Optimal Placement and Sizing of Multiple FACTS Devices Installation

[1]Siti Amely Jumaat,
[1]Faculty of Electrical and Electronics Engineering
Universiti Tun Hussein Onn Malaysia (UTHM)
86400 Parit Raja, Batu Pahat, Johor, Malaysia
[1]sitiamely1979@gmail.com

[2]Ismail Musirin, [3]Muhammad Murtadha Othman, [4]Hazlie Mokhlis

[2,3]Faculty of Electrical Engineering
Universiti Teknologi MARA Malaysia (UiTM)
40450 Shah Alam, Malaysia
[2]ismailbm1@gmail.com

[4]Department of Electrical Engineering
Faculty of Engineering
University of Malaya, 50603 Kuala Lumpur, Malaysia

***Abstract*—This paper presents optimal placement and sizing of multiple FACTS devices based on computational intelligence techniques. In this study, particle swarm optimization (PSO) and Evolutionary Programming (EP) approach is proposed to minimize the transmission loss in the power system with flexible AC transmission systems (FACTS) devices. Two types of FACTS are used: static var compensator (SVC) and thyristors controlled series compensator (TCSC) are two FACTS devices chosen for the optimal installation for compensation purposes due to reported promising performances of the devices. Experiment results on the IEEE 30 bus system with FACTS devices show that the proposed PSO approach can obtain better solutions than EP technique.**

Keywords-component; transmission loss; static var compensator; tyristor controlled series compensator; particle swarm optimization; cost of installation

I. INTRODUCTION

In recent years, the greater demand have been placed on the transmission network, and these demands will be continued to increase because of the increasing number of neutrality generators and heightened competition among utilities themselves [1]. This problem it is very demanding to acquire new rights of way. One of the alternatives is by using flexible alternating current transmission system (FACTS). In [2], the FACTS device concept was introduced by the Electric Power Research Institute (ERPI) in the late 1980. The main benefit of FACTS devices is to increase a system transmission capacity and power flow control flexibility and rapidity [3]. Moreover, FACTS device technology is to get a system under control and also to transfer a power as ordered by the control centre cost-effectively [4-5]. It also allows increasing the usable transmission capacity to it maximum thermal limits.

In [6-7], the latest generation of FACTS device is convertible static compensator (CSC) was recently installed at the Marcy 345kV substation. In [8-9], two novel operating configurations are formed as Generalized Unified Power Flow Controller (GUPF) and Interline Power Flow Controller (IPFC), which are significantly extended to control power flow of a single line by a TCSC and UPFC.

In this paper, PSO technique is a computational intelligence based technique proposed to optimize the location and sizing of multiple FACTS devices in order to minimize the transmission loss in the system. The installation of FACT devices are performed into the busdata or linedata system which directly affect the power flow solution in a system. Experiments were done for IEEE 30 bus system to recognize the effectiveness of the proposed technique, although verification was conducted through relative studies with EP technique.

II. COST FUNCTION

Optimal placement and sizing of multiple FACTS device considering the cost of installation of FACTS device has been mathematically formulated and is given by equation (1) in [20] and [21]:

$$IC = C \times B \times 1000 \quad (1)$$

Using database of [10], cost function for SVC and TCSC are shown in Figure 1 and modeled as follows:
For SVC:

$$C_{SVC} = 0.0003B^2 - 0.3051B + 127.38 (US\$/kVar) \quad (2)$$

For TCSC in [20], [21]:

$$C_{TCSC} = 0.0015B^2 - 0.7130B + 153.7 (US\$/KVar) \quad (3)$$

$$B = | R_A - R_B | \quad (4)$$

where
IC is cost of installation of FACTS device in [US\$]
C is cost of FACTS device in [US\$/kVar].
B is operating range of the FACTS device in [MVar].
C_{SVC} and C_{TCSC} are in [US\$/kVar].
R_A is reactive power flow through the branch before FACTS

device installation in [MVar].

R_B is reactive power flow through the branch after FACTS device installation in [MVar].

