Journal of Fundamental and Applied Sciences

ISSN 1112-9867

Available online at http://www.jfas.info

Research Article

Σ-MULTI-OBJECTIVE EVOLUTIONARY PARTICLE SWARM OPTIMIZATION APPROACH FOR TRANSMISSION LOSS AND COST MINIMIZATION WITH SVC INSTALLATION

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Published online: 24 February 2018

ABSTRACT

This paper presents sigma-multi-objective evolutionary particle swarm optimization (σ-MOEPSO) technique for optimal placement of Flexible AC Transmission Systems (FACTS) devices. The proposed MOEPSO technique has been implemented to minimize the transmission loss in the system and minimize the cost of investment FACTS device. Experiment has been implemented on IEEE 30-Bus RTS and IEEE 118- Bus RTS. On the other hand, for the comparison the proposed technique was compared with Multi-Objective Particle Swarm Optimization (MOPSO) and Multi-objective Evolutionary Programming (MOEP). The effects of optimization performance at several loading conditions are also investigating using three optimization techniques.

Keywords: Multi-Objective Optimization; Particle Swarm Optimization; Static Var Compensators; Power System Stability; Flexible AC Transmission Systems.

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doi: http://dx.doi.org/10.4314/jfas.v10i3s.61

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1. INTRODUCTION

In this century, high efficiency and safety in the design and operation of the power system are more significant than ever. Difficulty in constructing new transmission lines due to limits in their right to access, making it necessary to use the maximum capacity of the transmission line. For that reason, it would be difficult to provide voltage stability even in normal condition [1]. This is due to the facts that the current network capacity is not able to cater the increasing demand.

In the attempt to alleviate the problems, initiative has been put in place by EPRI 1970s with the main objective to provide power the electronics-based, real-time control for transmission systems [2]. Problem related to optimal location FACTS devices in power systems has been studied and discussed extensively and several strategies have been recommended. In [3], Abido et. al. has proposed a multi-objective particle swarm optimization (MOPSO) technique to solve the optimal power flow problem with minimization of fuel cost and voltage stability enhancement objectives. Besides that, in [4] Radu et. al. has conducted a study which focused on definition the location of FACTS device in system using Multi-objective Genetic Algorithm (MOGA) with objective function of maximization of system security and minimization of investment cost. R. Benabid et.al [5] applied the Non-dominate Sorting Particle Swarm optimization (NSPSO) to maximize the static voltage stability margin, reduce real power losses and load voltage deviation. In [6], an approach termed the NGSA-II method (Ellisit Non-Dominated Sorting Genetic Algorithms) to minimize two objective functions related to the total transmission active loss and the compensation device amount with optimal location of FACTS devices.

This paper mainly focuses on the determination of optimal allocation of FACTS device into power system, from both technical and economical point of view, in order to provide a better power system security. To carry out these multi criteria optimization problems, MOEPSO technique has been employed to optimize the multi-objective function. Implementation on two IEEE reliability test systems indicated that the proposed multi-objective optimization techniques can solve the power problem.

2. RESULTS AND DISCUSSION

In order to realize the effectiveness of the proposed MOEPSO, MOPSO and MOEP techniques, IEEE 30-Bus RTS was tested to find the allocation and size of FACTS device. The FACTS device installation in power system the for the transmission loss and cost of installation minimization in the system have been conducted at several load conditions subjected to bus 26, and 29 for IEEE 30-Bus RTS.

This system had 6 generator buses and 25 load buses with 41 interconnected lines and the single line diagram is illustrated in Fig. 2. The FACTS device installations in power system to improve the transmission loss and cost of installation in the system have been conducted at several load conditions subjected to buses 26 and 29. The buses 26 and 29 are the weak buses in IEEE 30-Bus RTS and also the best location to carry out any corrective action in order to increase its operating margin.

