PSO Based Technique for Loss Minimization Considering Voltage Profile and Cost Function

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Abstract-- **This paper describes optimal sizing of FACTS devices based on Particle Swarm Optimization for minimization of transmission loss considering voltage profile and cost function. Particle Swarm Optimization (PSO) is one of the artificial intelligent search approaches which have the potential in solving such a problem. In this study one of FACTS devices is used as a scheme for transmission loss. For this study, static var compensator (SVC) is chosen as the compensation device. The effect of population size during the optimization process towards achieving the solution is also investigated. Validation through the implementation on the IEEE 30-bus RTS indicated that PSO is feasible to achieve the task.**

***Index Terms*— FACTS devices, optimal sizing, Particle Swarm Optimization, transmission loss, minimization, static var compensator.**

I. Introduction

In recent years, the greater demand have been placed on the transmission network, and these demands will be continue to increase because of the increasing number of nonutility generators and heightened competition among utilities themselves [1]. This problem it is very difficult to acquire new rights of way. One of alternative is by using flexible alternating current transmission system (FACTS). 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 be provide benefits in increasing system transmission capacity and power flow control flexibility and rapidity [2].

Population based, cooperative and competitive stochastic search algorithms very popular in the recent year in the

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), Genetic Algorithm (GA), Repetitive Power Flow method (RPF), Bee Algorithms 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. From the results it is shown that TCSC device has improved the line flows even to their thermal limits [3]. With multitype FACTS devices installed; the reduction in total generator of fuel cost is more than the individual installed FACTS devices [4]. The hybrid TS/SA converges at a faster computation time. In [5], BA does not require external parameters such as cross over rate and mutation rate. BA gives better result in terms of speed of optimizations and accuracy of the results. BA needs the large number of trials. On the other hand, GA based approach is proposed to determine the suitable types of FACTS devices and evaluate the total costs system [6]. EP in [7] is used to identify the location of four FACTS devices. Optimal Power Flow using GA can also used to obtain the optimal locations of SVC. The results shown that this method can be used to minimize the total cost function, including generations cost of power plants and investments costs [8]. 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].

In this paper, PSO technique is proposed to optimize the sizing of FACTS devices in order to minimize the transmission loss in the system. The SVC is chosen as the device for compensation and modeled as a reactive source added at the bus. Placement of SVC is done empirically as the pilot study. Computer simulations were done on the IEEE 30-bus RTS. The effect of population size on loss reduction is also investigated.

II. Material and Methods

Flexible AC Transmission Systems (FACTS) devices have several types namely: thyristor controlled static compensator (TCSC), static var compensator (SVC), thyristor controlled phase shifter transformer (TCPST), unified power flow controller (UPFC) and static compensator (STATCOM) [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 $Q_{SVC} < 0$ and absorbs reactive power from the system if $Q_{SVC} > 0$ [14]. The working range of SVC is between -100MVar and 100MVar [2]. The SVC is modeled

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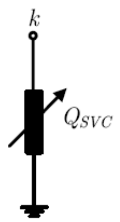
as a generator or absorber of reactive power as shown in Fig 1. It is modeled as an ideal reactive power injection at bus i, as shown in Fig 2. The injected power at bus i is: [15 - 16]

$$\Delta Q_{is} = Q_{SVC} \tag{1}$$



$$Q_{\min} \le Q_{SVC} \le Q_{\max}$$

Fig 1 Block diagram of SVC

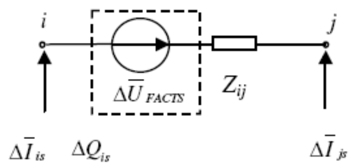


Fig 2 Mathematical model of SVC

A. Cost of Installation

The cost of installation of SVC devices has been mathematically formulated and given by the following equation [2, 12]:

$$IC = C_{SVC} \times S \times 1000 \tag{2}$$

Where

IC = the installation cost SVC devices in [US$],
C_{SVC} = the cost of SVC devices in [US$/KVar]

Installation of SVC device can be calculated using the cost function given by [2, 6, 15].

$$C_{SVC} = 0.0003\text{S}^2 - 0.3051\text{S} + 127.38[\text{US\$/KVar}] \tag{3}$$

$$S = |Q_2 - Q_1| \tag{4}$$

where

S = operating range of SVC in [MVar]
Q_1 = reactive power flow through the branch before SVC installation.
Q_2 = reactive power flow through the branch after SVC installation.

