Placement and Sizing of Thyristor Controlled Series Compensator Using PSO Based Technique for Loss Minimization

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Abstract—**Minimizing the transmission loss in power system is one of the important issues in power system research these days. Transmission loss can be reduced by installing reactive power compensation components. Installing the thyristor controlled series compensator (TCSC) in power system has been known to increase the voltage level in the system and hence reduce the system losses. This paper describes placement and 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 device is used as a scheme for transmission loss. For this study, TCSC 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 the Evolutionary Programming (EP) technique in the attempt to highlight its merit.**

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

I. Introduction

The IEEE PES Task Force of the FACTS working Group defined for Flexible AC Transmission System (FACTS) as an alternating current transmission systems incorporating power electronic-based and other static controllers to enhance controllability and increase power transfer capability [1]. FACTS device is a concept proposed by N.G. Hingorani [2]; a well-known term for higher controllability in power system by means of power electronics devices. The Electric Power Research Institute were supporting the development of high power electronic for such applications as High Voltage DC (HVDC) transmission and reactive compensation of ac line, and in the late 1980s formalized the concept of FACTS [3]. The FACTS initiative was originally launched with main objectives to increase the power transfer capability of transmission system and to keep power flow over designed routes. The benefits of FACTS devices are increasing system transmission capacity, power flow, control flexibility and rapidity [4], to improve transmission system management, increased dynamic, transient grid stability and enabling environment [5]. FACTS devices provide strategic benefits for improved transmission system management through better utilization of existing transmission assets, increased transmission system reliability and availability, increased dynamic and transient grid and enabling environmental benefits [6].

In this paper, PSO technique is proposed to optimize the placement and sizing of FACTS devices in order to minimize the transmission loss and increase the voltage profile in the system. The TCSC is chosen as the device for compensation and modeled as a reactive source added at the line. The PSO and EP techniques performed on the IEEE 30-bus system have indicated that the proposed methods are worth in loss minimization scheme.

II. Thyristor Controlled Series Compensator (TCSC)

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 model of a transmission line with series impedance ($z_{ij}=r_{ij}+jx_{ij}$) and a TCSC connected between bus-*i* and bus-*j* is shown in Figure 1.a. and Figure 1.b. During the steady state the TCSC can be considered as a static reactance -jx_c. By modifying the reactance of the transmission line, the TCSC acts as the inductive or capacitive compensation respectively. In this research, the reactance of the transmission line is adjusted by TCSC directly. The rating of TCSC depends on the reactance of the transmission line where the TCSC is located:

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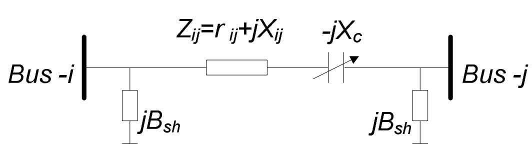

Fig. 1.a Model of TCSC

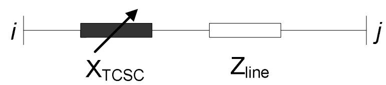

Fig. 1.b Block diagram of TCSC

$$Z_{ij} = Z_{line} = r_{ij} + X_{ij}$$

$$X_{ij} = X_{line} + X_{TCSC} \quad (1)$$

$$X_{TCSC} = r_{tcsc} \times X_{line} \quad (2).$$

Where X_{ij} is the total reactance of the transmission line, X_{line} is reactance of the transmission line, X_{tcsc} is reactance of TCSC, and r_{tcsc} is the coefficient which represents the degree of compensations by TCSC. To avoid over compensation, the working range of the TCSC is chosen between -0.8X_{line} and 0.2X_{line} [7,8,9,10].

A. *TCSC Cost Function*

The cost of installation of TCSC devices has been mathematically formulated and given by the following equation [9,11]:

$$IC = C_{TCSC} \times S \times 1000 \quad (3).$$

Where

IC = the installation cost TCSC devices in [US$],

C_{TCSC} = the cost of TCSC devices in [US$/KVar]

Installation of TCSC device can be calculated using the cost function given by [9, 11]:

$$C_{TCSC} = 0.0015S^2 - 0.7130S + 153.7 \text{[US\$/KVar]} \quad (4)$$

$$S = |Q_2 - Q_1| \quad (5)$$

where

S = operating range of TCSC in [MVar]

Q_1 = reactive power flow through the branch before TCSC installation.

