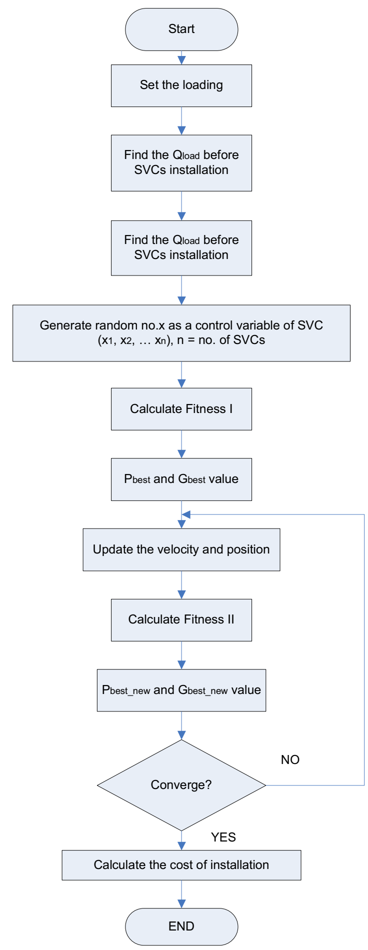

Figure 2: A Flowchart of Particle Swarm Optimization (PSO)

IV. TEST RESULTS

A. *Transmission Loss Reduction and Cost of Installation*

In order to realize the effectiveness of the proposed PSO technique, the IEEE 30-bus system was tested to find the optimal location and sizing of SVC. The parameters of the optimization algorithm can be referred to [2, 3, 14, 20]. Results for transmission loss reduction when load i.e. buses

26 and 29 are subjected to load variation are tabulated in Table I, and II. The location and sizing of SVC to achieve loss reduction at several loading conditions can be referred to the same table. For instance in Table I with loading condition of 20MVar, the transmission loss has been reduced to 17.5478MW. In order to achieve this, the location of SVC at Bus 26 and the sizing of SVC is 20.1679MVar as indicated in the table. The cost of installation at this scenario is US$1,083,300. From Table II it is observed that the value of transmission losses decrease rapidly and the cost of installation increase accordingly as the reactive power loading increase. Figure 4 shown the cost of installation SVC when load variation on Bus 26.

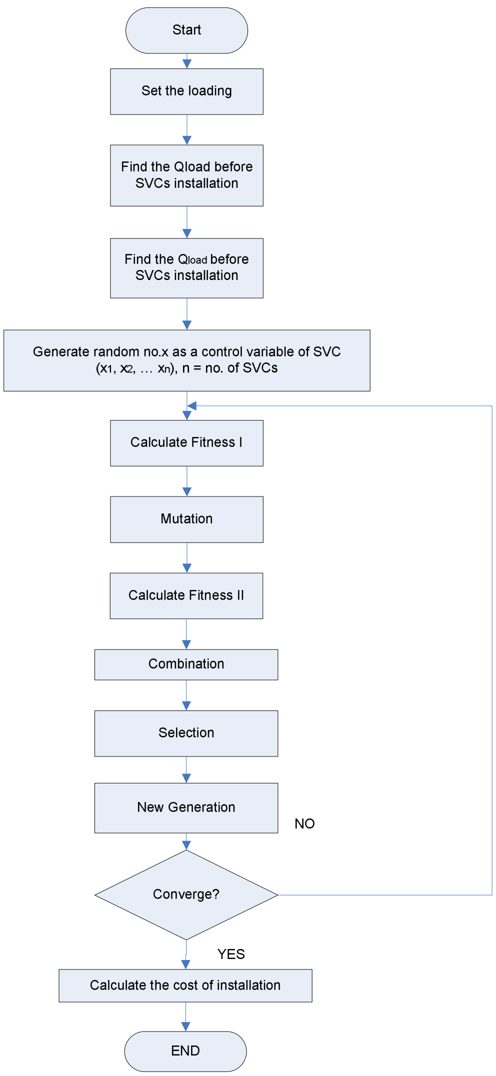

Figure 3: A Flowchart of Evolutionary Programming (EP)

TABLE I: TRANSMISSION LOSS REDUCTION LOAD VARIATION AT BUS 26

Loading Condition Q_{d26}(Mvar)	SVC location bus	SVC sizing (Mvar) s1	Loss (MW)	IC (US$)
5	26	6.2032	17.5415	88,284
10	26	10.2864	17.5466	429,440
15	26	16.6998	17.5415	697,340
20	26	20.1679	17.5478	1,083,300
25	26	27.1565	17.5432	1,869,000
30	26	27.9195	17.5919	2,916,700