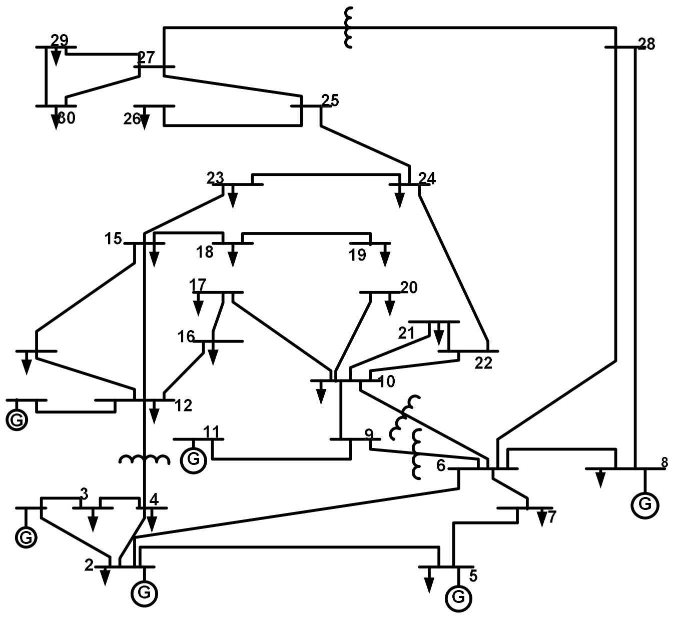

Fig.1. Single line diagram of IEEE 30-Bus system

A. Load variation at Bus 26

Results for MO problems when load is increased from 20MVar and 30MVar subjected to bus 26 using MOEPSO, MOPSO and MOEP tabulated in Table I. For example, when load is increased to 30MVar, the best results using MOEPSO technique is 17.70MW for transmission loss and US$2,935,800 for cost of installation with 8 units of SVC installation. While, the best results using MOPSO technique is 17.56MW (loss) and US$3,020,700 (cost) with 8 units of SVC installation. The best results using MOEP for the same case is 17.64MW (loss) and US$2,946,000(cost) also with 3 units of SVC installation. It can be observed that MOEPSO technique can be implemented to optimal the SVC installation. The results shown the cost of installation increased consequently as the transmission loss in minimized.

B. Load variation at Bus 29

Results for MO problems when load is increased from 10MVar and 30MVar is subjected at bus 29 using MOEPSO, MOPSO and MOEP are tabulated in Table II. For example, when load is increased to 30MVar, the best results using MOEPSO technique is 17.61MW for transmission loss and US$2,316,500 (loss) with 1 unit of SVC installation. Although, the best results using MOPSO technique is 17.44MW (loss) and US$2,481,800 (cost) with 8 unit of SVC installation. The best results using MOEP for the same case is 17.56MW (loss) and US$2,280,100(cost) with 3 unit of SVC installation. It can be observed that MOEPSO.

3. EXPERIMENTAL

3.1. Flexible AC Transmission System

Static Var Compensator (SVC) has two possible characteristics, capacitive and inductive and primarily utilized to improve voltage in static and dynamic conditions, reduce the reactive power loss, and enhance static margin. Fig. 1 shown that the drawn current by SVC can be expressed [1],[7],

$$I_{SVC} = jB_{SVC}V_k \tag{1}$$

The reactive power drawn by SVC that is the same as injected power to bus *k* is written as [7].

$$Q_{SVC} = Q_k = -B_{SVC}V_k^2 \tag{2}$$

Table 1. Results for Load Variation is Subjected at Bus 26

Load (MVar)	Technique	Location	Post-Installation	
			Loss (MW)	Cost (US$)
20	MOEPSO	25	18.94	1,080,900
		4,30,25	18.90	1,172,700
		8,8,26,13,9	18.16	1,476,300
		21,5,26,7,6,25,4,4	17.89	1,134,000
	MOPSO	26	17.75	1,290,200
		22,26,26	18.06	962,580
		28,23,23,26,22	17.62	1,112,500
		30,26,11,30,29,23,16,16	17.50	535,340
	MOEP	25	18.94	1,080,200
		9,26,10	17.79	569,910
		11,12,26,24,29	17.72	1,177,800
		11,12,28,22,27,23,26	18.06	1,039,400
30	MOEPSO	25	21.04	3,021,300
		8,25,7	21.51	3,098,300
		8,8,26,13,9	18.60	3,566,800
		11,8,3,8,30,10,25,7	17.70	2,935,800
	MOPSO	26	17.66	3,652,500
		6,16,26	18.63	2,763,500
		18,20,18,28,26	18.50	2,772,200
		29,29,19,26,28,24,23,9	17.56	3,020,700
	MOEP	25	21.05	3,020,700
		6,26,13	17.64	2,946,000
		26,13,29,22,29	17.65	2,976,000
		8,10,27,23,22,26,20,20	18.75	2,761,600

