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COMPUTATIONAL INTELLIGENCE BASED TECHNIQUE IN MULTIPLE FACTS DEVICES INSTALLATION FOR POWER SYSTEM SECURITY

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ABSTRACT

This paper presents a study on optimal location and sizing of multiple FACTS devices based on Particle Swarm Optimization (PSO) for minimization of transmission losses, and voltage profile improvement, which takes into account the cost of installation. In this study, Static Var Compensator (SVC) and Thyristor Controlled Series Compensator (TCSC) are chosen as the compensating device for the purposes of maintaining security in power system. Simulations for various loading conditions at several load buses have been conducted in order to evaluate its robustness and feasibility for broad implementation. In addition, installation of several FACTS devices into the system has been also conducted in the attempt to evaluate their impact to the system in terms of loss reduction and voltage profile improvement. Validation through the application on the IEEE 30-bus system indicated that PSO is feasible to achieve the task. Results from the study are compared with those obtained from Evolutionary Programming (EP) method in the attempt to highlight its merit.

Keywords: *Flexible AC Transmission System (FACTS) device, optimal location (OL), optimal sizing (OS), power system security (PSS), particle swarm optimization (PSO).*

NOMENCLATURE

$P_{ij}^{l} + P_{ji}^{l}$	The transmission loss of line *l*,
P_{ji}^{l}	Active power flow from bus *i* to bus *j* of line
P_{ji}^{l}	Active power flow from bus *j* to bus *i* of line *l*
N_L	Number of transmission line.
IC	Cost of installation of FACTS device (US$)
C	Cost of FACTS device (US$/KVar)
S	The operating range of the FACTS device (MVar)
C_S, C_T	(US$/kVar)
Q_1	Reactive power flow through the branch before FACTS device installation.
Q_2	Reactive power flow through the branch after FACTS device installation.
X_{Line}	The reactance of the transmission line
r_{tcsc}	The coefficient which represents the degree of compensation by TCSC
v_i^{k+1}	Velocity of particle *i* at iterations.
w	Weight function.
c_1, c_2	Weight coefficient
$rand_1$, $rand_2$	Random number between 0 and 1
$s_i^{\,k}$	Current position of particle *i* at iteration k
P_{besti}	Best position of particle *i* th up to the current iteration
G_{besti}	Best overall position found by the particles up to the current iteration.
$w_{\max}$	Maximum weight equal to 0.9

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$w_{\min}$ Minimum weight equal to 0.4
$iter_{\max}$ Maximum iteration number
$iter$ Current iteration number

1. INTRODUCTION

Electric utilities are forced to manage the systems close to their thermal and stability limits due to major hurdles such as environmental, right-of-way and cost problems for the power transmission network expansion. Hence, there is an interest in better utilization of available capacities by installing Flexible AC Transmission Systems (FACTS) Devices such as static var compensator, thyristor controlled series compensator, thyristor controlled phase angle regulators and unified power flow controller. FACTS device by supervising the power flow in the network, can help to decrease the flows in heavily loaded lines, resulting in raised loadability, low system loss, improved stability of the network, reduced the cost of production and fulfilled contractual requirement. They can enable lines to flow the power near its nominal rating and maintain its voltage within the desired level while enhancing power system security during contingencies [1-5]. For a meshed network, an optimal location of FACTS device allows to control its power flow and also to improve the system loadability and the security [1]. The effect of FACTS device on power system security, realiability and loadability has been studied according to proper control objectives as reported in [4], [6-9]. Researchers have tried to find suitable location for FACTS device to improve power system security and loadability in [10-13].

The security of power system can be defined as its ability to withstand a set of severe but credible contingencies and to survive transition to an acceptable new steady state condition as reported in [14]. Security of a power system also refers to the degree of risk in its ability to survive imminent disturbances (contingencies) without interruption to customer service. It relates to robustness of the system to imminent disturbances and, hence, depends on the system operating condition as well as the contingent probability of disturbances as highlighted in [15].

This paper mainly focuses on the determination of optimal locations and sizings of multiple FACTS device using Particle Swarm Optimization (PSO), and Evolutionary Programming (EP) algorithm. The installation of FACTS device into the busdata or linedata system which directly affects the power flow solution in a system has been investigated. Tests were performed on the IEEE-30 bus system to realize the effectiveness of the proposed technique, while verification was conducted through comparative studies with EP.