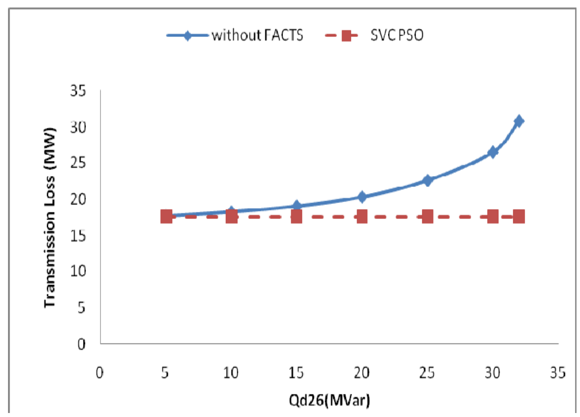

Figure 3: Results for Transmission Loss Reduction at Bus 29

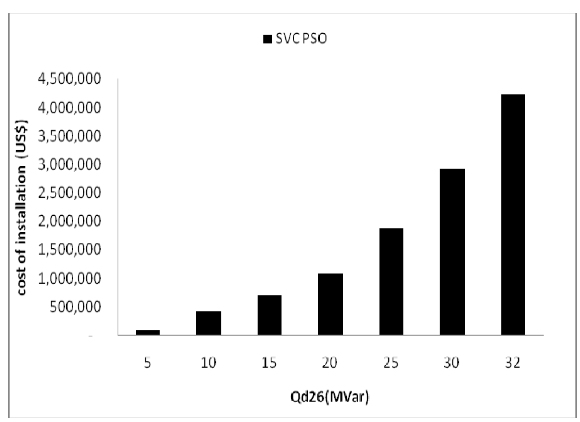

Figure 4: Cost of Installation SVC When Load Variotion at Bus 26

The results for location and sizing of SVC to achieve optimal loss reduction at with load variation at Bus 29 are tabulated in Table II. For instance, at loading condition of 20MVar the transmission loss has been reduced 17.5582MW. In order to achieve this, the location of SVC is Bus 29 and the sizing of SVC is 23.7697MVAr as indicated in Table II.

The cost of installation at this scenario is US$1,004,800. It is also shown the installation of SVC has significantly reduced the transmission loss in the system at all loading conditions as shown in Figure 5. Figure 6 shown the cost of installation SVC when load variation at Bus 29 is subjected to the system. Result shows that the implementations of PSO have reduced the transmission loss of the system indicating it as a feasible technique to perform optimization process in practical system.

TABLE II: TRANSMISSION LOSS REDUCTION LOAD VARIATION AT BUS 29

Loading Condition Q_{d29}(Mvar)	SVC location (Bus)	SVC sizing (Mvar) s1	Loss (MW)	IC (US$)
5	29	9.0711	17.5591	195,055
10	29	13.0427	17.5577	448,910
15	29	16.6507	17.5635	664,840
20	29	23.7697	17.5582	1,004,800
25	29	27.2707	17.5598	996,490
30	29	32.8218	17.5580	2,338,300

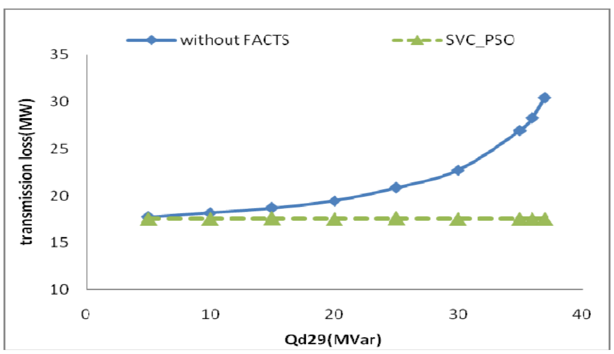

Figure 5: Results for Transmission Loss Reduction at Bus 29

B. Comparative Studies with Other Technique.

Comparative studies were conducted with respect to the results obtained using EP. The results are tabulated in Table III - VIII for load subjected to buses 26 and 29.

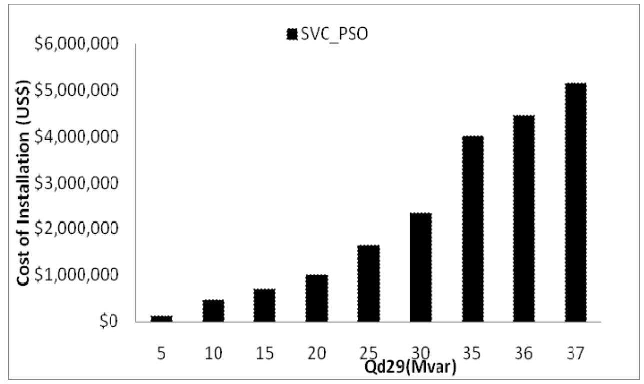

Figure 6: Cost of Installation SVC When Load Variotion at Bus 29

TABLE III: TRANSMISSION LOSS REDUCTION LOAD VARIATION AT BUS 26 PERFORMED USING PSO AND EP.