III. Particle Swarm Optimization (PSO)

PSO algorithm originally is developed by Kennedy and Eberhart based on the social behaviors of animal swarms (e.g. bird blocks and fish schools) [17]. 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 by equation (5) [2, 3, 20].

$$v_i^{k+1} = w \times v + c_1 \times rand_1 \times (P_{best\,i} - s_i^k) + c_2 \times rand_2 \times (G_{best\,i} - s_i^k) \tag{5}$$

where

v_i^{k+1} = velocity of particle t at iterations
w = weight function
c_1 and c_2 = weight coefficient both equal to 2
rand_1 and rand_2 = random number between 0 and 1
$\text{s}_\text{i}^\text{k}$ = current position of particle i at iteration k
P_{best} = best position of particle i - th up to the current iteration
G_{best} = best overall position found by the particle up to the current iteration.

Weight function is given by (6) [2, 3, 14, 20]

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{iter_{\max}} \times iter \tag{6}$$

where

$w_{\max}$ = initial weight equal to 0.9
$w_{\min}$ = initial weight equal to 0.4
$iter_{\max}$ = maximum iteration number, and
$iter$ = current iteration number.

The new position can be modified (7)

$$s_i^{k+1} = s_i^k - v_i^{k+1} \tag{7}$$

The general flowchart of PSO is shown in Fig. 1 [10].

IV TEST RESULTS

In order to realize the effectiveness of the proposed PSO technique, the IEEE 30-bus RTS was tested to find the optimal sizing of SVC. The line data and the bus data of the IEEE 30-bus RTS are given in [12]. The parameters of the optimization algorithm are listed in Table 1 [2, 3, 14, 20].

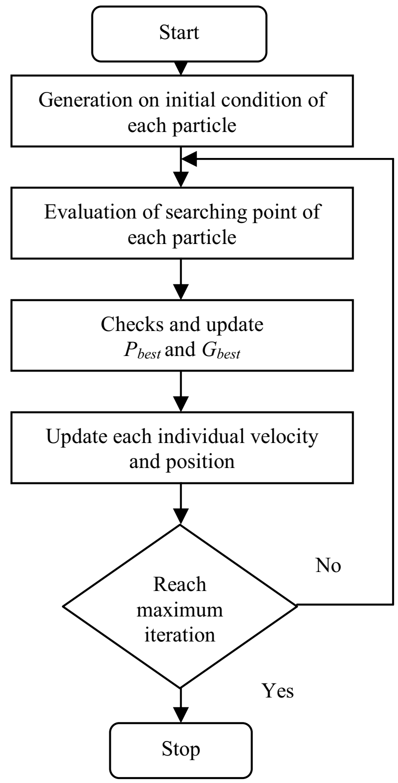


Fig. 2 A General Flowchart of Particle Swarm Optimization

TABLE I
PARAMETERS OF OPTIMIZATIONS TECHNIQUES

Parameters	PSO
Population Size	5, 10, 15, 20
Inertial Weight, *w*	0.9 - 0.4
Constant, C1	2
Constant, C2	2
Number of iteration	50
Rand1	0 to 1
Rand2	0 to 1

The SVC installations in the transmission system to improve the transmission loss in the system have been conducted at several load conditions subjected to buses 9, 17 and 24. The impact of population size to the optimization performance was also monitored so that the best population size can be identified from the simulations.

A. Transmission Loss and Voltage Profile with SVC Installations.

Results for transmission loss reduction when load buses i.e. buses 9, 17 and 24 are subjected to load variation are shown in Table 2, 3 and 4. The results for the sizing of SVC to achieve loss reduction at several loading conditions can be referred to the same table. For instance, at loading condition is 70MVar the transmission loss has been reduced from 18.2654MW to 17.6188MW.

TABLE 2
TRANSMISSION LOSS REDUCTION LOAD VARIATION AT BUS 9.