2. POWER SYSTEM SECURITY

The power system networks have become more heavily loaded due to increase in load and larger interconnection, there will be a rise in the number of situation where power flow equations have either no real solution (unsolvable limits) or solution with violating operating limits such as voltage limits; especially, in contingency analysis and planning applications. The solution of the power flow problem has received much consideration over the last several decades. This is expected to its fundamental importance to power system analysis. Nevertheless, little attention has been focused on how to pick up situation where power flow equations have no real solutions and any attempt to operate the system there, probably results in the system instability and voltage collapse.

The non-convergence of any power flow method is usually not guaranteed as an unsolvable case. This situation cloud is due to either a poor initial guess or a case where no real solution exists. The later cases will be referred as unsolvable rather than no contingent to emphasize that be a problem is not just that a power flow did not converge, but rather than no solution exists.

In a given operating condition system slates can lie in any of the three regions as shown in Figure 1. The state can lie in the secure region (I) where the power flow equations have a solution and all system value (such as line flows, bus voltages) are within their limits. Normally this is the desired operating region for the system. The insecure region (II) is the set of points where power flows equations have a solution, but one or more limits are violated. Usually it is possible to operate the system (at least for a while) in this region. However, the unsolvable region (III) is the set of points where the power flow equations have no real solution [14].

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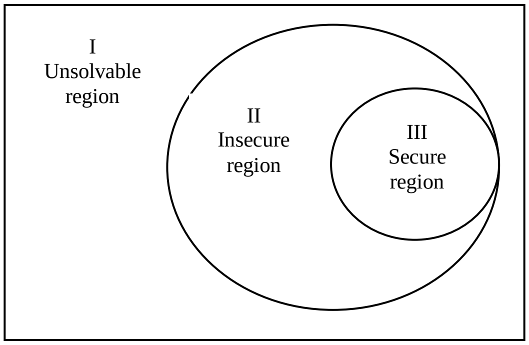

Figure 1: Power System security regions

3. PROBLEM FORMULATION

This section describes the problem formulation of single objective function using PSO and EP under loading conditions at several load buses in the system.

3.1 Objective Function

The objective function is in term of the transmission loss. Mathematically, it is formulated as follows:

$$\min \sum_{l=i}^{N_L} \left(P_{ij}^l + Q_{ij}^l \right) \qquad (1)$$

3.2 Cost Function of FACTS Device.

Optimal placement and sizing of FACTS device considering the cost of installation of FACTS device has been mathematically formulated and is given by equation (2):

$$IC = C \times S \times 1000 \qquad (2)$$

Using database of [16], cost function for SVC and TCSC are shown in Figure 2 and modeled as follows:

For SVC:

$$C_S = 0.0003S^2 - 0.3051S + 127.38 \qquad (3)$$

For TCSC:

$$C_T = 0.0015S^2 - 0.7130S + 153.7 \qquad (4)$$

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

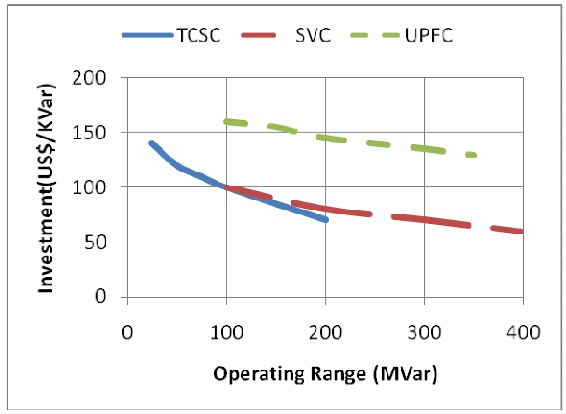

Figure 2 Cost Function of the FACTS devices: SVC, TCSC and UPFC.

4. MODELING OF FACTS DEVICE

In this research, two different FACTS devices have been selected to be installed at the suitable location. The optimal sizing is meant to reduce the transmission loss of the system. These devices are: SVC (Static Var Compensator) and TCSC (Thyristor Controlled Series Compensator).

Power flow through the transmission line *i-j* namely P_{ij} which depends on the line reactance, X_{ij}, the bus voltage magnitudes V_i, and V_j, and phase angle between sending and receiving buses δ_i and δ_j, is expressed by (6).

$$P_{ij} = \frac{V_i V_j}{X_{ij}} \sin\left(\delta_i - \delta_j\right) \qquad (6)$$

TCSC can change line reactance and SVC can be used to control the bus voltage. Power flow can be controlled and optimized by changing power system parameter using FACTS devices. Therefore, optimal device, allocation and sizing of FACTS device can result in suitable utilization of power system [17].

