Cluster Identification for Optimal Placement of Static Var Compensator

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Abstract- **This paper introduces a new concept of artificial intelligence based algorithm for clustering the placement of SVCs in power system. The algorithm is based on particle swarm optimization (PSO) technique with objective function to minimize the transmission loss in the system. Experiments were performed on the IEEE 30- and IEEE 118-bus RTS to realize the effectiveness of the proposed technique, while verification was conducted through comparative studies with evolutionary programming (EP).**

I. INTRODUCTION

The idea of Flexible AC Transmission System (FACTS) device refers to a family of power electronics-based devices able to improve AC system controllability and stability and to increase power transfer capability. The design of the different schemes and configurations of FACTS devices is based on the combination of traditional power system with power electronics elements. Over the last years, the current rating of thyristors has evolved into higher nominal values making power electronics capable of high power applications. Some of the advantages of installing FACTS device are steady-state and dynamic reactive power compensation and voltage regulation, increasing power transfer capability of existing assets, reduced fault current, and reduced the transmission losses [1]. In practical system, optimal placement of FACTS device depends on complete analysis of steady-state stability, voltage stability with consideration cost of installation. Also, due to the expensive cost of FACTS devices, it is significant to place them optimally in power system network [2].

Optimal placement of FACTS device installation in power system has been challenged using diverse techniques such as Genetic Algorithm (GA), Bee Algorithm (BA), Hybrid Tabu Search and Simulated Annealing (TS/SA), and Particle Swarm Optimization (PSO), In [3], an approach hybrid TS/SA for individual- and multi-type FACTS device installation to reduce the total generator of fuel cost. From the results, shows this method converges at faster computation time. R.M Idris *et. al* [4] compared GA and PSO techniques for placement of five units of TCSCs in the system with objective function to maximum increase in system loadability. In [5], BA does not need cross over rate or mutation rate. However, this method gives better results in terms of speed and accuracy of optimizations. But this method needs the large numbers of trials. In [6], GA technique to identify the suitable the types of FACTS devices and count the total of cost systems. In [7], comparison with GA and PSO to optimize the size of TCSC and from results shows that PSO have benefits in terms to balanced mechanism, better variation to the global and local exploration abilities.

This paper mostly focuses on the cluster identification of optimal allocation of SVCs into power system. The optimization techniques are PSO and EP techniques were applied when the load variation is subjected to bus 26, and 30 of IEEE 30-Bus RTS. Also, the same techniques are used when the load variation are subjected to bus 20 of IEEE 118-bus RTS. The one type of FACTS device is chosen in this research is SVC.

II. STATIC VAR COMPENSATOR (SVC)

The SVCs is a shunt-connected static var generator or absorber whose output is adjusted to exchange capacitive or inductive so as to maintain or control specific parameters of electrical power system (typically controller reactor). In this paper, the SVC is modeled as a variable shunt reactive susceptance [2], [8], [9-13].

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III. PROBLEM FORMULATION

A. Objective Function

The objective for this research is to minimize the transmission loss in the power system. The total transmission loss in the system can be calculated by (1):

$$f_1 = \sum_{l=1}^{N_G} P_{Gl} - \sum_{l=1}^{N_{PQ}} P_{Dl} \quad (1)$$

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

B. Compensation Devices Cost

In (2) is represented by the total investment cost of SVC, C_{SVC}:

$$f_2 = C_{SVC} \times r_{re} \quad (2)$$

where r_{re} is the operating rate. The investment cost given in US$/kVar, are determined by the following relations [9-13]:

$$C_{SVC} = 0.0003 r_{re}^2 - 0.3051 r_{re} + 127.38 \quad (3)$$

II. OPTIMIZATION TECHNIQUE

A. Particle Swarm Optimization (PSO)

PSO is one of the modern heuristics algorithms suitable to solve large-scale no convex optimization problems [14]. It is a population–based search algorithm and searches in parallel using a group of particles. The PSO algorithm was originally developed in 1995 by Kennedy and Eberhant based on the analogy of swarm of bird and school of fish [15]. The update position and velocity of each particle can be referring in [3], [10], [16-17].