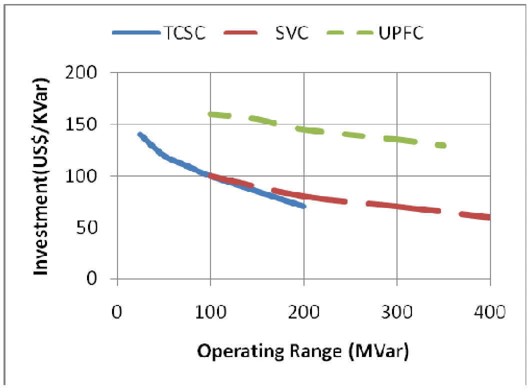

Figure 1 Graph of Cost Function SVC, TCSC and UPFC device

III. FACTS DEVICE

In this paper, steady-state models of FACTS device are developed for power flow studies. SVC is modeled using the power injection model. While, TCSC is modeled using the reactance of the transmission line. The power program has been developed in MATLAB by incorporating the mathematical models of FACTS devices.

A. Static Var Compensator (SVC)

SVC can be used for both inductive and capacitive compensation. In this paper, SVC is modeled as an ideal reactive power injection at bus i in Figure 2 and 3. The SVC consists of a thyristors controlled reactor (TCR) in parallel with a bank of capacitors. From an operational point of view, the SVC is like a shunt connected variable reactance, which both to generates or absorbs reactive power with the function of regulate the voltage magnitude at the point of connection to the power system. It is used comprehensively to provide fast reactive power and voltage regulation support. The TCR is reactive impedance is X_L, with a bidirectional thyristor valve. The controllable reactance of the TCR part is X_V, which is defined by (5);

$$X_V = X_L \frac{\pi}{2\pi - 2\alpha + \sin(2\alpha)} \qquad (5)$$

where α is the firing angle of the thyristor.
The SVC equivalent susceptance is equation (6) in [4],

$$B_{SVC} = \frac{X_L - \frac{X_C}{\pi}\left(2(\pi - \alpha) + \sin(2\alpha)\right)}{X_C X_L} \qquad (6)$$

and the reactive power equation is

$$Q_i^{SVC} = -V_i^2 B_{SVC} \qquad (7)$$

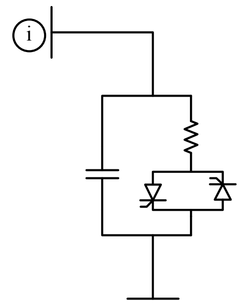

Figure 2 A Model of SVC

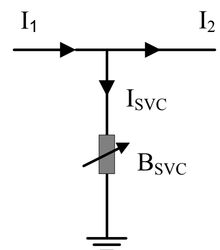

Figure 3 Block diagram of SVC

B. Thyristor Controlled Series Compensator (TCSC)

A model of TCSC as shown in Figure 4. A TCSC device consists of a capacitor bank, and also a thyristor controlled inductive branch connected in parallel and series connected to the transmission line. The equivalent reactance of TCR X_{Leq}, is shown in eq. (8). The controllable reactance, X_{TCSC}, is directly used as the control variable that can be determined by:

$$X_{TCSC} = \frac{X_C X_L}{\frac{X_C}{\pi}\left[2(\pi - \alpha) + \sin(2\alpha)\right] - X_L} \qquad (8)$$

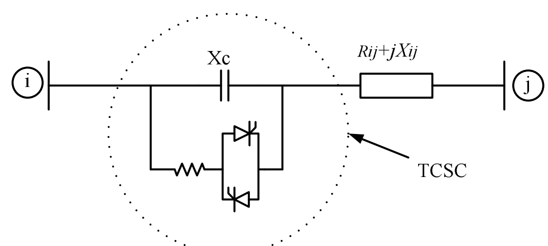

Figure 4 A Model of TCSC

The rating of TCSC is dependent upon the reactance of the transmission line where the TCSC is located. This can be written by:-

$$X_{ij} = X_{Line} + X_{TCSC} \qquad (9)$$

$$X_{TCSC} = r_{tcsc} \cdot X_{line},$$

where X_{Line} is the reactance of the transmission line and r_{tcsc} is the coefficient which represents the degree of compensation by TCSC. To avoid overcompensation, the working range of the TCSC is chosen between -0.8X_{Line} and 0.2X_{Line} [11, 12].

