Comparative Analysis of Multi Techniques in Loss Minimization Schemes for Power Transmission Planning

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Abstract
The demand for electricity in power system has been steadily increased due to the increasing urbanization around the world. Due to the limitation of equipment capacity and operation, the power system has been forced to operate under stress conditions. During this condition, the transmission losses are increasing resulted from the voltage decay phenomenon and limited the maximum power transfer capability. With the optimum location and sizing of Flexible AC Transmission System (FACTS) installation, this can provide to increase system transmission capacity, power flow flexibility and stability, controlling the voltage, and security of transmission lines. This paper presents allocation of FACTS device in transmission system for loss minimization using Multi Verse Optimization (MVO) algorithm. IEEE 30-bus system is used as the test system to validate the algorithm. The performance of MVO is analysed, based on optimal location and sizing of SVC to minimize power system loss. In this study, the effectiveness of MVO algorithm is compared with Evolutionary Programming (EP) and Particle Swarm Optimization (PSO). Comparison analysis demonstrates that MVO algorithm outperformed EP and PSO in achieving lower minimum losses.

Keywords: FACTS Device, Evolutionary Programming, Particle Swarm Optimization, Multi-Verse Optimization, Optimal Location and Sizing, Loss Minimization

Introduction

In recent years, highly complex interconnected power system required security and maximum power transfer capability in its operation. In condition of increasing load demand and dynamic load pattern, these can deteriorate voltage profile [1], limit the transmission capability during system disturbances and become power transfer limiting factor [2]. One of alternative is by using

Flexible Alternating Current Transmission System (FACTS) with an advance technology to improve the stability of transmission and various power system stability problems. As mentioned by N.G. Hingorani in [3], FACTS is static equipment used for the AC transmission of electrical energy and capable of controlling voltage, stability, power flow and security of transmission line.

The author in [1] reported that, FACTS device installation can improve the voltage profile, reduce line loadings, and line losses and provide reactive power support through modulating and reversing power flow. Also, FACTS device will act as a power network controller which will decrease the heavily loaded lines hence increasing its load ability. Simultaneously, this action will enhance the security and stability of the power system network [4]. Additionally, FACTS devices can also enhance the power transfer capability in the existing line. Without involving any modification on the existing generation or switching operation in the network, the power flow of the network can be controlled [5]. However, to gain benefits of utilizing FACTS devices, the installation of FACTS must be at a suitable location with optimal sizing.

Many optimization techniques have been deployed to find optimal location for FACTS device to solve manually in determining the capacity and placement of FACTS. This can offer better results solution to get provide optimal location and sizing of FACTS placement [6]. Hence, modern computational intelligent method has been proposed in [7] to overcome the shortcoming of conventional method which adopted population base, cooperative and competitive stochastic search algorithms [8]. Several methods and different metaheuristic algorithms have been proposed to optimize the placement and capacity of multi type of FACTS as mentioned in [9], [10]. In [11], PSO techniques has been employed to get optimal location of FACTS devices, with maximum load ability and low-cost installation and improve stability of transmission line. Others highlighted the comparison performance of PSO and EP techniques for optimal FACTS location and sizing [12], [13]. The author reported that PSO provide minimal losses than EP. However, the research analyzed [14], proved that the MVO can provide better optimization result rather than PSO.

This paper presents comparative analysis of MVO technique for loss minimization in power system by using SVC with EP and PSO. Optimization technique was adopted to optimize the SVCs location and sizing to be installed in the power transmission network.

Problem Formulation

The SVC is one of the shunt-connected FACTS controllers, which is widely utilized for the reactive power compensation in the transmission power systems. The output of the SVC can be regulated to exchange inductive or capacitive current to control a specific power system parameter [15].

In this paper, SVC is modelled as a reactive power injection device. The structure of the SVC is shown in

F. It consists of a capacitor bank connected in parallel to a thyristor-controlled reactor. The reactive power output of the SVC can be expressed as given below:

$$Q_i = -V_i^2 * B_{SVC} \tag{1}$$

Where V_i is the voltage magnitude of the i[th] bus and B_{SVC} represents the susceptance of the SVC. The value of B_{SVC} can be controlled by adapting the firing angle of the thyristor as given in reference [16]:

$$B_{SVC} = \frac{x_l - (2\pi - 2\alpha + 2\sin(2\alpha))\left(\frac{x_l}{\pi}\right)}{x_l x_c} \tag{2}$$

Where X_l and X_c are the reactance of the reactor and capacitor, respectively, and α represents the firing angle of the thyristors.