B. Cluster Identification

Placement clustering technique was conducted in order to identify the cluster, which includes the higher and lowest placement of SVCs installation in power system. Run the transmission loss analysis with the reactive power loading at a being increased at the weak bus. At the same time, a post-installation SVCs analysis was conducted and the results were sorted in descending order with the largest was ranked highest. The following procedures were implemented in order to form SVCs location cluster. Fig. 1 shows the flowchart of FACTS device cluster Identification.

Step i: Set the loading condition.
Step ii: Perform pre-installation SVCs.
Step iii: Run the load flow to calculate the transmission loss with the reactive power loading at a weak bus is increased.
Step iv: Rank the results based on the frequency selectively of particle buses of SVC installation.
Step v: Represent the SVC installation on the system by highlighting the placement categorized as the cluster identification form.

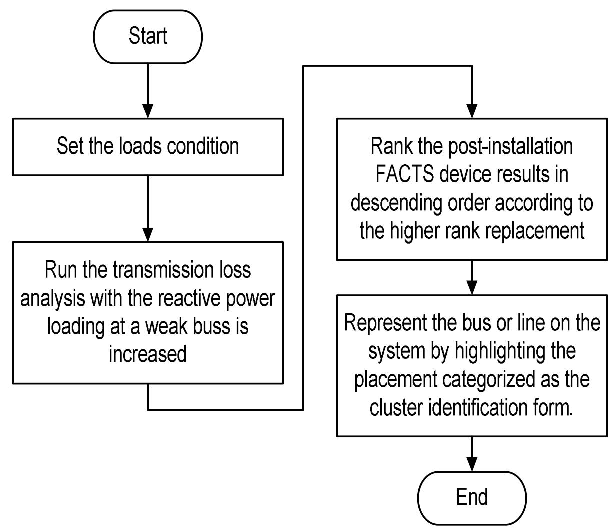


Fig. 1 The flowchart of FACTS device cluster Identification

IV. RESULTS AND DISCUSSION

The effectiveness of the optimal location and size of SVCs installation using PSO and EP techniques has been tested on two test system namely the IEEE-30 Bus RTS and IEEE-118 bus RTS. The SVCs device installations in the power system for transmission loss minimization in the system have been conducted at several load conditions.

A. Cluster Identification for Multiple-SVCs Installation for IEEE-30 Bus RTS

The cluster identification for the IEEE 30-bus RTS was conducted by looking at the frequency selectivity on particle buses for each SVC installation. In other words, the participated buses are monitored for each installation i,e for single-, 2-, 3-, 5-, and 8-SVCs installation. Table I tabulates the results for SVC installation when load is increased from 5MVar to 30MVar subjected to Bus 26 in the system. While, Table II tabulates the ranking of SVC installation based on the frequency selectivity of particle buses via PSO and EP techniques. From Table I and II, fifteen locations were chosen to form the clusters are buses 26, 27, 24, 21, 25, 12, 13, 16, 19, 29, 11, 20, 22, 17, 18, and 25. These buses are closely and connected to bus 26. Besides that, eleven locations were chosen to form the cluster via EP technique are tabulated in the same table are buses 26, 24, 29, 23, 28, 27, 22, 20, 21, 30 and 25. This implies the same phenomena with PSO technique. The buses are highlighted in the system to form the cluster via PSO and EP illustrated in Fig. 2. From Table II and Fig. 2 it is observed that buses 26, 24, 21, 27 and 29 are the ranked higher in cluster identification via PSO and EP techniques. Also from Fig. 2; it observed that the main cluster where closely with bus 26 in the list.

Next, Table III tabulates the results for SVC installation when load is increased from 5MVar to 30MVar subjected to Bus 30 in the system. While, Table IIV tabulates the ranking of SVC installation based on the frequency selectivity of particle buses via PSO and EP techniques. From PSO results, fifteen buses which have higher ranking are buses 30, 29, 24, 21, 27, 22, 16, 26, 13, 14, 25, 11, 12, 18, and 28. Besides that, from EP results; fifteen buses were chosen to form the clusters are buses 30, 21, 22, 24, 23, 26, 27, 28, 29, 17, 12, 13, 14, 20, and 25. Majority of the buses in the top rank are the load bus, which are directly connected and closely connected to bus 30.