Loading Condition (Mvar)	Transmission Loss (MW)		SVC sizing (MVar)	Cost SVC	IC
	without SVC	with SVC		(US$/KVar)	10^3 (US$)
10	17.6292	17.5091	-11.4131 9.6018 13.3722	127.3434	15.297
20	17.7889	17.5365	44.3900 13.7469 9.2735	127.3030	32.128
30	17.8398	17.4964	6.3383 4.4443 13.5235	127.2752	43.712
40	17.9024	17.5085	46.4236 3.5552 9.8267	127.2599	50.130
50	18.0871	17.5107	55.8046 4.1166 17.4648	127.2042	73.319
60	18.1748	17.7035	51.8879 -20.1158 13.4827	127.2363	59.964
70	18.2654	17.6188	-37.4615 14.3503 22.3326	127.1828	82.240
80	18.6583	17.5968	32.2160 -12.0845 12.5587	127.0565	134.880

In order to achieve this, the sizing of SVCs are -37.4615MVar 14.3503MVar and 22.3326MVar as indicated in the Table 2. From Table 2 it is observed that the value of transmission losses is decreased and the cost of installation is increased accordingly as the reactive power loading is increased. It is also shown that, with the installation of SVC the transmission loss of the bus for all loading condition have been reduced significantly as shown in Fig 3. The results for the transmission loss reduction and voltage profile improvement at several loading conditions variation is subjected to bus 9. Figure 4 illustrates the voltage profile at bus 9 when load at this bus is gradually increased. It is pretty obvious that, with the installation of SVC optimized using PSO, the voltage is improved at all loading conditions.

The sizing of SVCs to achieve loss reduction when the load is subjected to bus 17 can be referred to Table 3. For instance, at loading condition of 70MVar the transmission loss has been reduced from 20.7221MW to 17.6174MW. In order to achieve this, the sizing of SVCs are 8.2606MVar, -7.0477MVar, and 6.2365MVar as indicated in the table. From Table 3 it is observed that the value of transmission losses is decreased and the cost of installation is increased accordingly as the reactive power loading is increased. It is also shown that, with the installation of SVC the transmission loss of the bus for all loading conditions have been reduced significantly as shown in Fig 5. Fig 6 illustrates the voltage profile at bus 17 when load at this bus is gradually increased. It is pretty obvious that, with the installation of SVC optimized using PSO; the voltage is improved at all loading conditions.

TABLE 3
TRANSMISSION LOSS LOAD VARIATION AT BUS 17

Loading Condition (Mvar)	Transmission Loss (MW)		SVC Sizing (Mvar)	Cost SVC	IC
	without SVC	with SVC		(US$/KVar)	10^3 (US$)
10	17.6372	17.4961	27.2333 4.3301 14.1114	127.3369	17.971
20	17.9108	17.4973	3.2431 7.4281 15.2213	127.2539	52.620
30	18.1565	17.6216	26.9790 -6.7321 20.4170	127.2169	68.042
40	18.5051	17.5488	19.1235 17.3285 17.8376	127.0885	121.530
50	19.0813	17.6995	-2.2342 -4.2457 1.4957	126.9690	175.440
60	19.6813	18.3239	-16.7474 59.1462 3.1942	126.9664	17.2350
70	20.7221	17.6174	8.2606 -7.0477 6.2365	126.4357	392.540
80	21.6623	18.9359	32.0966 60.7261 46.5629	126.5504	345.030

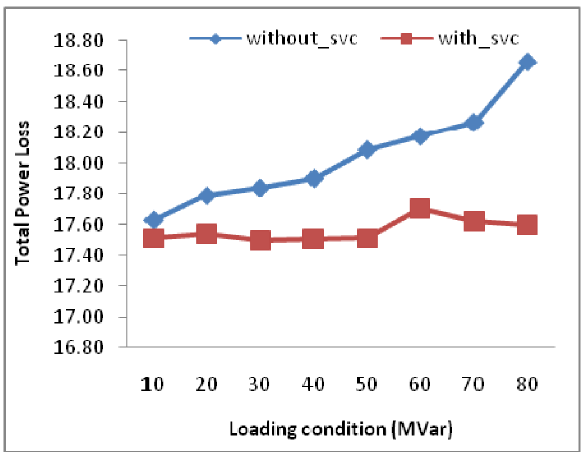


Fig 3 Results for transmission loss reduction load variation at bus 9 with and without SVC