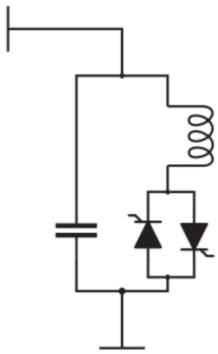

Figure 1. Schematic Diagram of SVC

The installation cost of SVC devices has been formulated and given by equation (3) [17]:

$$IC = C_{SVC} * S * 1000 \tag{3}$$

Where:

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

Installation of SVC device can be calculated using the cost function given in equation (4) and (5).

$$C_{SVC} = 0.0003S^2 - 0.3051S + 127.38 \tag{4}$$

$$S = |Q_2 - Q_1| \tag{5}$$

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

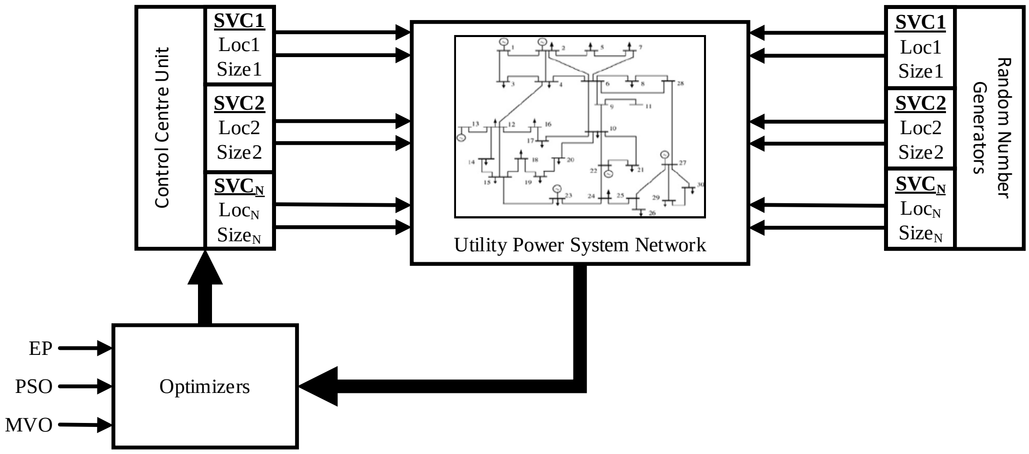

Figure 1. Conceptual Model for SVC Installation Schemes

Figure 1 shows the conceptual model for SVC installation schemes. In this figure, a random location and sizing of the SVC will be generated by the random number generators within the specified control variables. These variables are symbolize by x_1, x_2, …, x_n and L_1, L_2, …, L_n respectively and fed to the utility of the power system network. The variables will be utilized by optimizers which are EP, PSO or MVO to find the optimal location and size of SVC. The results will be monitored and saved by the control centre unit.

Evolutionary Programming

EP evolving a population of candidate solutions over a series of generations or iterations to find the optimum solution. Via the use of a mutation operator, a second new population from the original population is created at each iteration. By disrupting each part of an existing solution by a random number, this operator creates a new solution. The degree of optimality of each of the candidate solutions or persons is calculated by their fitness, which can be characterized as a function of the problem's objective function. To seek an ideal (minimum) solution, it is necessary to pay a great price in terms of emission and time. The mathematical formulation of these alternatives is continuously changing and improving. For the EP, the flowchart is shown in Figure 2. In general, EP usually requires initialization, mutation, fitness computation, combination, and selection.

i. Initialization - The random number parameters will created to represent the control parameters. It is known as five variables of real power generator, namely x1, x2, x3, x4 and x5.

ii. Offspring Mutation / Development - Mutation is a mechanism by which original populations (parents) are converted into offspring (children). These descendants are developed based on the Gaussian mutation approach by using equation (6)

$$X_{i+m,j} = X_{i,j} + \left(0, B\left(X_{j\max} - X_{j\min}\right)\right)\left(\frac{F_r}{F_{\max}}\right) \quad (6)$$

Where:

$X_{i+m,j}$ = mutate parent
$X_{i,j}$ = parent
β = range of mutations ($0 < \beta < 1$)
X_{jmax} = maximum random number for every variable
X_{jmin} = minimum random number for every variable
F_r = fitness for r^{th} random number
F_{max} = maximum fitness

iii. Selection/Tournament - The importance of this part is to minimize the generation cost in the system. The matric structure of the combination has become [2n x m]. The variable, n represents the number of individuals in the system become two times at this process, while m represents the number of the control variables.

iv. Check for convergence - To obtain the optimum solution, the stopping criterion determines the convergence of the optimization process. It will converge when the difference value is the smallest. If the convergence criterion is not reached, it would repeat the entire operation.