In this paper, steady state model of FACTS device are developed for power flow studies. SVC is modeled using the power injection model. TCSC is modeled simply to just modify the reactance of transmission line.

4.1 Static Var Compensator (SVC)

SVC can be used for the both inductive and capacitive compensation. In this research, SVC is modeled as an ideal reactive power injection at bus *i* as shown in Figure 3 and Figure 4. The SVC consists of a combination of a fixed capacitors and reactors. Thyristor switched capacitors and thyristor controlled reactors (TCR) in parallel with the power system. From an operational point of view, the SVC behaves like a shunt connected variable

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reactance, which either generates or absorbs reactive power in order to regulate the voltage magnitude at the point of connection to the AC network. It is used extensively to provide fast reactive power and voltage regulation support. The TCR is reactive impedance, X_L, with a bidirectional thyristor valves. The controllable reactance of the TCR part is X_V, which is defined by (7).

$$X_V = X_L \frac{\pi}{2\pi - 2\alpha + \sin(2\alpha)} \quad (7)$$

where α is the firing angle of the thyristor.

The SVC equivalent susceptance is [18],

$$B_{SVC} = \frac{X_L - \frac{X_C}{\pi}\left(2(\pi-\alpha)+\sin(2\alpha)\right)}{X_C X_L} \quad (8)$$

and the reactive power equation is

$$Q_i^{SVC} = -V_i^2 B_{SVC} \quad (9)$$

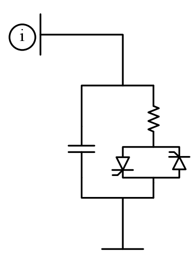

Figure 3 Model of SVC

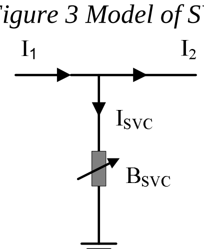

Figure 4 Block diagram of SVC

4.2 Thyristor Controlled Series Compensator (TCSC)

The model of the network with TCSC is shown in Figure 5 and Figure 6. The TCSC consists of a capacitor bank and a thyristor controlled inductive branch connected in parallel and series connected to the transmission line. The controllable reactance, X_{TCSC}, is directly used as the control variable that can be determined by:

$$X_{TCSC} = \frac{X_C X_L}{\frac{X_C}{\pi}\left[2(\pi-\alpha)+\sin(2\alpha i)\right] - X_L} \quad (10)$$

The power flow equation of the branch can be derived as follows [17]:

$$P_{ij} = V_i^2 g_{ij} - V_i V_j [g_{ij}\cos(\delta_i-\delta_j) + b_{ij}\sin(\delta_i-\delta_j)] \quad (11)$$

$$Q_{ij} = -V_i^2 b_{ij} - V_i V_j [g_{ij}\sin(\delta_i-\delta_j) - b_{ij}\cos(\delta_i-\delta_j)] \quad (12)$$

where $g_{ij} = \frac{r_{ij}}{r_{ij}^2 + \left(x_{ij} + X_{TCSC}\right)^2}$,

$$b_{ij} = -\frac{x_{ij} + X_{TCSC}}{r_{ij}^2 + \left(x_{ij} + X_{TCSC}\right)^2}$$

The rating of TCSC depends on the reactance of the transmission line where the TCSC is located:

$$X_{ij} = X_{Line} + X_{TCSC},$$
$$X_{TCSC} = rtcsc \cdot X_{line}, \quad (13)$$

To avoid overcompensation, the working range of the TCSC is chosen between -0.8X_{Line} and 0.2X_{Line} [17, 18].

$$rtcsc_{min} = -0.8 \qquad rtcsc_{max} = 0.2$$

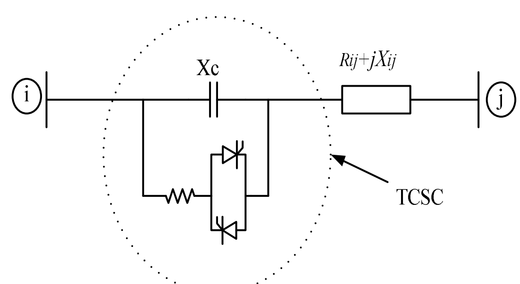

Figure 5 A Model of TCSC

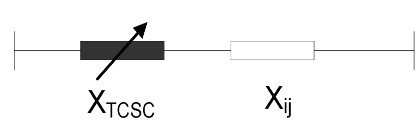

Figure 6 Block Diagram of TCSC

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5. OPTIMIZATION TECHNIQUES

In this section, the fundamental of PSO and EP algorithms and the ways how to relate FACTS device variables with PSO, and EP parameters will be explained briefly. The new category of computational intelligence tools has emerged to cope with some the conventional methods algorithms shortcomings. The modern techniques include genetic algorithms (GA), evolutionary programming (EP), artificial neural network (ANN), simulated annealing (SA), ant colony optimization (ACO), particle swarm optimization (PSO) and artificial immune system (AIS). These techniques have been successfully applied to a wide range of optimization problems in which global solutions are more preferred than local ones. Also, they are known for their capabilities of fast search of large solution spaces and ability to account for uncertainty in some parts of the power system networks [19].