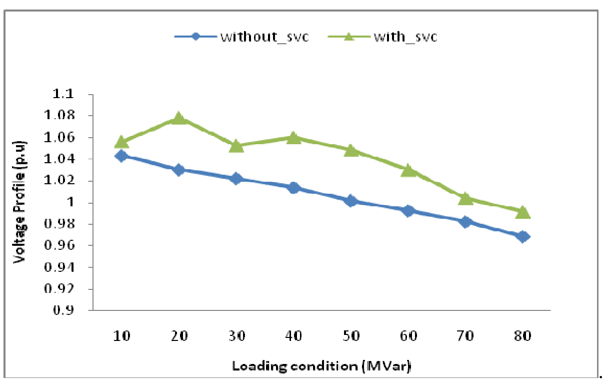


Fig 4 : Results of voltage profile improvement at bus 9 with and without SVC

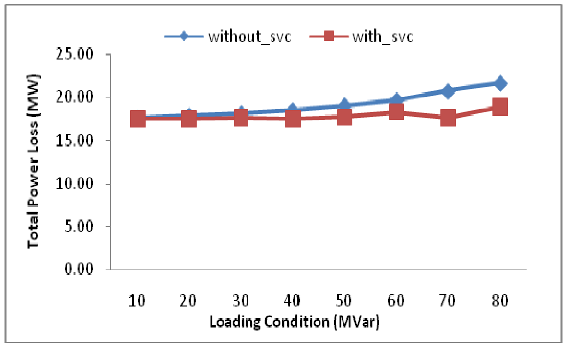


Fig 5: Results for transmission loss reduction load variation at bus 17 with and without SVC.

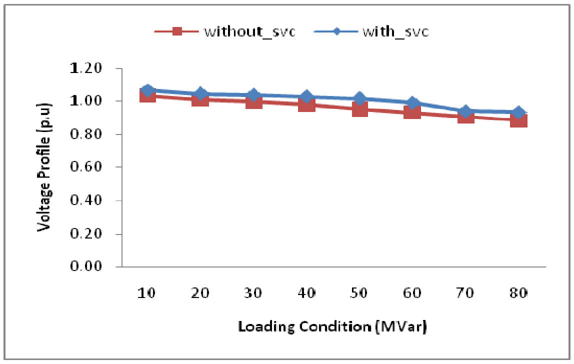


Fig 6: Results of voltage profile improvement at bus 17 with and without SVC

The sizing of SVCs to achieve loss reduction when load variation is subjected to bus 24 can be referred to Table 4. For instance, at loading condition of 70MVar the transmission loss has been reduced from 24.4930MW to 18.5055MW. In order to achieve this, the sizing of SVCs are -27.8060MVar, 60.2440MVar and 7.6894MVar as indicated in the table. From Table 4 it is observed that the value of transmission losses is decreased and the cost of installation is increased accordingly as the reactive power loading is increased. It is also shown that, with the installation of SVC the transmission loss of the bus for all loading condition have been improved significantly as shown in Fig 7. The results for the transmission loss reduction and voltage profile improvement at several loading condition variation is subjected to bus 24. Fig 8 illustrates the voltage profile at bus 24 when load at this bus is gradually increased.

B. The Effect of Population Size to Optimization Performance

The results for effect of population size to transmission loss reduction are tabulated in Table 5, and 6. Table 5 tabulates the effect of population size to transmission loss when the reactive power loading variation is subjected to bus 17. From the table, it is observed that the transmission loss increased accordingly as the restive power loading is increased. Large population size gives the lowest transmission loss reduction in the system, and vice versa. For instance at Q_{d17} = 50MVar the losses value is 17.6995 MW for population size of 5, while the transmission loss is 17.5600 MW when the population size is increased to 20. This indicates that higher population sizes will give better performance [11]. The same scenarios can also be observed at different loading conditions. From the results it is found that the large population size has a significant impact in performing optimization process using the PSO technique.