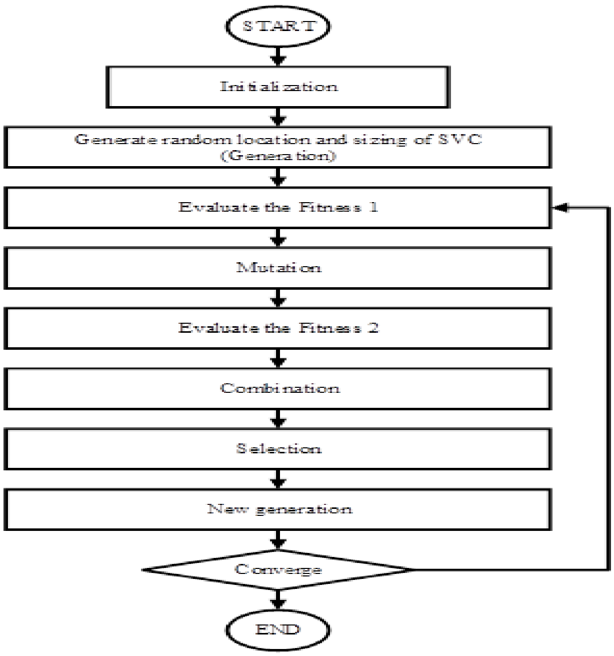

Figure 2. Flowchart of Basic Evolutionary Programming

Particle Swarm Optimization

PSO which originally invented by Kennedy, Eberhart and Shiand was first intended for simulating social behaviour, as a stylized representation of the movement of organisms in a bird flock or fish school. The variables in PSO can take any values based on their current position in the particle space and the corresponding velocity vector. The flowchart for the PSO is shown in Figure 3. Position of the individual particles are updated as in equation (7) [18]:

Where:

$$v_i^{k+1} = w * v + c_1 * rand_1 * \left(P_{best,i} - S_i^k\right) + c_2 * rand_2 * \left(G_{best,i} - S_i^k\right) \qquad (7)$$

Where:

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

w = weight function

c = weight coefficient

rand = random number between 0 and 1

S_i^k = current position of particle i at iteration k

P_{best} = best position of particle ith up to the current position

G_{best} = best overall position found by the particle up to the current position.

Weight function is given by (8)

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} * iter \qquad (8)$$

Where:

w_{max} = initial weight equal to 0.9

w_{min} = initial weight equal to 0.4

$iter_{max}$ = maximum iteration number

iter = current iteration number

The new position can be modified by using equation (9)

$$s_i^{k+1} = s_i^k - v_i^{k+1} \qquad (9)$$

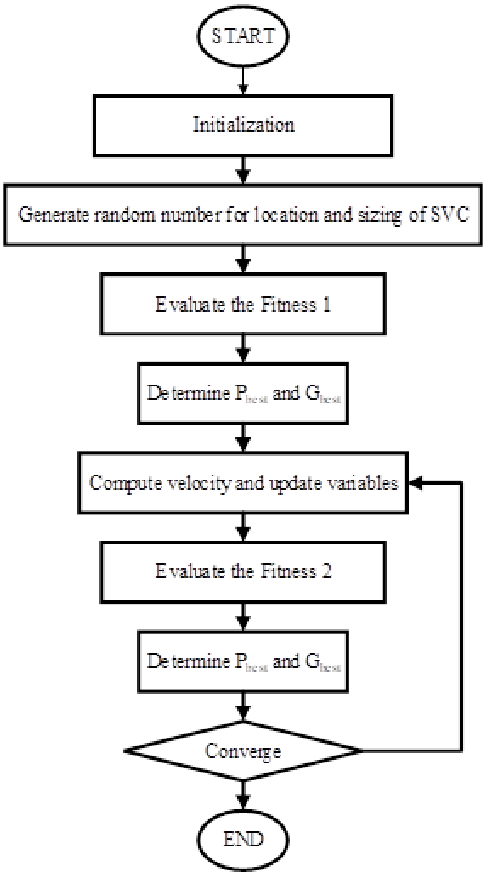

Figure 3.Flowchart of Particle Swarm Optimization

Multi-Verse Optimization (MVO)

