MOPSO Approach for FACTS Device Installation in Power System

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***Abstract-* This paper presents an approach to sigma multi-objective optimization particle swarm (σ-MOPSO) technique for optimal allocation of Flexible AC Transmission System (FACTS) devices. For this study, Static Var Compensator (SVC) is selected as a compensation device. Proposal σ-MOPSO technique has been implemented to minimize the transmission losses and the cost of investment in the system. Simulations performed on standard IEEE RTS 30-bus and IEEE 118-bus RTS. Results are compared with those obtained from the programming of multi-objective evolutionary technique (MOEP) in order to highlight its advantages.**

I. INTRODUCTION

Lately, the researcher in optimal placement of FACTS device in power system is oriented towards technical, economic, or both concerns. In [1] FACTS devices at different locations installation has been proposed to improve loading margin. [2], using NSGA II (Non-dominated Sorting Genetic Algorithm) approach is used to find optimum location and sizes of TCSCs in transmission system. A multi-objective genetic algorithm (MOGA) approach in [3] has been implemented for FACTS device placement with multi-objective functions to reduce the voltage violation and line overload. The evolutionary algorithm approach consists of an MOGA (multi-objective genetic algorithm was used for solving the problem of optimal allocation of FACTS device in power system by maximizing of system security and minimizing of investment cost. On the other hand, fuzzy decision making and efficient genetic algorithm to optimal placement of multi-type FACTS device with multi-objective multi-case problem have been proposed.

This study basically focuses on solving the optimal placement and size SVCs into the power system, from a technical and economic point of view, to provide a better power system security. To implement these problems various optimization criteria, σ-MOPSO technique has worked.

II. PROBLEM FORMULATION

This part explains the problem formulation of multi-objective optimization.

A. Multi-Objective Optimization (MOO)

The aim of optimization was the determined of optimal placement and size of FACTS devices into a power system with objective functions to minimize the transmission loss, and minimize the cost of investment. For that reason, the presented problem becomes a multi-objectives problem and this can be expressed, as

$$Min \quad f(x) = \{f_a(x), f_b(x), \ldots, f_z(x)\} \tag{1}$$

$$\begin{aligned} &Under \\ &g_J(x) = 0 && J=1, \ldots, M \\ &h_k(x) \le 0 && k=1, \ldots K \end{aligned}$$

where f_z number of objectives; M, K are numbers of equality and inequality constraints, respectively; x is decision vector [4].

B. The Total Transmission Loss

The first objective function is to minimize the total transmission loss in the system, as given by the following function:

$$f_1 = \sum_{l=1}^{N_G} P_{Gl} - \sum_{l=1}^{N_{PQ}} P_{Dl} \tag{2}$$

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

C. The Cost of Investment

The second objective for this research is to reduce the cost of investment FACTS device where represented by the total investment cost of SVC, C_{SVC}:

$$f_2 = C_{SVC} \times r_{or} \tag{3}$$

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where r_{or} is the operating rate [MVar]. The investment cost given in US$/kVar, are determined by (4) [5-6], [12-13]:

$$C_{SVC} = 0.0003r_{or}^2 - 0.3051r_{or} + 127.38 \quad (4)$$

III. Sigma MULTI-OBJECTIVE PARTICLE SWARM OPTIMIZATION (σ-MOPSO)

In modern years, PSO [5-6], [7-8] has been presented as an effective population-based heuristic techniques in a flexible and balanced mechanism to develop and adjust to the global and local exploration capabilities. On the other hand, changes to SOPSO various objectives requires clarity of global and local best individuals because, in MOPSO no absolute global best, but a set of solutions that are not dominated. Additionally, there may be no single individual local best for each particle of the population. Choosing the global best and local best to guide a particle to be a non-trivial task in the domain of MO [9]. From this problem, and Teich Mostagim proposed MOPSO with sigma method in [9]. This method can choose the best local guides for each particle. The general flowchart to optimal location of FACTS device installation using σ-MOPSO shown in Fig. 1.