The SVCs installation cluster when load variations at bus 30 using PSO and EP techniques are illustrated in Fig. 3. From Table IV, and Fig.3 it is observed that buses 30, 29, 24, 21, 27, 22, and 26 are at the higher rank in cluster identification SVCs installation via PSO and EP techniques. Also, from Fig. 3 and it is observed that the main cluster where closely located to bus 30 in the list.

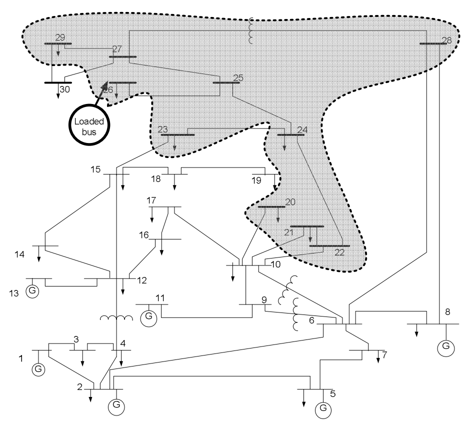
On the other hands, Table I to Table IV and Fig. 2 to Fig. 3 it is observed that buses 29, 24, 21, and 27 are at top rank and chosen to form cluster for load variation at Bus 26 and 30. It can be observed that the main clusters are closely located to the loaded bus.

Table I
Optimal Location of SVC Installation when Q_{d26}= 5MVar to 30MVar via PSO.

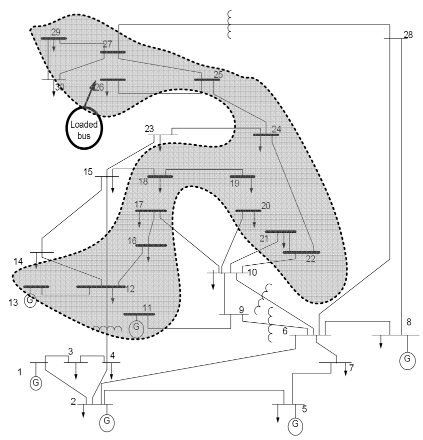
Q_{d26} (Mar)	Quantity	Locations (Bus)							
5	1	25							
	2	24	26						
	3	20	21	26					
	5	12	25	27	13	24			
	8	27	24	21	14	15	13	14	18
10	1	24							
	2	26	24						
	3	26	21	26					
	5	19	26	12	25	12			
	8	26	24	13	29	28	11	17	30
15	1	27							
	2	27	26						
	3	27	21	26					
	5	11	26	21	21	19			
	8	23	26	25	17	10	23	25	22
20	1	27							
	2	26	25						
	3	24	26	26					
	5	24	26	18	26	11			
	8	26	16	16	19	26	18	16	20
25	1	27							
	2	26	29						
	3	22	22	26					
	5	13	26	19	29	20			
	8	11	26	30	16	12	17	17	13
30	1	27							
	2	26	28						
	3	29	21	26					
	5	27	12	26	19	16			
	8	29	26	22	26	23	21	20	26

Table II
Ranking of SVC Installation when Q_{d26}= 5MVar to 30MVar via PSO and EP Techniques.

Rank	PSO		EP	
	SVC Loc.	Freq.	SVC Loc.	Freq.
1	26	28	26	37
2	27	9	24	10
3	24	8	29	8
4	21	8	23	7
5	25	6	28	7
6	12	5	27	6
7	13	5	22	5
8	16	5	20	3
9	19	5	21	3
10	29	5	30	3
11	11	4	25	2
12	20	4	[redacted]	
13	22	4		
14	17	4		
15	18	3		



a) PSO Technique



b) EP Technique

Fig. 2 Cluster Identification SVCs Installation Q_{d26}= 5MVar to 30MVar

B. Cluster Identification for Multi-SVCs Installation for IEEE 118- Bus RTS

The cluster identification for the IEEE 118-bus RTS was conducted by looking at the frequency selectivity on particle buses for each SVC installation. In other words, the participated buses are monitored for each installation i,e for 3 SVCs, 5 SVCs installation until 10 SVCs installation. Table V tabulates the results for SVC installation when load is increased from 100MVar to 180MVar subjected to Bus 20 in the system. On the other hand, Table VI tabulates the ranking of SVC installation based on the frequency selectivity of particle buses via PSO and EP techniques. From this table, fifteen locations which at higher rank were chosen from PSO technique when the load at bus 20 is increased until 180MVar. Although using EP technique, eleven locations are chosen to form the cluster. The locations are highlighted in the system to form the clusters via PSO and EP techniques illustrated as in Fig. 3.