Syedali Mirjalili [19] proposed Multi Verse Optimization (MVO) in 2015. MVO is based on the theory of multiple universes and the big bang. Figure 4 illustrates the three fundamental concepts of MVO, which are:

1. White hole
2. Black hole
3. Worm hole

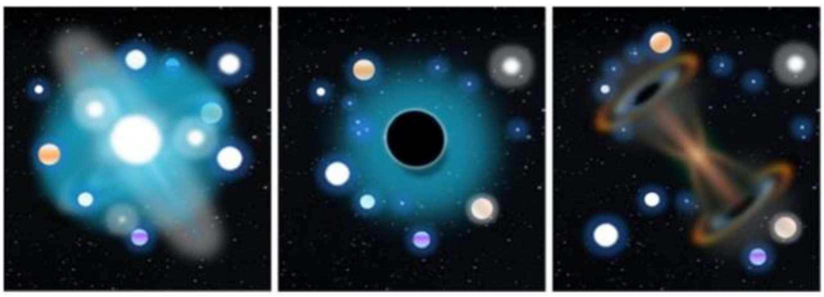

Figure 4. Image of White Hole, Black Hole, and Worm Hole

According to the Multi verse theory, big bang is considered as white hole and it not spotted in the universe. It may be the main source of universe. Black hole is spotted in the universe. It pulls the objects of the universe inside. Lastly, wormhole is a tunnel between two universes. The objects are travelling between the universes through these tunnels. Each universe contains inflation rate. By the inflation rates, the fitness value is calculated. The position of the universe has been updated by the following formula [20]:

Worm hole existence probability:

$$(WEP) = \min + n * \left(\frac{\max - \min}{L} \right) \tag{10}$$

Travelling distance rate:

$$(TDR) = 1 - \left(\frac{n^{\frac{1}{P}}}{L^{\frac{1}{P}}} \right) \tag{11}$$

Where L is maximum iteration, n is the current iteration, min and max are constants (min = 0.2, max = 1). P is exploitation accuracy constant (P = 6). The best universe constants more WEP values and less TDR values it. Figure 5 shows the flowchart of MVO for optimal location and sizing of FACTS Devices. The inflation rate of this study will be loss minimization of the system.

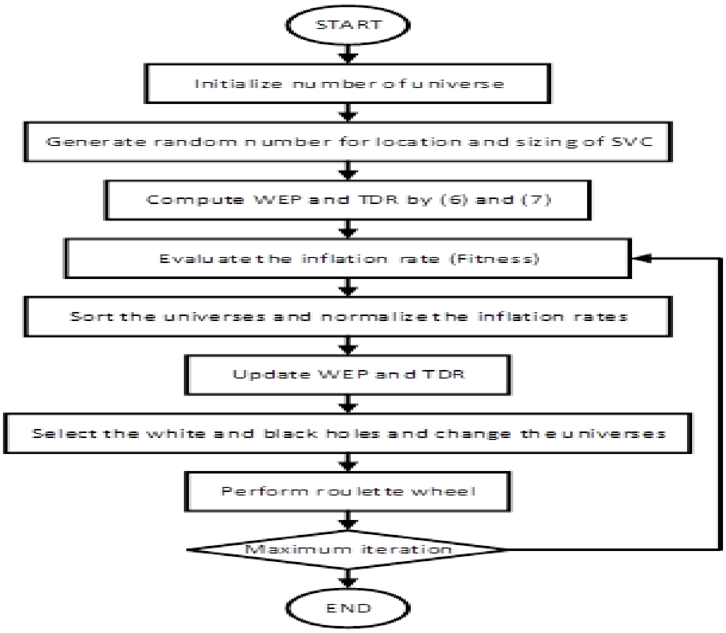

Figure 5. Flowchart of Multi Verse Optimization

Result and Discussion

The IEEE 30-bus RTS was utilized to test the MVO's effectiveness in resolving the FACTS device allocation by using MATLAB. The single line diagram of the test system is shown in Figure 6. The system consists of 41-branches, 6 generators buses and 22 load buses. The effects of SVC installations in transmission system were simulated with different load variations which are 5MVar to 30 MVar. These load variations, then is analyzed at three different buses, proposed as:

Case 1: Load variation at Bus 26
Case 2: Load variation at Bus 29
Case 3: Load variation at Bus 30

These buses are the weak load buses in the system which having among the lowest in maximum loadability condition [21]. In order to analyze the performance of the MVO in optimally locating and sizing the SVC over the load variation, comparative analysis with PSO and EP algorithm is carried out. The analysis will include 2 parts: Loss reduction with SVC installation and Comparative analysis with other techniques.