$$r_{tcsc\,min} = -0.8 \qquad r_{tcsc\,max} = 0.2$$

IV. PARTICLE SWARM OPTIMIZATION (PSO)

PSO algorithm originally is matured by Kennedy and Eberhant based on the social behaviors of animal swarms. From [13], PSO is created through model of bird flocking or fish schooling in two-dimensional space. The position of each particle is represented by its *xy* axis and also its velocity is expressed by *vx* and *vy*. Variation of the particle position is realized by the position and velocity information. Fish schooling optimizes a certain objective function. Each particle has known its value as P_{best} and its *x*, *y* position. This information is an analog of the personal experience of each particle. In addition, each particle knows the best value so far in the group as G_{best} among P_{best}. One of the advantages the swarm intelligence techniques is they are impressively resistant to the local optimal problem. Furthermore, PSO is employed mostly because it is simple of concept, and easy to implement. In [13], PSO is effective, and also it is a flexible mechanism to enhance global and localized exploration abilities. From [14], the main merits of PSO are simplicity in concept implementation, computationally efficient, and validity to control parameters [20]. The step by step algorithm for the proposed optimal location and sizing of multiple FACTS device is given below:

Step 1: Set the loads condition, Q_{load} at the weak bus before multiple FACTS installation (base case value). Set the loss and voltage constraints, i.e $loss1 \leq loss\_0$ and $voltage1 \geq voltage\_0$. 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 device). The random numbers, *x* as a control variables of multiple FACTS device ($x_1, x_2, \ldots x_{tn+8}, x_{tn+9}$) where $x_1, x_2, x_3, x_4, x_5 \ldots x_{tn}, x_{tn+1}, x_{tn+2}, x_{tn+3}, x_{tn+4}$ are the location of multiple FACTS device and $x_6, x_7, x_8, x_9, x_{10} \ldots x_{tn+5}, x_{tn+6}, x_{tn+7}, x_{tn+8}, x_{tn+9}$ are the sizing of multiple FACTS device.

$$[X] = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ \vdots & \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix} \tag{10}$$

where: n *is population size*

Step 4: Calculate fitness I of each particle in the population is evaluated by taken of the objective function. Determine the $P_{best\ old}$ and $G_{best\ old}$ value and it is stored. $P_{best\_old} = min(x_{tn},\ldots x_{tn+9})\_old$ and $Fitness\ I = Loss_{min\_old}$

Step 5: Update the velocity and position of the particle according the equations (11), (12) and (13). Velocity of each particle can be modified by using (11) [3], [19], [20], [21]:

$$v_i^{k+1} = w \times v + c_1 \times rand_1 \times (P_{best\,i} - s_i^k) + c_2 \times rand_2 \times (G_{best\,i} - s_i^k) \tag{11}$$

where

v_i^{k+1} is velocity of particle *i* at iterations.

w is weight function.

c_1 and c_2 is weight coefficient

$rand_1$ and $rand_2$ is random number between 0 and 1

s_i^k is current position of particle *i* at iteration k.

$P_{best\ i}$ is best position of particle *i* th up to the current iteration.

$G_{best\ i}$ is best overall position found by the particles up to the current iteration.

Weight function is given by (12) [3], [15], [19], [20], [21]:

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} \times iter \tag{12}$$

where

w_{max} is maximum weight equal to 0.9

w_{min} is minimum weight equal to 0.4

$iter_{max}$ is maximum iteration number, and

$iter$ is current iteration number

The new position can be modified using (13) [15], [16], [17], [18], [19], [20], [21].

$$s_i^{k+1} = s_i^k + v_i^{k+1} \tag{13}$$

Step 6: Calculate the fitness II and determine the P_{best_new} and G_{best_new} value and it is stored. $P_{best\_new} = min(x_{tn\_new},\ldots x_{tn+9\_new})\_new$ and $fitness\ II = Loss_{min\_new}$.

V. RESULTS AND DISCUSSION

In order to realize the effectiveness of the proposed PSO and EP technique, the IEEE 30-Bus system was tested to determine the placements and sizings of multiple FACTS device where the busdata and linedata of bus system in [13]. The parameters of the optimization algorithm are listed in Table I [20], and [21]. The FACTS device installations in the power system networks have been conducted at 30MVar load conditions subjected to bus 26 in IEEE 30 bus system.