Q_2 = reactive power flow through the branch after TCSC installation.

III. Modern Optimization Techniques

Optimization technique is an important approach in the aim to obtain the most suitable location and sizing of TCSC installation. In this study PSO is chosen due to its capability to achieve optimal solution.

A. *Particle Swarm Optimization (PSO)*

The Particle Swarm Optimization (PSO) algorithm originally is developed by Kennedy and Eberhart based on the social behaviors of animal swarms (e.g. bird blocks and fish schools) [12]. 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} [13-14].

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 (6) [15 - 17].

$$v_i^{k+1} = w \times v + c_1 \times rand_1 \times (P_{best\,i} - s_i^k) + c_2 \times rand_2 \times (G_{best\,i} - s_i^k) \quad (6)$$

where

v_i^{k+1} = velocity of particle i 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

s_i^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 (7) [15 -18]:

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} \times iter \quad (7).$$

where

w_{max} = maximum weight equal to 0.9

w_{min} = minimum weight equal to 0.4

$iter_{max}$ = maximum iteration number, and

$iter$ = current iteration number.

The new position can be modified (8)

$$s_i^{k+1} = s_i^k + v_i^{k+1} \quad (8).$$

The general flowchart of PSO is shown in Fig. 2[19].

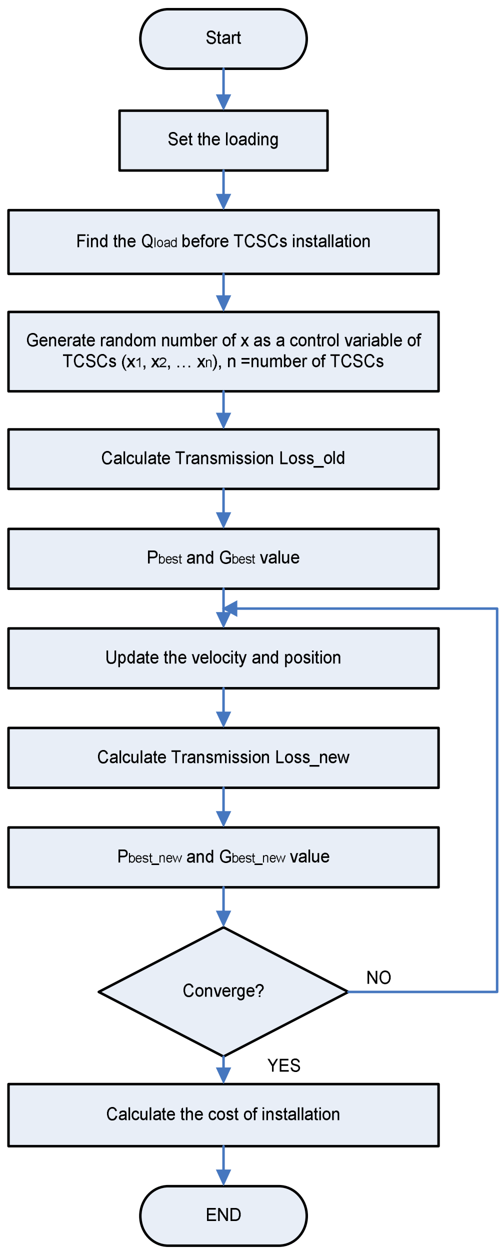

Fig. 2. Flowchart of Particle Swarm Optimization (PSO) algorithm for TCSC parameters.

B. *Evolutionary Programming (EP)*

The Evolutionary Programming (EP) is one of the artificial intelligent method which was introduced by David B. Fogel in 1960 [20]; inspired from natural selection process to find the global optimums of complex problem [21]. It is an evolutionary algorithm which based on computational models of fundamental evolutionary processes such as initialization, mutation, selection and reproduction. Fogel [21], 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. The flowchart of EP is shown in Figure 3.