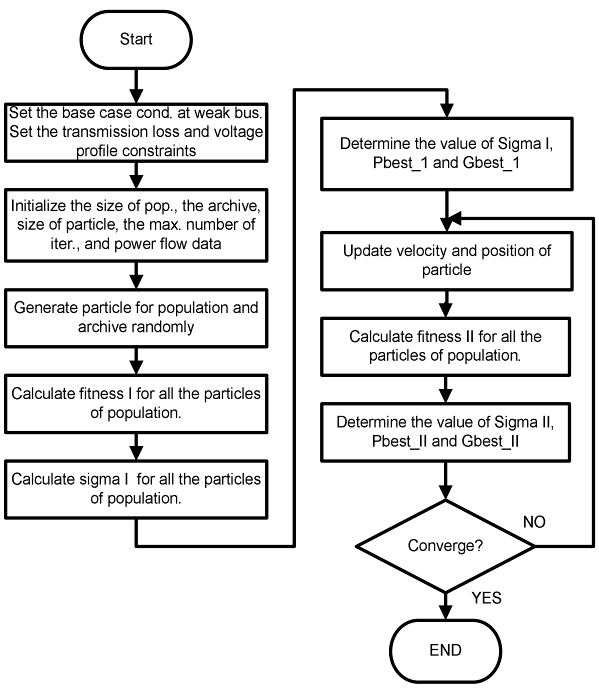

Fig.1 The General flowchart Sigma Multi-objective Particle Swarm Optimization (σ-MOSPO).

In the MOPSO method, velocity vector of each particle is modified and updated by (5):

$$V_i^{k+1} = w \times V_i^k + c_1 \times Random_1() \times \left(P_{best}^i - X_t^i\right) + c_2 \times Random_2() \times \left(P_t^{i,lbest} - X_t^i\right) \quad (5)$$

For finding the best local guide for each particle sigma, the method proposed by [9]. Each particle is assigned value σ with coordinate (f_a, f_b) for two objectives. Therefore, for two objectives, σ is written as

$$\sigma = \frac{\left(f_a^2 - f_b^2\right)}{\left(f_a^2 + f_b^2\right)} \quad (6)$$

where f_a and f_b are the objective function 1 and objective function 2, respectively [10].

IV. RESULTS AND DISCUSSION

With the purpose of understand the usefulness of the proposed MOPSO and MOEP techniques, IEEE-30 bus RTS and IEEE-118 bus RTS were tested to find the allocation of FACTS device. The FACTS device installation in power system the transmission loss and cost of investment minimization has been conducted at several load conditions subjected to bus 26 and 29 for IEEE-30 bus RTS while, bus 20 and bus 53 for IEEE-118 bus RTS.

A. Case 1: Q_{d26}=20MVar in IEEE-30 bus RTS

Result for MOO problem when bus 26 is subjected 20MVar using MOPSO and MOEP are illustrated in Fig.1, Fig. 2, Table I and Table II. It observed that the transmission loss value has been minimized at this loading condition using MOPSO and MOEP techniques. The optimal value of transmission loss and cost of installation using MOPSO technique is 18.00790MW and US$869,460. Besides that, the best value of transmission loss and cost of installation using MOEP technique is 17.7994MW and US$569,910 as tabulated in Table I. Also, with the SVCs installation at load bus system the voltage profile has been increased greater than 0.95p.u. as shown in Table II. Besides that, Fig. 2 illustrates the single-line diagram of IEEE-30 Bus RTS with optimal location of SVCs installation when Q_{d26}=20MVar using MOPSO. It can be observed that the placements of SVCs installation are the load bus and the generator bus in the system.

TABLE I
RESULTS OF LOSS AND COST USING MOPSO AND MOEP WHEN Q_{d26}=20MVAR

Method	Pre-Installation	Post-Installation	
	Loss (MW)	Loss (MW)	Cost (US$)
MOPSO	20.3393	18.0790	869,460
MOEP		17.7994	569,910

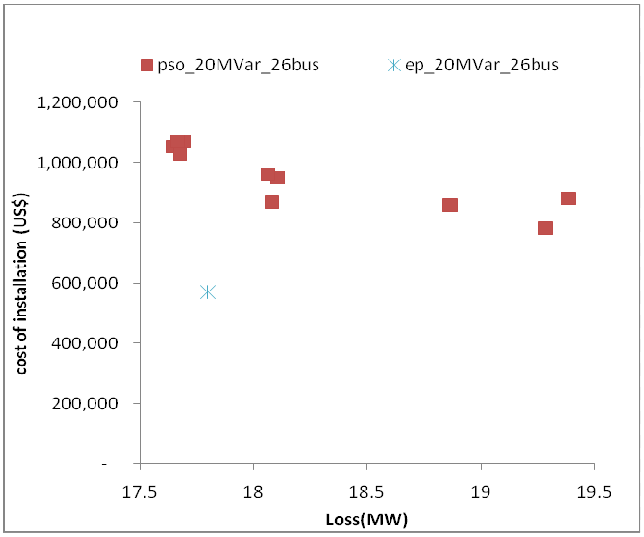

Fig. 1: Sigma front for loss and cost minimization obtained using MOPSO and MOEP when Q_{d26}=20MVar.