TABLE I 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

A. Multiple SVCs Installation

Results for transmission loss reduction when bus 26 is subjected to increase the loads variation until 30MVar are tabulated in Table II and Table III. The location and sizing of SVCs to achieve loss reduction at 30MVar can be referred to the same table. The results for number and location of SVCs to minimize transmission loss with 30MVar at bus 26 using PSO technique are tabulated in Table II. For instance, the transmission loss reduced to 17.4613MW was installed three units of SVC in the system. In order to achieve this value, the locations of SVCs are bus 29, bus 21 and bus 26. Besides that, to achieve this value the sizings for SVCs are 3.8920MVar, 14.8372MVar, and 28.6368MVar as tabulated in Table III.

TABLE II RESULTS OF MULTIPLE SVC LOCATION WHEN Q_{d26} = 30MVar USING PSO TECHNIQUE.

Loss (MW)	Unit	SVCs Location (Bus)
26.5184	0	
17.5987	1	27
17.6836	2	26 28
17.4613	**3**	**29 21 26**
17.5005	5	27 12 26 19 16

TABLE III RESULTS OF MULTIPLE SVC SIZING WHEN Q_{d26} = 30MVar USING PSO TECHNIQUE.

Unit	SVCs Sizing (MVar)
0	
1	27.6946
2	29.2317 20.8601
3	**3.8920 14.8372 28.6368**
5	4.8967 76.3765 66.9451 13.0268 32.0506

Comparative studies for the multiple SVCs installation were conducted with respect to the results obtained using EP [23]. The results tabulated in Table IV for load 30MVar to bus 26. In Table IV at loading condition of 30MVar; PSO manage to reduce the transmission loss 26.5184MW to 17.4613MW, while EP managed to reduce the transmission loss to 17.5542MW. From these results as shown that, PSO technique can be optimizing the transmission loss better than EP.

TABLE IV RESULTS OF MULTIPLE SVC LOCATION AND SIZING WHEN Q_{d26} = 30MVar USING PSO AND EP TECHNIQUE.

Item \ Technique	PSO	EP
Loss (MW)	**17.4613**	**17.5542**
Number of FACTS	3	3
SVCs Location (Bus)	29, 21, 26	26, 29, 29
SVCs Sizing (MVar)	3.8920, 14.8372, 28.6368	8.2638, 89.4036, 6.0064

B. Multiple TCSC Installation

Results for transmission loss reduction when bus 26 is subjected to increase the loads variation until 30MVar are tabulated in Table V and Table VI. The location and sizing of SVCs to achieve loss reduction at 30MVar can be referred to the same table. The results for number and location of SVCs to minimize transmission loss with 30MVar at bus 26 using PSO technique are tabulated in Table V. For instance, the transmission loss reduced to 21.0910MW where installed two units of TCSCs in the system. In order to achieve this value, the location of TCSCs is line-12 and line-27. Besides that, to achieve this value the sizing for TCSC is -0.1778p.u and -0.3330p.u as tabulated in Table VI.

TABLE V RESULTS OF MULTIPLE TCSC LOCATION WHEN Q_{d26} = 30MVar USING PSO TECHNIQUE.

Loss (MW)	Unit	TCSCs Location (line)
26.5184	0	
22.6478	1	34
21.0910	**2**	**12 27**
22.5026	3	26 35 34
23.5599	5	15 23 22 34 2

TABLE VI RESULTS OF MULTIPLE TCSC LOCATION WHEN Q_{d26} = 30MVar USING PSO TECHNIQUE.

Unit	TCSCs Sizing (p.u.)
0	
1	-0.4584
2	**-0.1778 -0.3330**
3	-0.0192 -0.4249 -0.3837
5	0.00366 -0.3852 -0.2184 -0.3543 -0.028

Besides that, comparative studies for the multiple TCSCs installation were conducted with respect to the results obtained using EP [23]. The results tabulated in Table VII for load 30MVar to bus 26. In Table VII at loading condition of 30MVar; PSO manage to reduce the transmission loss 26.5184MW to 21.0910MW, while EP managed to reduce the transmission loss to 23.3369MW. Similar phenomenon is observed as those for the multiple SVCs installation.