Note: Loss for pre-optimization when Qd26=20MVar is 20.33MW and Qd26=30MVar is 26.51MW

Table 2. Results for Load Variation is Subjected at Bus 29

Load (MVar)	Technique	Location	Post-Installation Loss (MW)	Post-Installation Cost (US$)
20	MOEPSO	29	17.59	1,009,600
		13,29,13	17.60	1,011,700
		11,12,19,27,10	18.88	3,531,800
		7,29,14,7,27,5,7,5	17.75	1,057,500
	MOPSO	29	17.65	935,200
		8,5,29	17.57	983,190
		11,14,29,6,18	17.60	1,052,400
		30,27,13,29,27,26,21,18	17.46	1,096,000
	MOEP	29	17.55	1,002,700
		27,4,29	17.48	1,072,900
		9,29,15,9,28	17.50	1,099,400
		8,10,23,20,21,20,24,29	18.05	941,890
30	MOEPSO	29	17.61	2,345,200
		27,4,29	17.67	2,382,600
		8,6,29,5,6	18.88	2,212,300
		7,29,14,7,27,30,22,11	18.23	2,254,000
	MOPSO	29	17.55	2,341,800
		13,29,22	18.75	1,939,900
		24,22,5,6,29	17.97	2,361,200
		29,27,27,28,27,21,21,4	17.44	2,481,800
	MOEP	29	17.64	2,280,100
		11,13,29	17.56	2,316,500
		9,29,15,8,30	17.71	2,338,700
		21,10,20,21,27,21,23,29	17.91	2,334,200

Note: Loss for pre-optimization when Qd29=20MVar is 19.46MW and Qd29=30MVar is 22.71MW

From [8], (3) to (5) are extra constraints are considered for determining the security margin while buses a and b belong to J_L.

$$g_b = P_{0b}V_b^{pb} + P_{injb} + \sum_{j=1}^{n} V_b V_j Y_{bj} \cos\left(\delta_b - \delta_j - \phi_{bj}\right) = 0 \tag{3}$$

$$g_a = P_{0a}V_b^{qa} + P_{inja} + \sum_{j=1}^{n} V_a V_j Y_{aj} \cos\left(\delta_a - \delta_j - \phi_{aj}\right) = 0 \tag{4}$$

$$h_b = Q_{0b}V_b^{qb} + P_{injb} + \sum_{j=1}^{n} V_b V_j Y_{bj} \cos\left(\delta_b - \delta_j - \phi_{bj}\right) = 0 \tag{5}$$

$$h_a = Q_{0a}V_a^{qa} + P_{inja} + \sum_{j=1}^{n} V_a V_j Y_{aj} \cos\left(\delta_a - \delta_j - \phi_{aj}\right) = 0 \tag{6}$$

These constraints are related to the power balance in load buses in locations where injection power exists. P_0V^p and Q_0V^q represent voltage dependency of loads and p, q ϵ {0, 1, 2}.