5.1 Particle Swarm optimization (PSO)

PSO algorithm was originally developed by Kennedy and Eberhant based on the social behaviors of animal warms. PSO is developed through simulation of bird flocking or fish schooling in two-dimensional space. The position of each particle is represented by its *x*, *y* axis position and also its velocity is expressed by *v* (the velocity of *x* axis) and *vy* (the velocity of *y* axis). Modification of the particle position is realized by the position and velocity information. Bird flocking optimizes a certain objective function. Each particle has known its value as P_{best} and its *x*, *y* position. This information is an analogy of the personal experience of each particle. In addition, each particle knows the best value in the group is G_{best} among P_{best}. This information is an analogy of the knowledge of how the other particles around them have performed. Each particle tried to modify its position using the following information: the current position (*x*, *y*), the current velocities (*vx*, *vy*), the distance between the current position and P_{best}, and the distance between the current position and G_{best} [20]. The main advantage of swarm intelligence techniques is that they are impressively resistant to the local optimal problem. Also, PSO is employed mostly because it is simple in concept, easy to implement, efficient and a flexible mechanism to enhance global and local exploration abilities. From [21], the main merits of PSO are simplicity in concept implementation, computationally efficient, and robustness to control parameters. The step by step algorithm for the proposed optimal location and sizing of FACTS device is given below:

Step 1: Set the loads condition, Q_{load} at weak bus before FACTS devices installation (base case value). Set the loss and voltage constraints, i.e $loss1 \le loss\_0$ and $voltage1 \ge voltage\_0$. This is to ensure that all the generated initial populations satisfy all the equality and inequality constraints.

Step 2: Initialize the related parameters, such as the population size, the size of particle, the maximum number of iteration, and the power flow data included linedata and busdata system.

Step 3: An initial population is randomly generated to consider the variable that should be optimized (the locations, and the sizings of multiple FACTS devices). The random numbers, *x* as a control variables of multiple FACTS devices ($x_1, x_2, \ldots x_{nm}$) where $x_1, \ldots x_5$ are the locations of multiple FACTS device and $x_6, \ldots x_{10}$ are the sizings of multiple FACTS devices.

$$[X_{at}] = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ \vdots & \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix} \qquad (14)$$

where: *n* is population size

Step 4: Calculate fitness I. Fitness is computed for each particle. Determine the $P_{best\ old}$ and $G_{best\ old}$ value and it is stored in ascending order to the purpose of minimization of loss. $P_{best\_old} = min(x_1, \ldots x_{10})\_old$ and $Fitness\ 1 = Loss_{min\_old}$

Step 5: Update the velocity and position of the particle according the equations (15), (16) and (17). Velocity of each particle can be modified by using (15) [22-24]:

$$v_i^{k+1} = w \times v + c_1 \times rand_1 \times (P_{best_i} - s_i^k) + c_2 \times rand_2 \times (G_{best_i} - s_i^k) \qquad (15)$$

Weight function is given by (16) [25], [22-23], [26-28]:

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} \times iter \qquad (16)$$

The new position can be modified using (17):

$$s_i^{k+1} = s_i^k + v_i^{k+1} \qquad (17)$$

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Step 6: Calculate the fitness 2 and determine the P_{best_new} and G_{best_new} value and it is stored. $P_{best\_new} = min(x_1,\ldots x_{10})\_new$ and $fitness\ 2=Loss_{min\_new}$.

Step 7: Convergence criterion. The convergence criterion determined by $Loss_{min\_new} << Loss_{min\_old}$. If not, repeat Steps 5 – 7 until stopping criterion, as such sufficiently excellent $Loss_{min}$ fitness or a maximum numbers of iteration is met.

Step 8: Calculate the cost of installation multiple FACTS devices using the equations (2) – (5).

Step 9: End the PSO process.