TABLE II
RESULTS OF VOLTAGE USING MOPSO AND MOEP WHEN Q_{d26}=20MVAR

Method	Pre-Installation	Post-Installation
	Voltage (p.u)	Voltage (p.u)
MOPSO	0.8383	0.9511
MOEP		0.9560

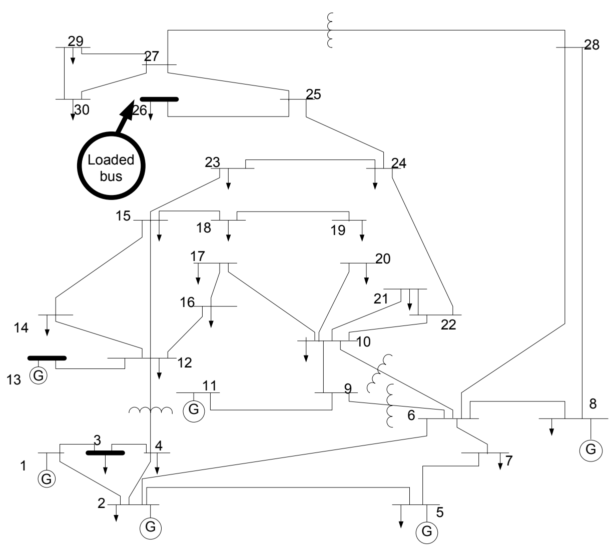

Fig. 2 Single line diagram of IEEE-30 bus RTS with optimal location when Q_{d26}=20MVar using MOPSO.

B. Case 2: Q_{d29}=20MVar in IEEE-30 bus RTS.

Result for MOO when bus 29 is subjected to load of 20MVar using MOPSO and MOEP are illustrated in Fig. 3, Fig. 4, Table III and Table IV. It observed that the transmission loss values minimized with 20MVar connected at bus 29 using MOPSO and MOEP techniques. The optimal value of transmission loss and cost of installation using MOPSO technique is 17.5731MW and US$983,190 respectively. The best value of transmission loss and cost of installation using MOEP technique is 17.4899MW and US$1,072,900 as tabulated in Table IV. With the SVCs installation the voltage profile has been increased greater than 1.00p.u as shown in Table V. Besides that, Fig. 4 illustrates the single-line diagram of IEEE-30 Bus RTS with optimal location of SVCs installation when Q_{d29}=20MVar using MOPSO. It can be observed that the placements of SVCs installation are at the generator bus.

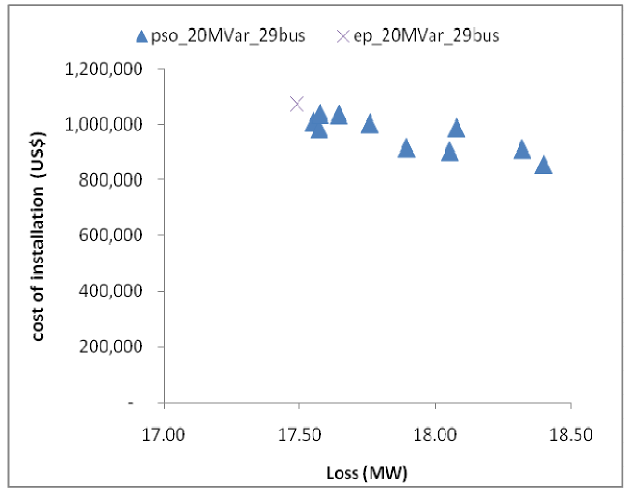

Fig. 3 Sigma front for loss and cost minimization obtained using MOPSO and MOEP when Q_{d29}=20MVar.