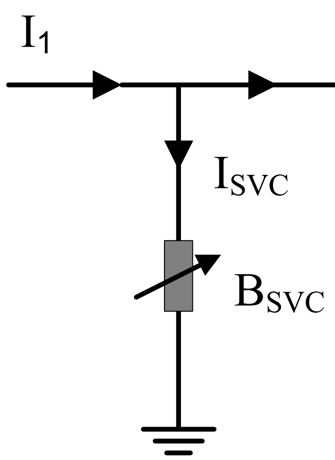

Fig.2. Current Flow Direction with SVC Installation

3.2 Multi-Objective Optimization Problem Formulation

The goal of optimization is to determination the optimal location of FACTS devices into a power system in order to enhance the system security level, and keeping in the same time a low investment cost for the new devices. Therefore, the presented problem becomes a multi-objective optimization problem, with two different criteria to be optimized and this can be expressed, as

$$\begin{aligned} &Min\ f(x)=\{f_1(x), f_2(x),\ldots, f_m(x)\} \\ &Under \\ &g_J(x)=0 \qquad J=1,\ldots,M \\ &h_k(x)\le 0 \qquad k=1,\ldots,K \end{aligned} \tag{7}$$

where f_m number of objectives; M, K are numbers of equality and inequality constraints, respectively and; x is decision vector [6].

A. Total Transmission Loss

The total transmission loss in the system is given by the following function:

$$f_1=\sum_{I=1}^{N_G} P_{GI}-\sum_{I=1}^{N_{PQ}} P_{DI} \tag{8}$$

where N_G is the number of generator buses and N_{PQ} is the number of load buses.

B. Compensation Devices Cost

As mentioned previously, it is important to take into account the economical aspects of the FACTS devices presence in the power systems due to high investment and operating costs. Hence, the economical objective function presented in (9) is represented by the total investment cost of SVC termed as C_{SVC}:-

$$f_2=C_{SVC}\times r_{re} \tag{9}$$

where r_{re} is the operating rate if the FACTS devices in MVar. The investment cost given in US$/kVar, are determined by the following relations [9 -10]:

$$C_{SVC}=0.0003r_{re}^2-0.3051r_{re}+127.38 \tag{10}$$

C. Equality Constraints

The constraints represent the typical load flow equation as follows:

$$\begin{aligned} &P_{GI}-P_{DI}-V\sum_{K=1}^{N}V_K\left(G_{IK}\cos\left(\delta_I-\delta_K\right)+B_{IK}\sin\left(\delta_I-\delta_K\right)\right)=0 \\ &Q_{GI}+Q_{CI}\cdot V_I^2-Q_{DI}-V_I\sum_{K=1}^{N}\left(G_{IK}\sin\left(\delta_I-\delta_K\right)-B_{IK}\cos\left(\delta_I-\delta_K\right)\right)=0 \end{aligned} \tag{11}$$

$$I = 1, \ldots, N$$

where N is the number of buses; P_{GI} and Q_{GI} are the generator real and reactive power; respectively, P_{DI} and Q_{DI} are the load real and reactive power, respectively; G_{ij} and B_{ij} are the transfer conductance and susceptance between bus i and bus j, respectively, σ_i is the phase and V_i is the voltage magnitude of the i^{th} bus [6].

D. Inequality Constraints

These constraints represent the system operating limits as follows:

$$\begin{aligned}
&V_{Imin} \le V_I \le V_{Imax} && I = 1, \ldots, N \\
&-0.8X_{ILINE} \le X_{ISVC} \le 0.2X_{ILINE} && I = 1, \ldots, N_L \\
&P_{GImin} \le P_{GI} \le P_{GImax} && I = 1, \ldots, N_G \\
&Q_{GImin} \le Q_{GI} \le Q_{GImax} && I = 1, \ldots, N_G \\
&T_{Kmin} \le T_K \le T_{Kmax} && K = 1, \ldots, N_T \\
&0 \le Q_{CI} \le Q_{CImax} && I = 1, \ldots, N_{PQ}
\end{aligned} \tag{12}$$

where N_T is the number of transformer, T_K is the transformer turn ratio at the k^{th} bus and N_L is the number of lines [6].