5.2 Evolutionary Programming (EP)

The EP is one of the artificial intelligence techniques which were aspired from natural selection process to find the global optimum of complex problem [29]. Its evolutionary algorithms are based on computational models of fundamental evolutionary processes such as initialization, mutation, selection and reproduction. This method has been thoroughly discussed since its introduction by Fogel in 1960 [30]. In [31], proposed EP to determine the optimal location of FACTS devices for maximizing the total transfer capability (TTC) of power transaction between source and sink area in deregulated power system. EP simultaneously searches for FACTS locations, FACTS parameters, and real power generations, real power loads in sink area and generation bus voltages. In [32], proposed algorithm for solving security constrained optimal power flow problem through the application of EP. In this work, the implemented EP technique can be described as follows:

Step 1: Set the loads condition, Q_{load} at weak bus before FACTS installation. Set the loss and voltage constraints, i.e $loss1 \le loss\_0$ and $voltage1 \ge voltage\_0$. This is to certify that all the generated initial populations satisfy all the equality and inequality constraints.

Step 2: Initialize the related parameters, such as the population size, the maximum number of iteration, and the power flow data included busdata and linedata system.

Step 3: An initial population is randomly generated to consider the variable that should be optimized (the location and the sizing of multiple FACTS device) such as equation (14). The variable, t indicates is population size from a set of random distributions ranging from x_{tn}^{min} to x_{tn}^{max} … x_{tn+9}^{min} to x_{tn+9}^{max}.

Step 4: Calculate the fitness I by running ac load flow program to evaluate transmission loss values. Determine minimum loss and maximum loss for statistical evaluation. Fitness for each variable in the population is evaluated. In this research, the objective function would not be a single mathematical equation but rather a subroutine which was executed accordingly in the EP main program. Eventually, evaluation of maximum, and minimum, of fitness is carried out, which will be utilized in the mutation process.

Step 5: Mutate the parent and generate offsprings. During mutation, the Gaussian mutation operator is performed to generate new population (offspring) to the selected individual, $x_{i,j}$ randomly by using a standard deviation, where γ which is the square root of the variance. The mutation process was implemented based on the following equation

$$x_{i+m,j} = x_{i,j} + N(0,\gamma^2)$$
$$\gamma^2 = \beta(x_{j\max} - x_{j\min})\left(\frac{f_i}{f_{\max}}\right) \qquad (18)$$

The β value can be manually adjusted to achieve better convergence. The lower value of β, convergence of EP is expected to occur more quickly vice versa. Also, it is represented in the following detail:

$$[\lambda_{at}] = \begin{bmatrix} \lambda_{11} & \lambda_{12} & \cdots & \lambda_{1m} \\ \vdots & \vdots & \cdots & \vdots \\ \lambda_{n1} & \lambda_{n2} & \cdots & \lambda_{nm} \end{bmatrix} \qquad (19)$$

Step 6: Recalculate the fitness II using the offsprings. Calculate the fitness II by running ac load flow program to evaluate transmission loss values. Resolve minimum loss and maximum loss for statistical evaluation.

Step 7: Combine the parents and offsprings. It is a process which combines the parents and offsprings in cascade mode. It is represented in the following general equation:

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$$[\Gamma]=\begin{bmatrix} x_{at} \\ \lambda_{at} \end{bmatrix} \quad (20)$$

Thus:

$$[\Gamma]=\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ \vdots & \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \\ \lambda_{11} & \lambda_{12} & \cdots & \lambda_{1m} \\ \vdots & \vdots & \vdots & \vdots \\ \lambda_{n1} & \lambda_{n2} & \cdots & \lambda_{nm} \end{bmatrix} \quad (21)$$

Matrix size = [2*t* × 2]

Step 8: Perform selection by a tournament process. EP employs a selection through the tournament scheme as to choose the survivals to the next generation. This selection is used to identify the candidates that can be transcribed into the next generation, and the others will be removed from the pools. The process continues until the solution converges.

Step 9: Convergence test is important to determine the stopping criteria of the evolution. The pre-determined accuracy is normally dependent on the problem orientation. The convergence criterion is defined as the difference between the maximum and minimum fitness of the objective function. The optimal solution is achieved when there is no significant changed between the new generation and the last generation. The $fitness_{max}$ and $fitness_{min}$ represent the maximum and minimum values of the objective function inside a given parent generation. The mathematical equation is given as follows:

$$fitness_{max} - fitness_{min} \leq 0.01 \quad (22)$$

Step 10: Calculate the cost of installation for multiple FACTS device using equations (2) – (5)

Step 11: End the EP process.