TABLE IV
RESULTS OF LOSS AND COST USING MOPSO AND MOEP WHEN Q_{d29}=20MVAR

Method	Pre-Installation	Post-Installation	
	Loss (MW)	Loss (MW)	Cost (US$)
MOPSO	19.4699	17.5731	983,190
MOEP		17.4899	1,072,900

TABLE V
RESULTS OF VOLTAGE USING MOPSO AND MOEP WHEN Q_{d26}=20MVAR

Method	Pre-Installation	Post-Installation
	Voltage (p.u)	Voltage (p.u)
MOPSO	0.8582	1.0155
MOEP		1.0103

C. Case 3: Q_{d20}=100MVar in IEEE-118 bus RTS.

Result for MOO when bus 20 is subjected to load of 100MVar using MOPSO and MOEP are illustrated in Fig. 5, Fig. 6, Table VI and Table VII. It observed that the transmission loss values reduced with 100MVar at bus 20 using MOPSO and MOEP techniques. The best value transmission loss and cost of installation using MOPSO and MOEP techniques are tabulated in Table VI. With the SVCs installation the voltage profile have been increased greater than 0.95p.u as shown in Table VII. Besides that, Fig. 6 illustrates the single-line diagram of IEEE-118 Bus RTS with optimal location of SVCs installation when Q_{d20}=100MVar using MOPSO. It can be observed that the placements of SVCs installation are at the load bus.

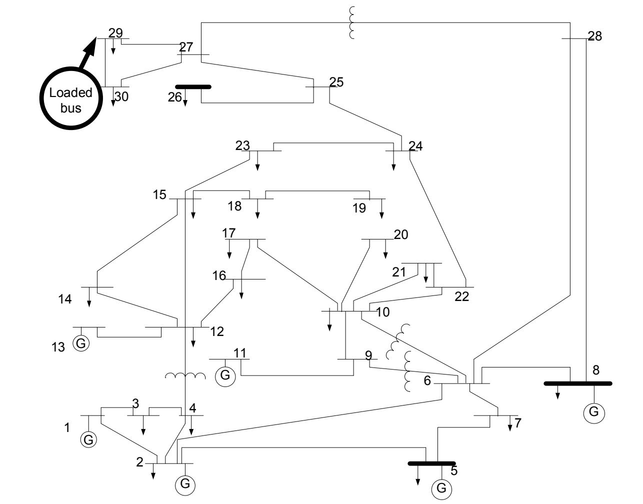

Fig. 4 Single line diagram of IEEE-30 bus RTS with optimal location when Q_{d29}=20MVar using MOPSO.

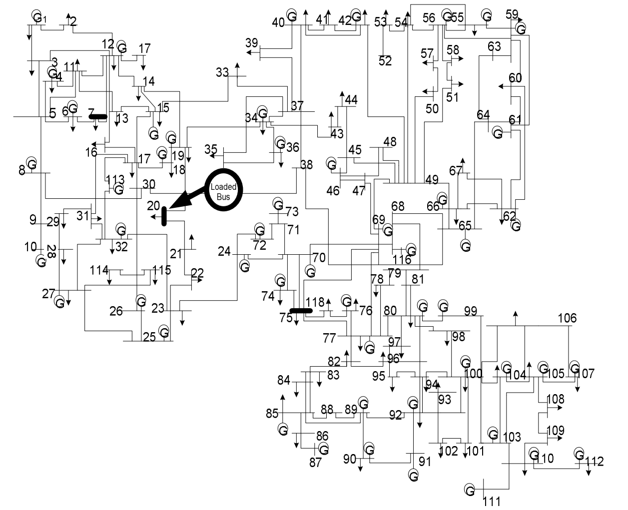

Fig. 6 Single line diagram of IEEE-118 bus RTS with optimal location when Q_{d20}=100MVar using MOPSO.

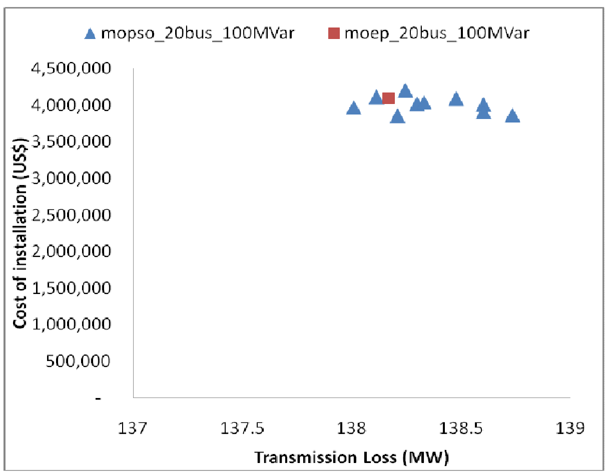

Fig. 5 Sigma front for loss and cost minimization obtained using MOPSO and MOEP when Q_{d20}=100MVar.