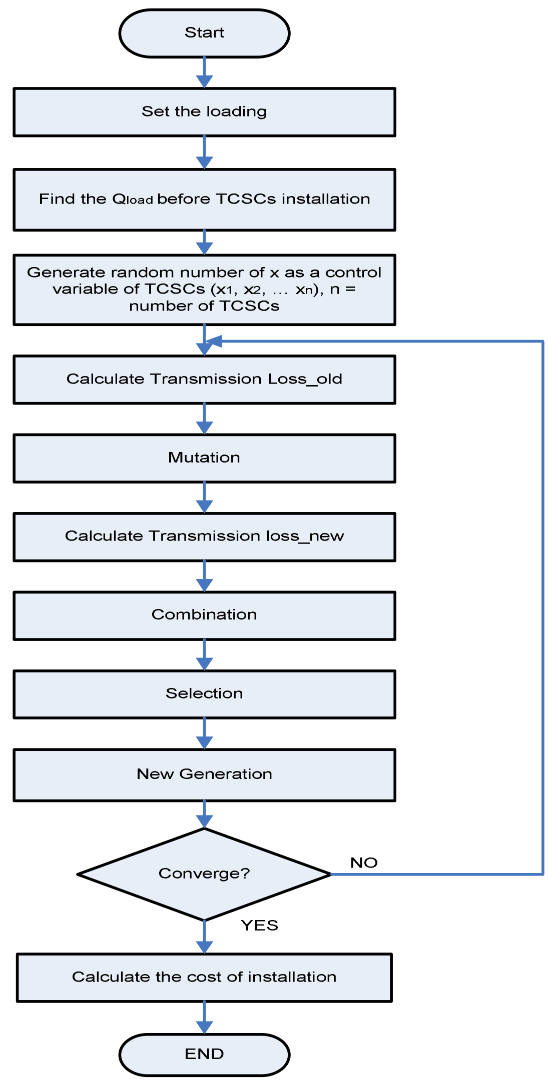

Fig. 3: Flowchart of Evolutionary Programming (EP) optimization algorithm for TCSC parameters.

IV. RESULTS AND DISCUSSION

The IEEE 30-bus system has been used to demonstrate the application of the proposed formulation and evaluate the effectiveness of the PSO and EP in the solving the TCSC installation problem. Figure 4 shows the single line diagram of the test system. The system consists of 41-branches, 6 generator buses, and 22 load-buses. The linedata and the busdata of the IEEE 30 bus system are given in [5]. The parameters for the optimization process are listed in Table I.

TABLE I
PARAMETERS FOR OPTIMIZATIONS PROCESS

Parameters	PSO
Population Size	20
Inertial Weight, w	0.4 and 0.9
Constant, c_1	3
Constant, c_2	3
Number of iteration	100
$Rand_1$	0 to 1
$Rand_2$	0 to 1

The TCSC installations in the transmission system to improve the transmission loss in the system have been conducted at several load conditions subjected to buses 26 and 29.

A. Transmission Loss, Voltage Profile and Cost of Installation at Bus 26

Results for transmission loss minimization when load at bus 26 are subjected to load variation are tabulated in Table II. Results for location and sizing of TCSC to achieve loss for this case can be referred to the same table. For instance, at loading condition is 30MVar the transmission loss has been reduced from 26.5184MW to 22.6478MW using the PSO technique. In order to achieve this, the location of TCSC, is line-34 and the sizing of TCSC, is -0.4584p.u. Besides that, the transmission loss has been reduced to 23.8334MW when using the EP technique. The location for installation of TCSC is line-34 and the sizing is -0.2248p.u. These are shown in Table III.

Figure 4 illustrates the results for voltage profile when load variation is subjected to bus 26. From the results it is shown that TCSC installation manages to improve the voltage profile better until 0.9p.u – 1.00p.u. Figure 5 shows the cost of installation for TCSC when load variations are subjected to Bus 26. From the chart bar, it is observed that the cost of installation increased consequently as the reactive power loading in increased.