6. RESULTS AND DISCUSSIONS

In order to realize the effectiveness of the proposed PSO and EP technique, the IEEE 30-Bus System was tested to determine the placement and sizing of multiple FACTS device. The busdata and linedata of the IEEE 30-Bus System are given in [20]. The parameters of the optimization algorithm are listed in Table I [26,] [33], [22], [23]. The FACTS device installations in the power system the for the transmission loss minimization in the system have been conducted at several load conditions subjected to bus 26 and bus 29.

Table 1: Parameters of Optimization Techniques

Parameters	PSO
Population Size	20
Inertial Weight, *w*	0.4 until 0.9
c_1	3
c_2	3
Number of iteration	100
$rand_1$	0 to 1
$rand_2$	1 to 1

6.1 Case 1: Installation of Multiple SVCs with Load Variation at Bus 26

Result for transmission loss reduction when bus 26 is subjected to load variation until 20MVar are tabulated in Table II and Table III. The location and sizing of SVCs to achieve loss reduction at 20MVar can be referred to the same table. The results for number, location, and sizing of SVCs to minimize transmission loss with 20MVar at bus 26 using PSO technique are tabulated in Table II. For instance, the transmission loss reduced to 17.4727MW when five units of SVCs are installed in the system. In order to achieve this value, the locations of SVCs are bus 24, bus 26, bus 18, bus 26 and bus 11 which the sizings for SVCs are 13.7442MVar, 19.4690MVar, 90.4474MVar, 18.6605MVar and 5.0615MVar. Besides that at the same loading condition, the EP technique only manages to reduce the transmission loss to 17.5542MW when three units of SVCs are installed as tabulated in Table III. In order to achieve this value, the location of SVCs are bus 26 and bus 29 which the sizings of SVCs are 8.2638MVar, 89.4036MVar and 6.0064MVar.

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6.2 Case 2: Installation of Multiple TCSCs with Load Variation at Bus 26

Result for transmission loss reduction when bus 26 is subjected to load variation until 20MVar are tabulated in Table IV and Table V. The location and sizing of TCSCs to achieve loss reduction at 20MVar can be referred to the same table. The results for numbers, locations, and sizings of TCSCs to minimize transmission loss with 20MVar at bus 26 using PSO technique are tabulated in Table IV. For instance, the transmission loss reduced to 19.6910MW when five units of TCSCs are installed in the system. In order to achieve this value, the locations of TCSCs are line-5, line-34, line-17, line-26, line-34 and line-26 which the sizing for TCSCs are -0.3649p.u, 0.1033p.u, -0.1224p.u, -0.3383p.u., and -0.0787p.u. Besides that; at the same loading condition, the EP technique can only manage to reduce the transmission loss to 19.9687MW when three units of TCSCs are installed as tabulated in Table V. In order to achieve this value, the location of TCSCs are line-39, line-34 and line-36 with the TCSCs sizing of 0.0435p.u., -0.2205p.u, and -0.4090p.u. From Table II until Table V: installation of SVCs at load bus is found to be the most suitable to achieve the best performance in transmission loss reduction optimized using PSO. Figure 7 shows the results of cost of installation for FACTS devices and voltage profile at to 20MVar load subjected to bus 26. From the graph it is shown that with the installation of TCSCs at load bus the cost less than SVC installation. However, with the SVC installation at load bus system the voltage profile improvement is better with TCSCs installation. With the SVCs installation, the voltage profile increases greater than 1.00p.u.

Table II: Results of Location and Sizing of SVCs when Q_{d26} = 20MVar Using PSO Technique.

LOSS (MW)	Qty	SVCs LOCATION (Bus)					SVCs SIZING (MVar)				
20.3393	0										
17.5543	1	27					19.6377				
17.6641	2	26	25				16.9737	14.0775			
17.5009	3	24	26	26			13.1069	97.1346	22.3052		
17.4727	**5**	**24**	**26**	**18**	**26**	**11**	**13.7442**	**19.4690**	**90.4474**	**18.6605**	**5.0615**

Table III: Results of Location and Sizing of SVCs when Q_{d26} = 20MVar Using EP Technique.

LOSS (MW)	Qty	SVCs LOCATION (Bus)					SVCs SIZING (MVar)				
20.3393	0										
17.6154	1	26					15.9568				
17.6882	2	26	26				44.1012	15.1048			
17.5542	**3**	**26**	**29**	**29**			**8.2638**	**89.4036**	**6.0064**		
17.6097	5	25	26	26	26	20	6.7310	46.2952	49.1343	11.5493	12.4869

Table IV: Results of Location and Sizing of TCSCs when Q_{d26} = 20MVar Using PSO Technique.