TABLE VII RESULTS OF MULTIPLE SVC LOCATION AND SIZING WHEN Q_{d26} = 30MVar USING PSO AND EP TECHNIQUE.

Item \ Technique	PSO	EP
Loss (MW)	**21.0910**	**23.3369**
Number of FACTS	2	3
TCSCs Location (line)	12, 27	34, 29, 29
TCSCs Sizing (p.u)	-0.1778, -0.3330	-0.4100, -0.7404, -0.6578

. From the Table II until Table VI; installation multiple SVC at load bus system as the most suitable to achieve the best performance in transmission loss reduction optimized using PSO and EP.

C. Voltage Profile and Cost of Installation.

Figure 5 illustrates the voltage profile when the load increases to 30MVar at bus 26. The results show that with the multiple SVC installation at load bus system the voltage profile improvement is better with multiple TCSC installation. With the multiple SVC installation, the voltage profile increases greater than 1.00p.u.

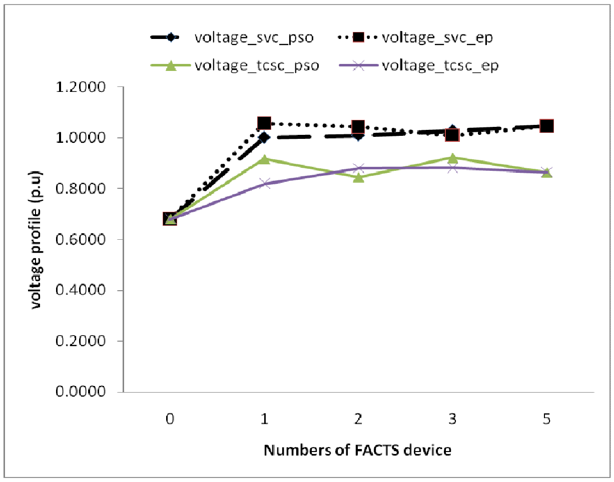

Figure 5. Results of voltage profile improvement when Q_{d26}=30MVar

Figure 6 illustrates the cost of installation FACTS device when the load increases to 30MVar at bus 26. From the chart bar it is shown that with installation of TCSC at load 30MVar the cost less than with SVC installation.

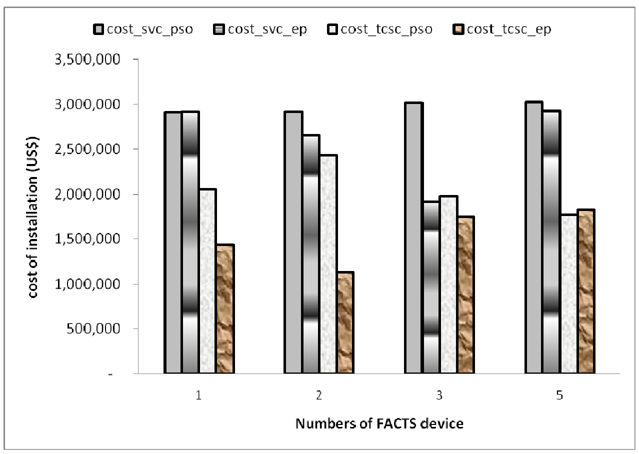

Figure 6. Results of cost of installation multiple FACTS device when Q_{d26}=30MVar

VI. CONCLUSION

An approach for transmission loss minimization by using FACTS device installation via PSO and EP as the optimization technique has been presented in this paper. Algorithm of PSO and EP technique was developed to find the best location and sizing of multiple FACTS device in order to minimize the transmission loss in the system. Besides that, the voltage profile and cost of installation of FACTS device resulted from the study could taken as reference for power system operators. Result shows that the performance of PSO have reduced the transmission loss and increased the voltage profile of the system on behalf of it as a practical technique to perform the optimization process.

REFERENCES

[1] G. Hingorani, "Power electronics in electrical utilities: role of power electronics in future power systems", in Proc 1988 IEEE, Vol. 76 No, 4 April 1988, pp.481-482. 1988.

[2] N. P. Padhly, M. A. A. Moamen, "Power flow conrol and solution with multiple and multi-type FACTS Devices", Electric Power System Research 74 , 2005, pp. 341-351. 2005.