TABLE II
TRANSMISSION LOSS REDUCTION LOAD VARIATION AT BUS 26 USING PSO TECHNIQUE.

Loading Condition Q_{d26} (MVar)	Loss (MW)		location TCSC	TCSC sizing
	without TCSC	with TCSC		
10	18.2785	18.0485	2	-0.0277
20	20.3393	19.8915	35	-0.5474
30	26.5184	22.6478	34	-0.4584

TABLE III
TRANSMISSION LOSS REDUCTION LOAD VARIATION AT BUS 26 USING EP TECHNIQUE

Loading Condition Q_{d26} (MVar)	Loss (MW)		location line	TCSC sizing
	without TCSC	with TCSC		
10	18.2785	18.1103	13	-0.2219
20	20.3393	19.8885	35	-0.5710
30	26.5184	23.8334	34	-0.2248

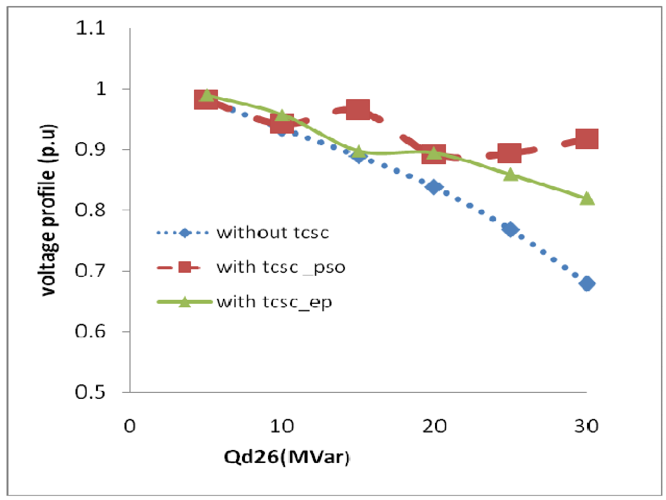

Fig. 4. Results for Voltage Profile When Load Variation at Bus 26

B. Transmission Loss, Voltage Profile and Cost of Installation at Bus 29

Results for transmission loss reduction when load buses 29 are subjected to load variation are tabulated in Table IV. The results for location and sizing of TCSC to achieve loss reduction at 22.7158MW to 20.6413MW using the PSO technique. In order to achieve this, the location of TCSC line-36 and the sizing of TCSC is -0.3912p.u. Besides that, the transmission loss is reduced to 21.9260MW using the EP technique as shown in Table V. The location for installation of TCSC is line-37 and the sizing is -0.3123p.u.

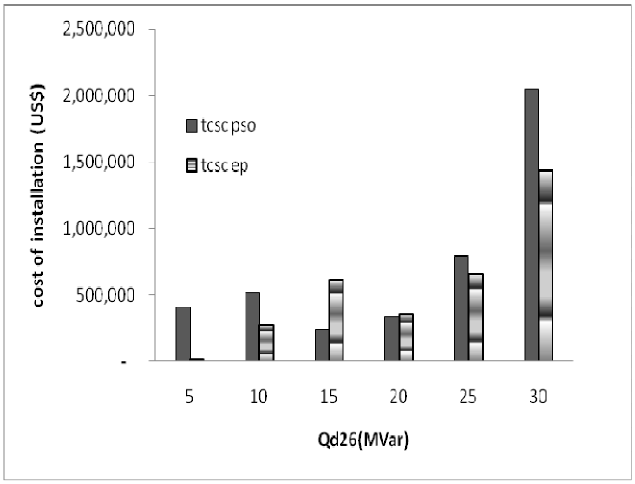

Fig. 5. Results of Cost Installation When Load Variation at Bus 26

Figure 6 shows the results of voltage profile when load variation is subjected to bus 29. The same phenomena as that bus 26 can be observed in this case. The results shown that TCSC installation manage to improve the voltage profile better until 0.9p.u – 1.00p.u. Figure 7 shows the cost of installation for TCSC when load variations are subjected to bus 29. From the figure, it is observed that the cost of installation increased consequently as the reactive power loading in increased.