TABLE IV
RESULTS OF LOSS AND COST USING MOPSO AND MOEP WHEN Q_{d20}=100MVAR

Method	Pre-Installation	Post-Installation	
	Loss (MW)	Loss (MW)	Cost (US$)
MOPSO	143.7236	138.0091	3,973,000
MOEP		138.1706	4,090,300

TABLE V
RESULTS OF VOLTAGE USING MOPSO AND MOEP WHEN Q_{d20}=100MVAR

Method	Pre-Installation	Post-Installation
	Voltage (p.u)	Voltage (p.u)
MOPSO	0.8291	0.9662
MOEP		0.9965

D. Case 4: Q_{d53}=100MVar in IEEE-118 bus RTS.

Result for MOO when bus 53 is subjected to load of 100MVar using MOPSO and MOEP are illustrated in Fig. 7, Fig. 8, Table VII and Table VII. It is observed that the transmission loss values reduce with 100MVar at bus 53 using MOPSO and MOEP techniques. The best value of transmission loss and cost of installation using MOPSO and MOEP techniques are tabulated in Table VI. With the SVCs installation the voltage profile have been increased greater than 0.95p.u. as shown in Table VII. Besides that, Fig. 8 illustrates the single-line diagram of IEEE-118 Bus RTS with optimal location of SVCs installation when Q_{d53}=100MVar using MOPSO. It can be observed that the placements of SVCs installation are at the generator bus or load bus. It is same phenomena with Bus 26.

TABLE VI
RESULTS OF LOSS AND COST USING MOPSO AND MOEP WHEN Q_{d53}=100MVAR

Method	Pre-Installation	Post-Installation	
	Loss (MW)	Loss (MW)	Cost (US$)
PSO	142.0012	138.3295	2,241,400
EP		138.0984	2,220,800

TABLE VII
RESULTS OF VOLTAGE USING MOPSO AND MOEP WHEN Q_{d53}=100MVAR

Method	Pre-Installation	Post-Installation
	Voltage (p.u)	Voltage (p.u)
PSO	0.8536	0.9526
EP		0.9595

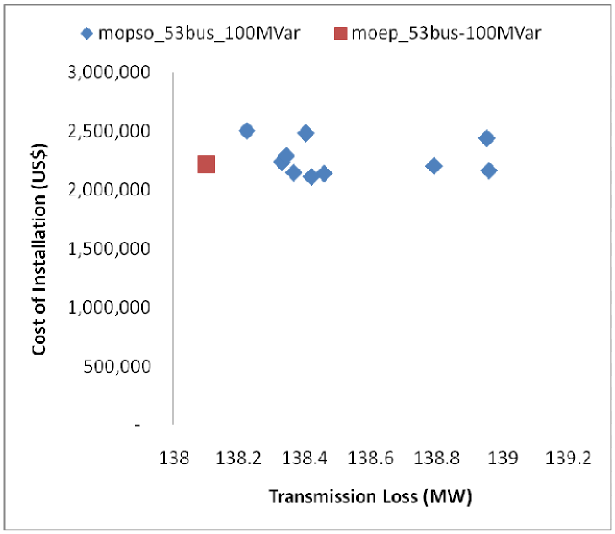

Fig. 7 Sigma front for loss and cost minimization obtained using MOPSO and MOEP when Q_{d53}=100MVar.

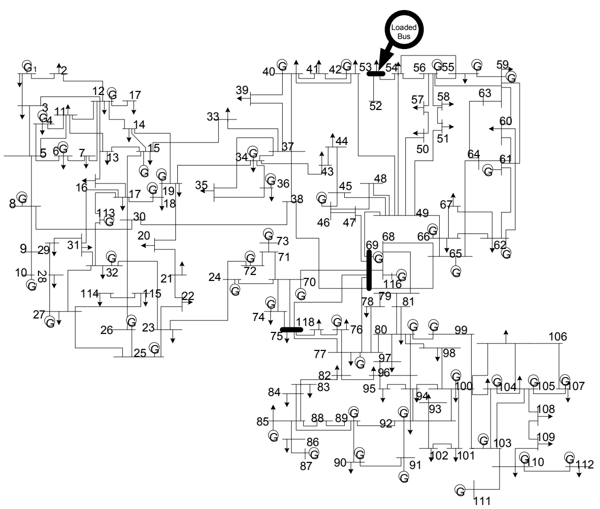

Fig. 8 Single line diagram of IEEE-118 bus RTS with optimal location when Q_{d53}=100MVar using MOPSO.