3.3. Multi-Objective Evolutionary Particle Swarm Optimization

In 2002[11], Miranda introduced Evolutionary Particle Swarm Optimization (EPSO) as one of optimization meta-heuristic algorithm. EPSO combines the conventional PSO technique [9],[10] with the evolutionary strategy to solve the optimal problem effectively. One of disadvantages of PSO is that it does not use selection and mutation process [12],[13]. EPSO introduced as the new approach for mutation on strategic parameters and selection by stochastic tournaments of particle passing to the new generation [14]. Also, the movement rules are: inertia, memory and cooperation [15]. Beside that, Multi-objective Particle Swarm Optimization (MOPSO) proposed by Mostagim and Teich [16] by sigma method can select the best local and guide for each particle. Nevertheless, in [17] the values of P_{best} and G_{best} of particles a no-constant change with times. Multi-objective Evolutionary Particle Swarm Optimization (MOEPSO) is a combination concept of Sigma method and EPSO. The Sigma method in [16], truncated elite archive is maintained which contains a set of non-dominated solution. The new non-dominated solutions are included in the archive in iteration, and archives updated to make it free domination. The proposed algorithm can be summarized through the following steps.

Step (i) Set the base case condition, Q_d at the weak bus. Set the loss and voltage profile constraints.

Step (ii) Initialize the size of population, the archive, the size of particle, the maximum number of iteration and power flow data.

Step (iii) Generate particle for population and archive randomly which consider the location and size of FACTS device.

Step (iv) Calculate the fitness values of each particle of population in the archive and make the archive dominate free by deleting dominates particles with respect to particle inside the archive. Compare the fitness values of each particle of population with the fitness values of the members of the archive.

Step (v) Check whether any particle, p_p in the population dominates any particle, p_a in archive. If yes, replace p_a with p_p. If p_p dominates more than dominates one p_a, replace others with non-dominated particles from the population. For each particle, identify the best local guide form the archive by the Sigma method in [17].

Step (vi) Update the velocity and position of the particle according to (13) to (16). Velocity of each particle can be modified by (13) and (15). Besides that, the new position can be calculated by (16).

Step (vii) Test the convergence criterion. If stopping criterion is satisfied, go to Step (viii). If not, increase the iteration number and go to step (v).

Step (viii) End the simulation process.

In EPSO technique, velocity of each particle is update and modified by [14 - 15],[18 - 23]:

$$v_i^{k+1} = w_{i0}^* \times v_i^k + w_{i1}^* \left(P_{besti} - s_i^k\right) + w_{i2}^* \left(G_{besti} - S_i^k\right) \tag{13}$$

where weights undergo mutation as represented in (14):

$$w_{ik}^* = w_{ik} + \tau N\left(0,1\right) \tag{14}$$

where *N(0,1)* is a random variable with Gaussian distribution; 0 mean and variance 1. The G_{best} is randomly distributed to give in (15):

$$G_{besti}^* = G_{besti} + \tau N\left(0,1\right) \tag{15}$$

The new position can be updated using (16):

$$s_i^{k+1} = s_i^{k+1} \times v_i^{k+1} \tag{16}$$

Each particle is assigned value σ with coordinate (f_1, f_2) for two objectives. Therefore, for two objectives, σ is written as:

$$\sigma = \frac{\left(f_1^2 - f_2^2\right)}{\left(f_1^2 + f_2^2\right)} \tag{17}$$

where f_1 and f_2 are the objective function 1 and objective function 2, respectively [16,17].

4. CONCLUSION

This paper has presented multi-objective optimization termed as MOEPSO, MOPSO and MOEP in implementing the optimal placement of SVC installation. The combination of transmission loss and cost of installation minimization as objective functions has been solved for IEEE 30-Bus RTS. The MOEPSO, MOPSO and MOEP techniques performed well in most cases. Simulations results demonstrated that the proposed MOEPSO technique is flexible for multi-objective optimization problem in other power system network.

5. ACKNOWLEDGEMENTS

The authors would like to acknowledge The Institute of Research Management and Innovation (IRMI) UiTM, Shah Alam, Selangor, Malaysia for the financial support of this research. This research is supported by IRMI under the LESTARI Grant Scheme with project code: 600-IRMI/DANA 5/3/LESTARI (0117/2016).

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How to cite this article:
Jumaat S A, Murisin I. Σ-multi-objective evolutionary particle swarm optimization approach for transmission loss and cost minimization with svc installation. J. Fundam. Appl. Sci., 2018, *10(3S), 715-728.*