V. CONCLUSION

An approach for transmission loss minimization by using TCSC installation via PSO and EP as the optimization technique has been presented in this paper. Source code of PSO and EP optimization techniques were developed to determine the optimal location and sizing of TCSC in order to minimize the transmission loss in the system. Besides that, the voltage profiles and cost installation of TCSC resulted from the study could be taken as a reference for power system operators. Result shows that the implementations of PSO and EP have minimized the transmission loss and improved the voltage profile of the system indicating it as a feasible technique to perform the optimization process. For the future work, other FACTS device such as static compensator (STATCOM), thyristor controlled phase shifter transformer (TCPST), or unified power flow controller (UPFC) can be incorporated together to achieve similar task.

TABLE IV
TRANSMISSION LOSS REDUCTION LOAD VARIATION AT BUS 26 USING PSO TECHNIQUE.

Loading Condition Q_{d29} (MVar)	Loss (MW) without TCSC	Loss (MW) with TCSC	location line	TCSC sizing
10	18.1682	17.9937	13	-0.1835
20	19.4699	19.0105	36	-0.3445
30	22.7158	20.6413	36	-0.3912

TABLE V
TRANSMISSION LOSS REDUCTION LOAD VARIATION AT BUS 26 USING EP TECHNIQUE.

Loading Condition Q_{d29} (MVar)	Loss (MW) without TCSC	Loss (MW) with TCSC	location line	TCSC sizing
10	18.1682	17.9944	13	-0.1557
20	19.4699	19.0111	36	-0.3076
30	22.7158	21.9260	37	-0.3123

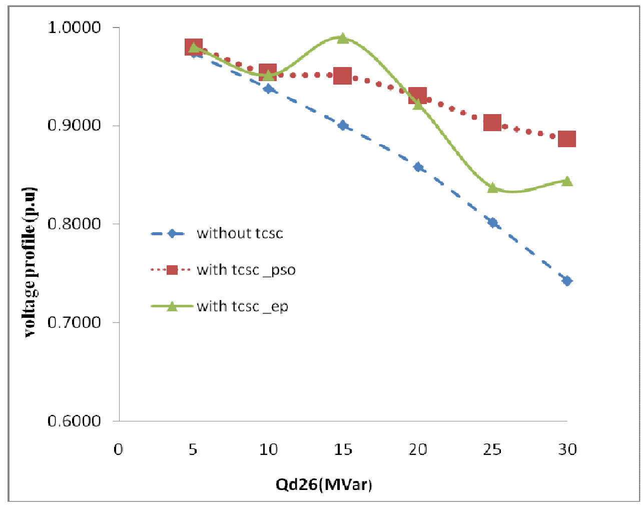

Fig. 6. Results for Voltage Profile When Load Variation at Bus 26

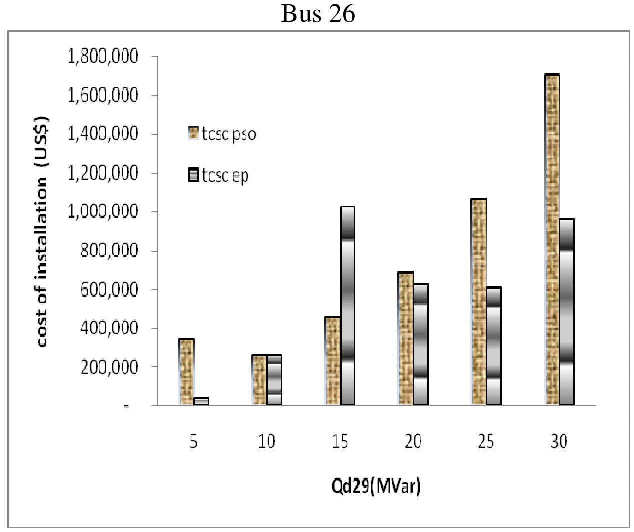

Fig. 7. Results of Cost Installation When Load Variation at Bus 29

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