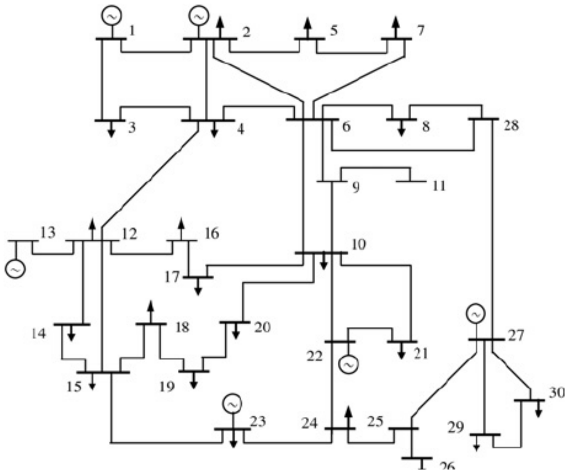

Figure 6. Single Line Diagram for IEEE 30-Bus Reliability Test System (RTS)

A. Loss Reduction with SVC Installation

In this section, the MVO techniques has been simulated to get the optimal location and sizing of SVC. The pre and post value of transmission loss for SVC as well as the cost of SVC installation for Bus 26, 29 and 30 subjected to different load variations is tabulated in **Error! Reference source not found.** until **Error! Reference source not found.** respectively.

For instance, in **Error! Reference source not found.**; with loading condition of 30MVar, the transmission loss has been reduced from 26.518MW to 17.541MW. To achieve this, the sizing of SVC is optimized to 31.450MVar as indicated in the table. The cost of installation at this scenario is US$3.714M.

Apart from that, the relationship between loss minimization and cost is analyzed for buses 26, 29 and 30 for all load variation cases. It is clearly seen that, the value of transmission losses is decreased, and the cost of installation is increased accordingly, as the reactive power loading is increased for all load variation at buses 26, 29 and 30. Hence, the implementations of MVO have reduced the transmission loss of the system indicating it as a feasible technique to perform optimization process in practical system

Table 1. Case 2 - Load Variation at Bus 29

Q Load Cond.	Loc.	SVC Sizing	Loss before	Loss after	SVC Cost [US$]
5	29	8.2473	17.717	17.557	1.030M
10	29	13.246	18.278	17.557	1.635M
15	29	18.243	19.062	17.557	2.224M
20	29	23.253	20.339	17.557	2.801M
25	29	28.252	22.632	17.557	3.362M
30	29	33.246	26.518	17.557	3.909M

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Table 1. Case 1 - Load Variation at Bus 26

Q Load Cond.	Loc.	SVC Sizing	Loss before	Loss after	SVC Cost [US$]
5	26	6.449	17.717	17.541	0.808M
10	26	11.450	18.278	17.541	1.419M
15	26	16.455	19.062	17.541	2.015M
20	26	21.454	20.339	17.541	2.595M
25	26	26.448	22.632	17.541	3.161M
30	26	31.450	26.518	17.541	3.714M

Table 1. Case 3 - Load Variation at Bus 30

Q Load Cond.	Loc.	SVC Sizing	Loss before	Loss after	SVC Cost [US$]
5	30	7.283	17.717	17.550	0.911M
10	30	12.284	18.278	17.550	1.519M
15	30	17.282	19.062	17.550	2.112M
20	30	22.287	20.339	17.550	2.691M
25	30	27.278	22.632	17.550	3.254M
30	30	32.282	26.518	17.550	3.804M

B. Comparative Analysis with other techniques

In this case, the comparative studies have been conducted with respect to the results obtained from three different optimization methods which is MVO, PSO and EP as tabulated in **Error! Reference source not found.** until **Error! Reference source not found.** for bus 26, 29 and 30 respectively. By using these optimization methods, the loss of transmission line is compared during pre and post installation with different load variations.