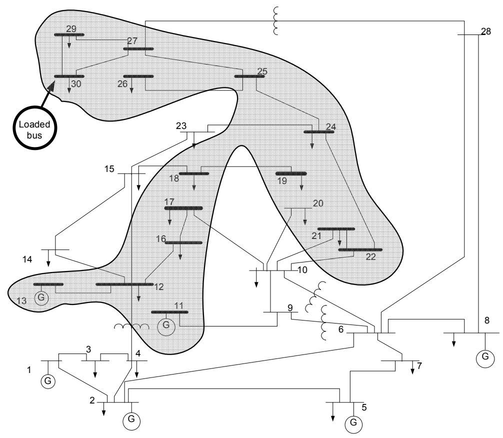
From Table VI, and Fig. 4, it is observed that Bus 20, 38 and 76 are the higher rank and top ten in cluster identification SVC installation via PSO and EP technique. From these figure shown that the main cluster where closely with Bus 20 in the system.

Table III
Optimal Location of SVC Installation when Q_{d30}= 5MVar to 30MVar via PSO.

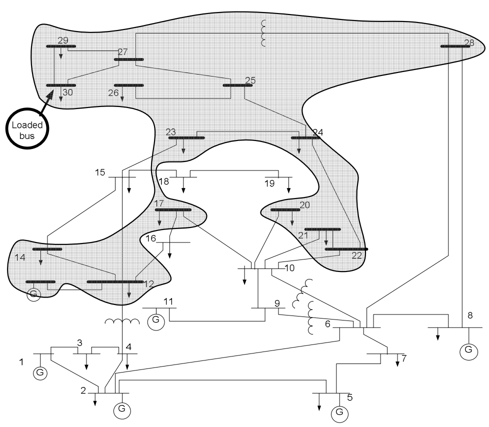
Q_{d30} (MVar)	Qty	Locations (Bus)							
5	1	27							
	2	29	24						
	3	22	29	29					
	5	19	12	27	11	13			
	8	13	21	29	10	24	22	13	29
10	1	24							
	2	26	24						
	3	26	21	26					
	5	19	26	12	25	12			
	8	26	24	13	29	28	11	17	30
15	1	26							
	2	29	30						
	3	21	20	30					
	5	30	19	24	17	27			
	8	17	27	30	16	30	22	14	19
20	1	27							
	2	26	25						
	3	24	26	26					
	5	24	26	18	26	11			
	8	26	16	16	19	26	18	16	20
25	1	30							
	2	29	30						
	3	20	30	24					
	5	12	30	16	15	18			
	8	22	16	30	22	24	30	21	18
30	1	27							
	2	26	28						
	3	29	21	26					
	5	27	12	26	19	16			
	8	29	26	22	26	23	21	20	26

Table IV
Ranking for SVC Installation when Q_{d30}= 5MVar to 30MVar via PSO and EP Techniques.

Rank	PSO		EP	
	SVC Loc.	Freq.	SVC Loc.	Freq.
1	26	19	30	32
2	16	18	21	8
3	30	12	22	8
4	24	10	24	8
5	29	9	23	6
6	27	7	26	5
7	21	6	27	5
8	19	6	28	5
9	22	6	29	5
10	11	4	17	4
11	18	4	12	3
12	13	4	13	2
13	12	4	14	2
14	11	3	20	2
15	17	3	25	2