LOSS (MW)	unit	TCSC locations (line)					TCSCs SIZING (p.u)				
20.3393	0										
19.8915	1	35					-0.5474				
20.0914	2	36	5				-0.3608	-0.0645			
20.0755	3	25	21	34			-0.4006	-0.0875	-0.0768		
19.6910	**5**	**34**	**17**	**26**	**34**	**26**	**-0.3649**	**0.1033**	**-0.1224**	**-0.3383**	**-0.0787**

Table V: Results of Location and Sizing of TCSCs when Q_{d26} = 20MVar Using EP Technique.

LOSS (MW)	unit	TCSC locations (line)					TCSCs SIZING (p.u)				
20.3393	0										
19.8885	1	35					-0.5710				
20.4385	2	34	29				-0.2833	-0.0525			
19.9687	**3**	**39**	**34**	**36**			**0.0435**	**-0.2205**	**-0.4090**		
20.0210	5	32	26	13	15	36	-0.0017	-0.1648	-0.2499	-0.0637	-0.2279

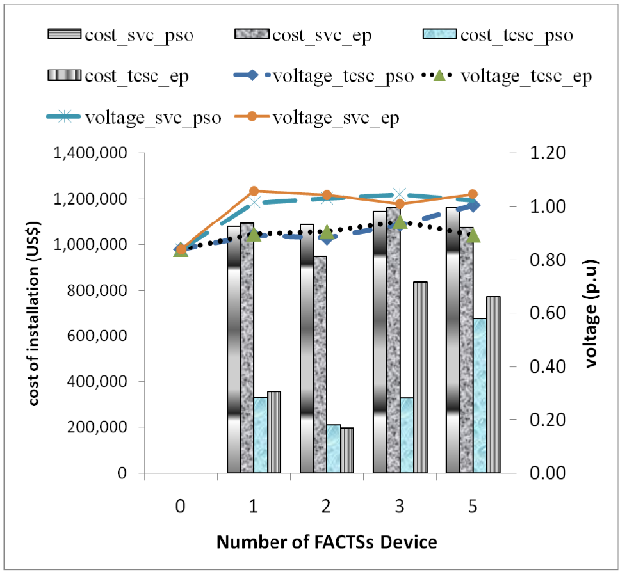

Figure 7 Results of Cost of Installation FACTS Device and Voltage Profile Improvement at Q_{d26}=20MVar

6.3 Case 3: Installation of Multiple SVCs with Loading Variation at Bus 29

Result for transmission loss reduction when bus 29 is subjected to load variation until 20MVar are tabulated in Table VI and Table VII. The number, location and sizing of SVCs to achieve loss reduction at 20MVar can be referred to the same table. The results for number, location, and sizing of SVCs to minimize transmission loss with 20MVar at bus 29 using PSO technique are tabulated in Table VI. For instance, the transmission loss reduced to 17.4928MW when three units of SVCs are installed in the system. In order to achieve this value, the locations of SVCs are bus 29, bus 22, and bus 29, with SVCs sizing of are 57.4949MVar, 13.4347MVar and 24.12MVar. Besides that; at the same loading condition, the EP technique can minimize the transmission loss to 17.4910MW when three units of SVCs are installed as tabulated in Table VII. In order to achieve this value, the locations of SVCs are bus 29, and bus 21 with SVCs sizing of 21.2509MVar, 63.0519MVar and 13.5685MVar.

6.4 Case 4: Installation of Multiple TCSCs with Loading Variation at Bus 29

Result for transmission loss reduction when bus 29 is subjected to load variation until 20MVar are tabulated in Table VIII and Table IX. The location and sizing of TCSCs to achieve loss reduction at 20MVar can be referred to the same table. The results for number, location, and sizing of TCSCs to minimize transmission loss with 20MVar at bus 29 using PSO technique are tabulated in Table VIII. For instance, the transmission loss reduced to 18.9329MW with two units of TCSCs being installed at the transmission line in the power system. In order to achieve this value, the locations of TCSCs are line-36 and line-11 with TCSCs sizing of -0.3706p.u, and -0.1538p.u. Besides that; at the same loading condition, the EP technique can minimize the transmission loss to 19.0111MW with one unit of TCSC is installed as tabulated in Table IX. In order to achieve this value, the location of TCSC is line-36 which the sizing of TCSC is -0.3076p.u. From Table VI until Table IX: installation the SVCs at load bus system is found to be the most suitable to achieve the best performance in transmission loss reduction optimized using EP. Figure 8 shows the results of cost of installation of FACTS device and voltage profile when the load increases to 20 MVar at bus 29. Similar phenomenon is observed as those for bus 26. From the graph it is shown that with installation of TCSCs at load bus the cost is less than SVC installation. However, with the SVC installation at load bus system the voltage profile improvement is better with TCSCs installation. With the SVCs installation, the voltage profile increases greater than 1.00p.u.