In **Error! Reference source not found.** at loading condition of 5MVar; EP managed to reduce the transmission loss from 17.717MW to 17.541MW, where it is contributed 0.47% loss reduction, while for MVO contributed 0.99%, from 17.717MW to 17.633MW. Based on this, MVO contributed much more higher loss reduction value compared to EP. However, for 10 MVar to 30 MVar load variations, MVO and PSO presented same loss reduction value which much higher compared to EP as shown in **Error! Reference source not found.** until **Error! Reference source not found.**.

Table 1. Case 1 - Load Variation at Bus 26

Q Load Cond.	Pre – Ins.	Post - Installation					
		MVO		PSO		EP	
	Loss (MW)	Loss (MW)	% of load reduction	Loss (MW)	% of load reduction.	Loss (MW)	% of load reduction.
5	17.717	17.541	0.99	17.581	0.77	17.633	0.47
10	18.278	17.541	4.03	17.541	4.03	17.614	3.63
15	19.062	17.541	7.98	17.541	7.98	17.913	6.03
20	20.339	17.541	13.76	17.541	13.76	18.750	7.81

Table 1. Case 2 - Load Variation at Bus 29

Q Load Cond.	Pre – Ins.	Post - Installation					
	Loss (MW)	MVO		PSO		EP	
		Loss (MW)	% of load reduction	Loss (MW)	% of load reduction.	Loss (MW)	% of load reduction.
5	17.717	17.557	0.90	17.588	0.73	17.597	0.67
10	18.278	17.557	3.94	17.557	3.94	17.777	2.74
15	19.062	17.557	7.89	17.557	7.89	18.031	5.40
20	20.339	17.557	13.68	17.557	13.68	17.999	11.50
25	22.632	17.557	22.42	17.557	22.42	17.763	21.51

The results for buses 29 and 30 are tabulated in **Error! Reference source not found.** and **Error! Reference source not found.** respectively. At 30MVar, it is clearly observed that the loss minimization simulated based on EP technique is 33.58% and 26.11%. MVO and PSO gave the same result which are 33.79% and 33.82% respectively. We can obviously see that MVO and PSO gave better results than EP in all cases. It should be noted that, the loss reduction value resulted from these 3 optimization techniques is increased with respect to the load variation.

Table 1. Case 3-Load Variation at Bus 30

Q Load Cond.	Pre – Ins.	Post – Installation					
	Loss (MW)	MVO		PSO		EP	
		Loss (MW)	% of load reduction	Loss (MW)	% of load reduction.	Loss (MW)	% of load reduction.
5	17.717	17.550	0.94	17.550	0.94	17.610	0.60
10	18.278	17.550	3.98	17.550	3.98	17.797	2.63
15	19.062	17.550	7.93	17.550	7.93	18.094	5.08
20	20.339	17.550	13.71	17.550	13.71	18.572	8.69

Moreover, **Error! Reference source not found.** shows the simulation running time for each case studies. This simulation is carried out using MATLAB R2018b in Windows 10 (64-bit) operating system, Intel® Core™ i7-600U and 12GB memory. Though MVO and PSO presented similar results previously, in Table 7 it is obviously showed MVO are faster than PSO and EP. Additionally, PSO normally being trap at local optima which is not effective for large system.

Table 1. Simulation Time for Each Algorithm

Bus	Q Load Cond.	MVO (sec)	PSO (sec)	EP (sec)
26	5	41.5	164.7	105.2
	10	51.0	201.6	86.3
	15	51.1	240.3	84.4
	20	60.6	226.0	86.8
	25	60.4	203.3	82.5
	30	60.4	108.2	82.7
29	5	59.5	97.6	86.6
	10	39.0	99.4	81.7
	15	33.3	99.8	75.9
	20	60.5	99.5	63.7
	25	61.3	99.7	63.6
	30	55.6	99.8	63.4
30	5	41.7	101.3	65.2
	10	38.7	99.4	64.7
	15	33.3	99.7	64.1
	20	44.0	100.2	74.4
	25	60.1	100.7	62.9
	30	59.1	101.2	59.2

Conclusion

This paper discussed the comparative between MVO, PSO and EP approach to reduce the power loss of transmission line. The comparison has been done by giving the different load variations and observed the result at the weakest bus which are Buses 26, 29, and 30 of IEEE 30-Bus RTS for find optimal location and sizing of SVC. The simulation results demonstrated the MVO offered more effective approach compared to PSO and EP techniques.

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