a) PSO Technique



b) EP Technique

Fig. 3 Cluster Identification SVCs Installation when Q_{d30}= 5MVar to 30MVar

V. CONCLUSION

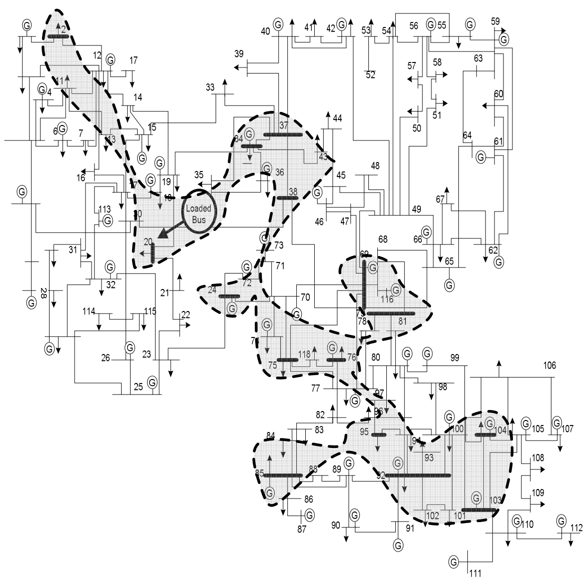
This paper has presented the formation of cluster for SVC installation in power system. The clusters were formed based on the results from optimal location of SVCs with objective function to minimize the transmission loss of the system. In this research, PSO and EP techniques are applied when the load variation are subjected to bus 26, and 30 of IEEE 30-Bus System. Also, the same techniques are used when the load variation are subjected to bus 20 of IEEE 118-Bus System. The one type of FACTS device chosen in this research is SVC. Comparison of cluster development between PSO and EP revealed that technique is feasible.

Table V
Optimal Location of SVC Installation when Q_{d20}= 10MVar to 180MVar Using PSO.

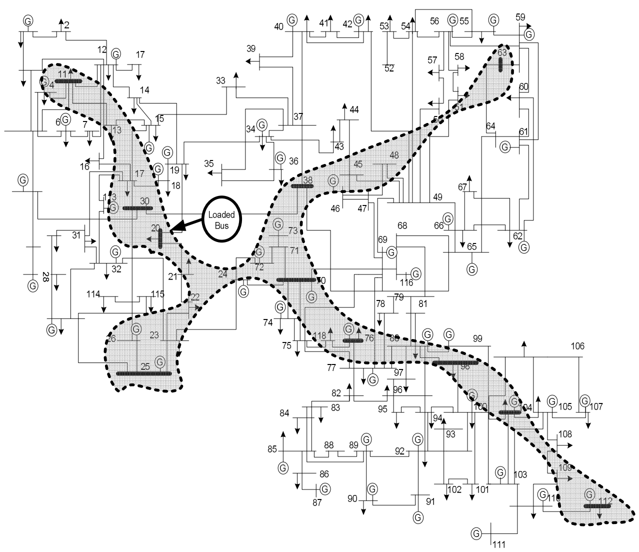
Q_{d20} (MVar)	Location (SVC)						
10	111	76	85				
	88	103	81	85	89		
	24	109	103	82	79	69	76
	79	24	37				
50	38	20	117				
	20	40	16	13	69		
	25	93	37	69	50	3	107
	106	20	80				
100	20	2	19				
	14	113	20	20	20		
	95	75	116	20	74	38	12
	104	71	37				
150	38	20	24				
	56	92	44	85	20		
	38	99	75	34	61	92	75
	20	38	115				
180	20	58	76				
	20	3	114	62	104		
	20	34	61	77	68	95	76
	6	52	41				

Table VI
Ranking for SVC Installation when Q_{d20}= 10MVar to 180MVar using PSO ad EP

Rank	PSO		EP	
	SVC Loc.	Freq.	SVC Loc.	Freq.
1	20	14	20	12
2	38	5	38	3
3	76	4	63	3
4	37	3	11	2
5	69	3	25	2
6	75	3	30	2
7	85	3	70	2
8	24	3	76	2
9	3	2	98	2
10	34	2	104	2
11	79	2	112	2
12	92	2	[redacted]	
13	95	2		
14	103	2		
15	104	2		



a) PSO Technique



b) EP Technique

Fig. 4 Cluster Identification SVCs Installation when Q_{d20}= 10MVar to 180MVar

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REFERENCES

[1] V. Hamidi, K.S.Smith, R.C. Wilson, "Smart Grid Technology Review within the Transmission and Distribution Sector", IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT Europe), 2010, pp. 1-8.