[3] M. Saravanan, S. M. R. Slochanal, P. Venkatesh, P.S. Abraham, "Applications of PSO Technique for Optimal Location of FACTS Devices Considering System Loadability and Cost of Installation," in Proc 2005 7th International Power Engineering Conference (IPEC). pp. 716 - 721 Vol. 2. 2005.

[4] J. Chen, T. T. Lie, D. M. Vilathgamuwa, "Basic Control of Interline Power Flow Controller", IEEE Power Engineering Society Winter Meeting, Vol. 1, January, 2002, pp. 521–525. 2002.

[5] X.-P. Zhang, "Modelling of the Interline Power Flow Controller and the Generalised Unified Power Flow Controller in Newton power flow", IEE Proc. Gen. Transm. Distribution 150, 2003, pp. 268–274. 2003.

[6] A. Edris, "FACTS technology development: an update", IEEE Power Eng. Rev. 20 (3) (2000) pp. 4–9. 2000.

[7] L. Gyugyi, K. K. Sen, C. D. Schauder, "The Interline Power Flow Controller concept: a new approach to power flow management in transmission systems", IEEE Trans. Power Deliv. 14 (3) (1999), pp.1115–1123. 1999.

[8] S. Arabi, P. Kundar, R. Adapa, "Innovative techniques in modeling UPFC for power system analysis", IEEE Trans. Power Syst. 15 (1) (2000), pp. 336–341. 2000.

[9] W. L. Fang, H. W. Ngan, "Control setting of Unified Power Flow Controllers through robust load flow calculation", IEE Proc. Gen. Transm. Distribution 146 (4) (1999), pp. 365–369. 1999.

[10] A. J. Wood, F. B. Wollenberg, "Power Generation, Operation, and Control", John Wiley & Sons, Inc., pp 430-432,1996.

[11] L. J. Cai, I. Erlich, "Optimal Choice and Allocation of FACTS devices in Deregulated Electricity Market using Genetic Algorithms", IEEE PES Power Systems Conference and Exposition, 2004, 10-13 Oct. 2004, pp. 201 - 207 Vol.1. 2004.

[12] S. Biansoongnern, S. Chusanapiput, S. Phoomvuthisarn, "Optimal SVC and TCSC Placement for Minimization of Transmission Losses", International Conference on Power System Technology, PowerCon 2006. 2006, pp. 1 – 5. 2006.

[13] K. Y. Lee, M. A. El-Sharkawi, "Modern Heuristic Optimization Techniques", Institute of Electrical and Electronics Engineers, Inc. 2008.

[14] S. Gerbex, R. Cherkaoui, and A. J. Germond, "Optimal location of multi-type FACTS devices in a power system by means of genetic algorithms", IEEE Trans. Power Systems, vol. 16, pp. 537-544, August. 2001.

[15] S. A. Jumaat, I. Musirin, M. M. Othman, H. Moklis, "PSO Based Technique for Loss Minimization Considering Voltage Profile and Cost Function", The 5th International Conference Power Engineering and Optimization (PEOCO), 2011, pp. 36 – 4. 2011.

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

[17] S. A. Jumaat, I. Musirin, "Static VAR Compensator for Minimizing Transmission Loss and Installation Cost Calculation via Particle Swarm Optimization", The 4th Engineering Conference Kuching, Sarawak, Malaysia (ENCON 2011), 2011.

[18] S. A. Jumaat, I. Musirin, M. M. Othman, H. Moklis, "Optimal Location and Sizing of SVC Using Particle Swarm Optimization Technique", The 1st International Conference Informatics and_Computational Intelligence (ICI 2011), 2011 , pp. 312 – 317. 2011.

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

[20] S. A. Jumaat, I. Musirin, M. M. Othman, H. Moklis, “Placement and Sizing of Thyristor Controlled Series Compensator Using PSO Based Technique for Loss Minimization,” 2012 International Conference on Innovation, Management and Technology Research (ICIMTR2012), Malacca, pp. 640-645, 21-22 May 2012. 2012.

[21] S. A. Jumaat, I. Musirin, M. M. Othman, H. Moklis, “Placement and sizing of thyristor controlled seriescompensator using P SO based technique for loss minimization,” IEEE International Power Engineering and Optimization Conference (PEOCO), 2012 , pp. 285 – 290. 2012.