TABLE 4
TRANSMISSION LOSS REDUCTION LOAD VARIATION AT BUS 24

Loading Condition (Mvar)	Transmission Loss (MW) without SVC	Transmission Loss (MW) with SVC	SVC sizing (Mvar)	Cost SVC (US$/KVar)	IC 10^3 (US$)
10	17.6615	17.5283	27.5171 1.6888 7.0346	127.3394	16.956
20	18.1052	17.5175	39.0523 8.6136 17.3855	127.2008	74.755
30	18.6418	17.5899	23.2198 -2.3829 20.7548	127.0594	133.650
40	19.4270	17.6018	13.3953 25.8458 11.4657	126.8241	231.480
50	20.6829	17.5620	31.5960 8.7664 19.5306	126.4308	394.560
60	22.3919	17.5546	31.9884 0.6204 20.0114	125.9112	609.070
70	24.4930	18.5055	-27.8060 60.2440 7.6894	125.5640	75.1820
80	27.5385	18.7234	61.2272 -49.5883 0.7810	124.7139	1099.300

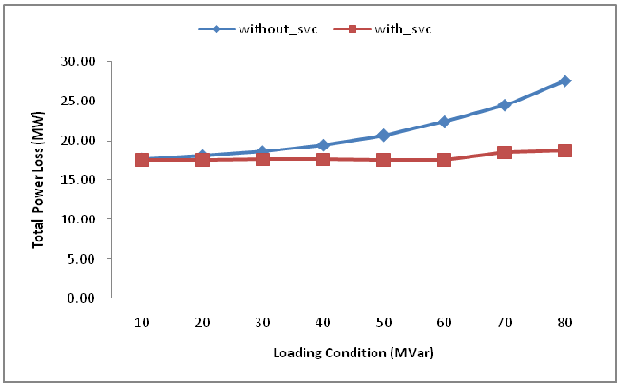


Fig 7 : Results for transmission loss reduction load variation at bus 24 with and without SVC.

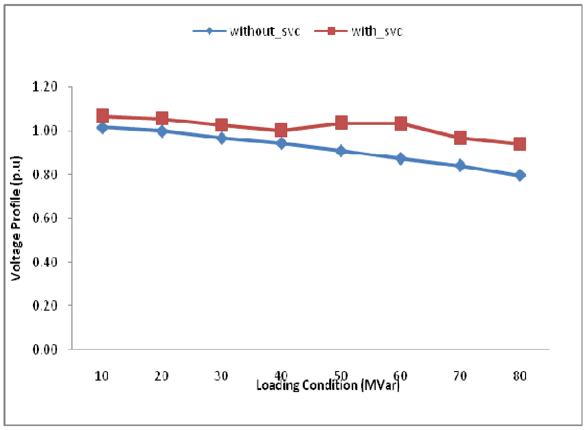


Fig 8 : Results of voltage profile improvement at bus 24 with and without SVC.

TABLE 5
RESULTS FOR THE EFFECT OF POPULATION SIZE PERFORMED AT BUS 17

Pop. Size	Transmission Loss when load at Bus-17 is varied: Q_{d17}=10 Mvar	Q_{d17}=20 Mvar	Q_{d17}=30 Mvar	Q_{d17}=50 Mvar
5	17.4961	17.4973	17.6216	17.6995
10	17.4933	17.5719	17.5217	17.5420
15	17.4937	17.5494	17.5038	17.5195
20	17.4992	17.5127	17.5110	17.5600

The effect of population size to transmission loss reduction to bus 24 is listed in Table 6. Similar phenomenon is observed as those for bus 24. From the table it is discovered that the best transmission loss can be observed at population size of 15. From Table 5 and 6; 20 is the population size as the most suitable to achieve the best performance in transmission loss reduction optimized using PSO. It is suggested to have populations size of 20 for all buses in order to reduce the transmission loss in the system.

TABLE 6
RESULTS FOR THE EFFECT OF POPULATION SIZE PERFORMED AT BUS 24

Pop. Size	Transmission Loss when load at Bus-17 is varied: Q_{d24}=10 Mvar	Q_{d24}=20 Mvar	Q_{d24}=30 Mvar	Q_{d24}=50 Mvar
5	17.5283	17.5175	17.5899	17.5620
10	17.5091	17.5062	17.5086	17.6585
15	17.4964	17.4972	17.5128	17.5431
20	17.5296	17.5147	17.5033	17.4988

IV. CONCLUSION

An approach for transmission loss reduction by using SVC installation via PSO as the optimization technique is presented. Source code of PSO optimizations technique was developed to determine the optimal sizing of SVC in order to minimize the transmission loss in the system. Besides that, the voltage profiles and cost installation of SVC are considered in the system. Tests are performed on the IEEE 30-bus RTS. Result shows that the implementations of PSO have reduced the transmission loss and improved the voltage profile of the system indicating it as a feasible technique to perform the optimization process.

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BIOGRAPHIES

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