E. Case 5: Q_{d53}=150MVar in IEEE-118 bus RTS.

Result for MOO problem when bus 53 is subjected to load of 150MVar using MOPSO and MOEP are illustrated in Fig. 9, Fig. 10, Table IX and Table X. It is observed that the transmission loss values reduce with 150MVar at bus 53 using MOPSO and MOEP techniques. The best value transmission loss and cost of installation using MOPSO and MOEP techniques are tabulated in Table IX. With the SVCs installation the voltage profile have been increased greater than 0.95p.u. as shown in Table X. Besides that, Fig. 10 illustrates the single-line diagram of IEEE-118 Bus RTS with optimal location of SVCs installation when Q_{d53}=150MVar using MOPSO. It can be observed that the placements of SVCs installation are the generator bus or load bus as same phenomena with Q_{d53}=100MVar.

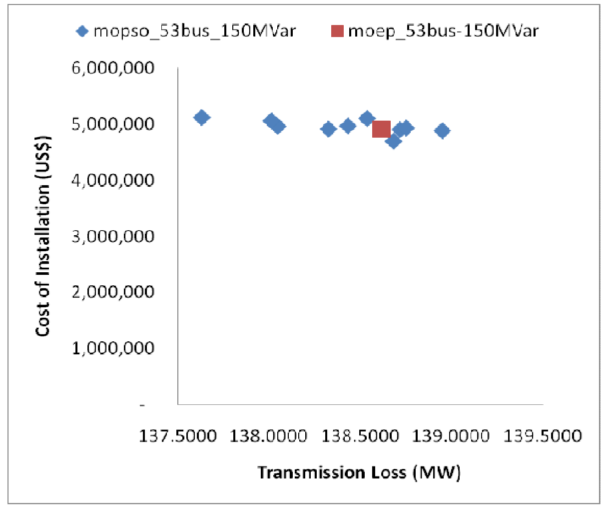

Fig. 9 Sigma front for loss and cost minimization obtained using MOPSO and MOEP when Q_{d53}=150MVar.

TABLE IX
RESULTS OF LOSS AND COST USING MOPSO AND MOEP WHEN Q_{d53}=150MVAR

Method	Pre-Installation	Post-Installation	
	Loss (MW)	Loss (MW)	Cost (US$)
PSO	147.7453	138.3249	4,915,800
EP		138.6179	4,914,200

TABLE X
RESULTS OF VOLTAGE USING MOPSO AND MOEP WHEN Q_{d53}=150MVAR

Method	Pre-Installation	Post-Installation
	Voltage (p.u)	Voltage (p.u)
PSO	0.7896	0.9771
EP		0.9753

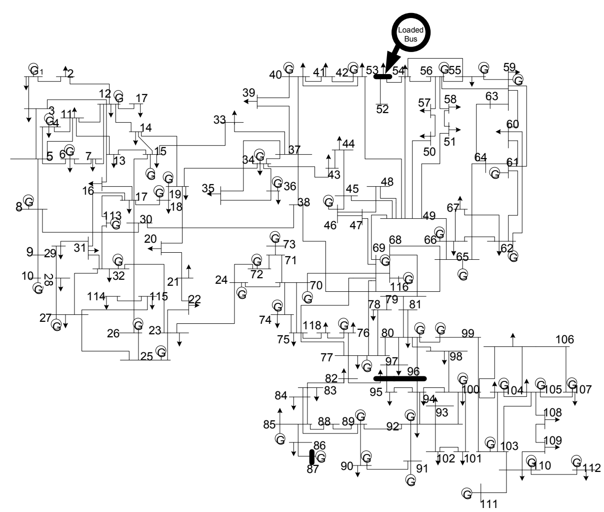

Fig. 10 Single line diagram of IEEE-118 bus RTS with optimal location when Q_{d53}=150MVar using MOPSO.

V. CONCLUSION

This paper has presented multi-objective optimization termed as MOPSO and MOEP in implementing the optimal placement of SVCs installation. The combination of transmission loss and minimization of installation cost as objective function has been solved for IEEE 30 bus RTS with bus 26 and 29 subjected to 20MVar. The study has been implemented on IEEE-118 bus RTS with bus 20 and 53 are subjected to 100MVar and 150MVar respectively. Both the MOPSO and MOEP techniques performed well in most cases. Simulations results demonstrated that the proposed MOPSO technique is flexible for multi-objective optimization problem in other power system network.

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