Loading Condition Q_{d26}(Mvar)	Pre-Installation	Post-Installation			
	Loss (MW)	PSO		EP	
		Loss (MW)	%	Loss (MW)	%
5	17.7175	17.5415	0.99%	17.6625	0.31%
15	19.0625	17.5415	7.98%	18.5395	2.74%
20	20.3393	17.5478	13.72%	19.4151	4.54%
30	26.5184	17.5919	33.66%	17.6128	33.58%

In Table III at loading condition of 15MVar; PSO managed to reduce the transmission loss from 19.0625MW to 17.5415MW (7.98%), while EP managed to reduce the transmission loss to 18.5395MW (2.74%). The same scenarios can be observed as well with 20MVar and 30MVar. It is shown that, PSO technique can be optimizing the transmission loss lower than EP. In Table IV at loading condition 15MVar; PSO managed to increase the voltage profile form 0.8896p.u to 1.0290pu (16%), while EP managed to increase the voltage profile to 0.9576pu (8%). The same scenarios can be observed as well with 20MVar and 30MVar. On other hand, Table V shown the cost of installation FACTS device when load variation at Bus 26. At loading condition of 15MVar; PSO managed the cost of installation FACTS device is US$697,340, while EP managed the cost of installation FACTS device is US$456,960. The cost of installation is related with reduction of reactive power in the system.

TABLE IV: VOLTAGE PROFILE IMPROVEMENT LOAD VARIOTION AT BUS 26 PERFORMED USING PSO AND EP.

Loading Condition Q_{d26}(Mvar)	Pre-Installation Voltage (p.u)	Post-Installation			
		PSO		EP	
		Voltage (p.u)	%	Voltage (p.u)	%
5	0.9814	1.0257	5%	0.9932	1%
15	0.8896	1.0290	16%	0.9576	8%
20	0.8383	1.0186	22%	0.9422	12%
30	0.6795	1.0028	48%	0.9981	47%

TABLE V: COST OF INSTALLATION FACTS DEVICES LOAD VARIOTION AT BUS 26 PERFORMED USING PSO AND EP.

Loading Condition Q_{d26}(Mvar)	Post-Installation	
	PSO	EP
	Cost (US$)	Cost (US$)
5	$88,284	$52,293
15	$697,340	$456,960
20	$1,083,300	$642,250
30	$2,916,700	$2,907,700

In Table VI at loading condition of 15MVar; PSO managed to reduce the transmission loss from 18.6839MW to 17.5648MW (5.99%), while EP managed to reduce the transmission loss to 17.5636MW (6%). The same scenarios can be observed as well with 20MVar and 30MVar. It is shown that, Both PSO and EP technique are comparable to optimizing the transmission loss. In Table VII at loading condition 15MVar; PSO managed to increase the voltage profile form 0.9p.u to 1.0412pu (16%), while EP managed to increase the voltage profile to 1.0214pu (13%). The same scenarios can be observed as well with 20MVar and 30MVar. On other hand, Table VII shown the cost of installation FACTS device when load variation at Bus 29. At loading condition of 15MVar; PSO managed the cost of installation FACTS device is US$681,960, while EP managed the cost of installation FACTS device is US$664,840.

IV. CONCLUSION

This paper has presented the application of Particle Swarm Optimization (PSO) and Evolutionary Programming (EP) technique for minimize the transmission loss and monitoring the voltage profile and SVC installation cost. In this study, PSO and EP methods are applied on bus 26 and 29 of IEEE 30-Bus system. From the simulation results demonstrated that the proposed PSO technique is feasible for loss minimization scheme in power system network. However, PSO is superior that EP in terms of loss minimizations. For the future work, other FACTS devices such as TCSC can be incorporated together to achieve similar task.

TABLE VI: TRANSMISSION LOSS REDUCTION LOAD VARIOTION AT BUS 29 USING PSO AND EP

Loading Condition Qd29(Mvar)	Pre-Installation Loss (MW)	Post-Installation			
		PSO		Loss (MW)	
		Loss (MW)	%	Loss (MW)	%
5	17.7284	17.5576	0.96%	17.5591	0.95%
15	18.6839	17.5648	5.99%	17.5635	6.00%
20	19.4699	17.5577	9.82%	17.5582	9.82%
30	22.7158	17.5604	22.70%	17.5580	22.71%

TABLE VII: VOLTAGE PROFILE IMPROVEMENT LOAD VARIOTION AT BUS 29 PERFORMED USING PSO AND EP.

Loading Condition Q_{d29}(Mvar)	Pre-Installation Voltage (p.u)	Post- Installation			
		PSO		EP	
		Voltage (p.u)	%	Voltage (p.u)	%
5	0.9800	1.0307	5%	1.0296	5%
15	0.9000	1.0412	16%	1.0214	13%
20	0.8582	1.0292	20%	1.0338	20%
30	0.7423	1.0373	40%	1.0283	39%

TABLE VIII: COST OF INSTALLATION FACTS DEVICES LOAD VARIOTION AT BUS 29 PERFORMED USING PSO AND EP.

Loading Condition Q_{d29}(Mvar)	Post-Installation	
	PSO	EP
	Cost (US$)	Cost (US$)
5	$111,170	$195,055
15	$681,960	$664,840
20	$1,000,900	$1,004,800
30	$2,344,900	$2,338,300

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