[2] S. A. Jumaat, I. Musirin, M.M. Othman, H. Mokhlis, "Comparison of FACTS Device Installation in Power Transmission System", International Review of Modelling and Simulations (IREMOS), Vol. 5, N. 4, August 2012. pp. 1679-1689.

[3] P. Bhasaputra, W.Ongsakul, "Optimal Power Flow with Multi-type of FACTS Devices by Hybrid TS/SA Approach", in IEEE ICIT, 02, 2002, Bangkok Thailand.

[4] I.Rashed, H.I.Shaheen, S.J.Cheng, "Optimal Locations and Parameters Settings of Multiple TSCSs for Increasing Power System Loadability Based on GA and PSO techniques, in Proc 2007 *Third IEEE International Conference on Natural Computation (ICNC 2007)*, 2007.

[5] Idris. R.M, Kharuddin. A, and Mustafa, M.W, "Optimal Choice of FACTS devices for ATC Enhancement Using Bees Algorithm," in *Power Engineering Conference, 2009 (AUPEC 2009). Australasian Universities* 2009, pp. 1 – 6, 2009.

[6] Phashant Kumar Towari, and Tog Raj Sood, "Optimal Location of FACTS Devices in Power System Using Genetic Algorithm," in Proc. *IEEE World Congress on Nature and Biologically Inspired Computing (NaBIC 2009),* 2009.

[7] S. Panda, and N.P.Padly, "Comparison of particle swarm optimization and genetic algorithm for FACTS-based controller design," *Applied Soft Computing*, vol 8, Issue 4, pp. 251-259, Mar. 2007.

[8] M. Bellazzoug, M. Boudour, "FACTS Placement Multiobjective Optimization for Reactive Power System Compensation", in *7th International Multi-Conference on Systems*, signals and Devices, 2010.

[9] S. A. Jumaat, I. Musirin, M.M. Othman, H. Mokhlis, "Computational Intelligence Based Technique in Multiple FACTS Device Installation for Power System Security", *Journal of Theoretical and Applied Information Technology,* 31st December 2012, Vol. 46. No.2. pp. 537-549.

[10] S. A. Jumaat, I. Musirin, M.M. Othman, H. Mokhlis, "PSO Based Technique for Loss Minimization Considering Voltage Profile and Cost Function", *The 5th International Conference Power engineering and Optimization (PEOCO),* 2011, pp. 36-42.

[11] S. A. Jumaat, I. Musirin, M.M. Othman, H. Mokhlis, "Transmission Loss Minimization Using SVC Based on Particle Swarm Optimization", *The IEEE Symposium Industrial Electronics and Applications (ISIEA 2011),* 2011, pp. 419-424.

[12] S. A. Jumaat, I. Musirin, M.M. Othman, H. Mokhlis, "Placement and Sizing of Thyristor Controlled Series Compensator using PSO Based Technique for Loss Minimization", *The IEEE International Power Engineering and Optimization Conference (PEOCO),* 2012, pp. 285-290.

[13] S. A. Jumaat, I. Musirin, M.M. Othman, H. Mokhlis, "Applications of PSO Technique to Optimal Location and Sizing of Static Var Compensator", *IEEE Symposium on Computers & Informatics (ISCI) 2012*, pp.170-175.

[14] J.B. Park, Y.W. Jeong, K.Y. Lee, "An Improved Particle Swarm Optimization for Nonconvex Economic Dispatch Problems", *IEEE Transactions on Power Systems*, Vol. 25, No. 1, February 2010.

[15] J. Kennedy, R.C. Eberhant, "Swarm Intelligence", *San Francisco, CA*: Morgan Kaufmann, 2001.

[16] S. A. Jumaat, I. Musirin, M.M. Othman, H. Mokhlis, Optimal Placement and sizing of Multiple FACTS Devices Installation", Power and Energy (PECon), 2012 IEEE International Conference on, pp. 145-150.

[17] S. A. Jumaat, I. Musirin, M.M. Othman, H. Mokhlis, Evolutionary Particle Swarm Optimization (EPSO) based Technique for Multiple SVCs Optimization", Power and Energy (PECon), 2012 IEEE International Conference on, pp. 183-188.