Table VI: Results of Location and Sizing of SVCs When Q_{d29} = 20MVar Using PSO Technique

LOSS (MW)	unit	SVCs LOCATION (Bus)					SVCs SIZING (MVar)				
19.4699	**0**										
17.5578	1	30					23.5453				
17.9635	2	27	29				33.4985	23.5477			
17.4928	**3**	**29**	**22**	**29**			**57.4949**	**13.4347**	**24.1200**		
17.5121	5	21	24	29	18	11	3.2724	61.1908	20.6143	10.9339	18.8218

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Table VII: Results of Location and Sizing of SVCs when Q_{d29} = 20MVar Using EP Technique.

LOSS (MW)	unit	SVCs LOCATION (Bus)					SVCs SIZING (MVar)				
19.4699	**0**										
17.5620	1	29					24.6541				
17.6229	2	29	21				16.2199	7.1064			
17.4910	**3**	**29**	**21**	**21**			**21.2509**	**63.0519**	**13.5685**		
18.2336	5	29	22	27	26	28	17.7123	36.7862	10.6258	12.9039	18.7038

Table VIII: Results of Location and Sizing of TCSCs when Q_{d29} = 20MVar Using PSO Technique.

LOSS (MW)	unit	TCSC locations (line)					TCSCs SIZING (p.u)				
19.4699	0										
19.0105	1	36					-0.3445				
18.9329	**2**	**36**	**11**				**-0.3706**	**-0.1538**			
19.0161	3	30	36	23			-0.1607	-0.3096	-0.2670		
19.1639	5	35	36	35	12	25	-0.186	-0.2024	0.0304	-0.1071	-0.1730

Table IX: Results of Location and Sizing of TCSCs when Q_{d29} = 20MVar Using EP Technique.

LOSS (MW)	unit	TCSC locations (line)					TCSCs SIZING (p.u)				
19.4699	0										
19.0111	**1**	**36**					**-0.3076**				
19.1222	2	29	36				-0.4804	-0.1932			
19.0342	3	34	36	32			-0.1285	-0.3215	-0.4329		
19.8071	5	21	23	13	23	36	-0.1069	-0.1380	0.0862	-0.5638	-0.3944

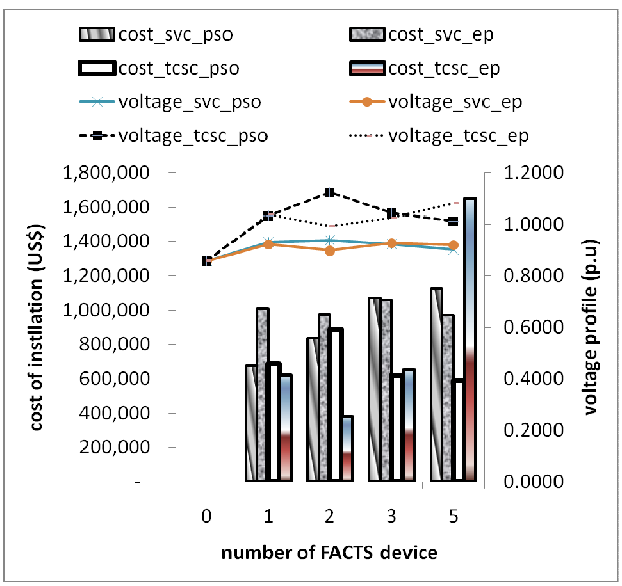

Fig 8 Results of Cost of Installation FACTS Device and Voltage Profile Improvement at Q_{d29}=20MVar

7. CONCLUSION

This paper has presented the application of particle swarm optimization and evolutionary programming techniques for loss minimization, voltage profile improvement and multiple FACTS devices installation cost. In this study, PSO, and EP methods are applied when loads are subjected to bus 26 and bus 30 of IEEE 30-Bus system for the minimization. Both the PSO and EP techniques performed well in most cases. Simulation results demonstrated that the proposed PSO technique is feasible for loss minimization scheme in other power system network. However, PSO is superior to EP in term of loss minimization. For future work, other FACTS devices such as UPFC, TCPAR and STATCOM can be incorporated together to achieve similar task.

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