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Particle Swarm Optimization Techniques for Optimal Location and Sizing of Thyristor Controlled Series Capacitor

Siti Amely Jumaat, Ismail Musirin, Muhammad Murtadha Othman, and Hazlie Mokhlis,

Abstract-- **One of the disturbances experienced by the power system is increase in loading condition, which often led the system to no longer remains in secure operating region. When the power system is exposed to any kind of time delay and inaccessibility of control scheme, system may become inconsistent leading to uncontrolled condition. Under this condition, the main purpose of the operator is to execute control actions to get the system back into the secure operating regions. Flexible AC transmission system (FACTS) device is one of the devices, which can be inserting to control power system stability improvement. This paper describes the optimal placement and sizing of TCSC using on Particle Swarm Optimization (PSO) method. The objective function for this study is to minimize the transmission loss, increase the voltage profile, while considering the cost of installation. Effect of weight coefficient and effect of population size during the optimization process towards obtaining the solution is also explored. To validate the proposed techniques, simulations are performed on an IEEE 30-bus system.**

Index Terms**—particle swarm optimization, thyristor controlled series compensator, transmission loss, cost of installation, FACTS device.**

I. INTRODUCTION

Mechanisms of power system operations become more complex due to the increasing load demands which led to increased pressure on the transmission line and high risk of faulted lines [1]. Therefore, the power system operation in a less safe or even loss of stability following the unexpected congestion and voltage violations need to be considered. Additionally, new transmission lines could be considered as one solution to require more stable and secure operations can be practiced by the power systems. However, it is a more expensive and time-consuming which is due to economical, government, and environmental limitations. One of the alternatives to address this challenge is using the Flexible AC Transmission System (FACTS). The IEEE PES Task Force of the FACTS working group clarified FACTS device as an alternating current transmission system combining the power electronic-based and other static controllers to enhance controllability and increased the power transfer capability [2]. The main objectives to apply the FACTS device increase the power transfer potential of transmission system and to keep power flow over designed routes. The advantages of FACTS device have been informed to be increasing system transmission capacity, power flow, control versatility and quickness [5]. It is also determined that its installation has enhanced transmission system management, enlarged dynamic, transient grid stability and empowering environment [6]. FACTS devices require critical advantages for improved transmission system management, increased transmission system reliability and availability, raised dynamic and transient grid and empowering environmental benefits [7].

In this paper, PSO method is proposed to optimize the location and sizing of FACTS device for minimization of the transmission loss in power system. The TCSC is chosen as the device permits the modifications of transmission line reactance. Computer simulations were conducted on the IEEE 30 bus system. The effect of weight coefficient and effect of population size on loss minimization is also investigated.

II. TCSC MODELLING AND FORMULATION

The Thyristor Controlled Series Compensator (TCSC) is a capacitive reactance compensator which consists of a series capacitor bank shunted by a thyristor-controlled reactor in order to provide a smoothly variable series capacitive reactance [2]. The TCSC can be connected in series with the line conductors to compensate for the inductive reactance of the line. Also, it can be operating in capacitive or inductive mode. The reactance of the TCSC (X_{TCSC}) depends on its compensation ratio (TCSC) and the reactance of the line (X_L) where it is located. The impedance of a line (Z_L) connected with the TCSC is then changed by the value of X_{TCSC}. TCSC provides capacitive reactance to decrease reactance of the line when $r_{TCSC}<0$ or it can increase the reactance of the line by adding inductive reactance if $r_{TCSC}>0$. The operating range of r_{TCSC} is between $-0.7X_L$ and $0.2X_L$ [8]. The TCSC is modeled shown in Figure 1.

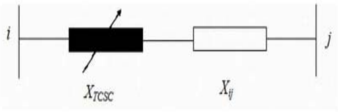

Fig. 1. TCSC Model

Siti Amely Jumaat is with Faculty of Electrical and Electronics Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia (e-mail: sitiamely1979@gmail.com).

Ismail Musirin is with the Faculty of Electrical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia (e-mail: ismailbm1@gmail.com).

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A. *Cost of Installation*

The cost of installation of TCSC device has been given by equation (1):

$$IC = C_{TCSC} \times A \times 1000 \qquad (1)$$

Where

C_{TCSC} = the cost of TCSC device [US$/KVar]

The installation of TCSC device can be calculated using the cost function given by (2) and (3):

$$C_{TCSC} = 0.001A^2 - 0.713A + 153.75 \qquad (2)$$

$$A = | Q_2 - Q_1 | \qquad (3)$$

Where

A = operating range of TCSC in [MVar]

Q_1 = reactive power flow through the branch before TCSC installation.

Q_2 = reactive power flow through the branch after TCSC installation.

III. PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization (PSO) algorithm is advanced by Kennedy and Eberhart in 1995 founded on the social activity of animal swarms (e.g. bird blocks and fish schools) [3] and its deals with problems in which a best answer can be appeared for as a point or surface in the n-dimensional space. PSO denotes a system that is initialized with a population of random results [4]. The PSO provides a populations-based search procedure in which individuals called particle and changes their positions. In PSO, the population is named “swarm” and the individual in the swarm is named “particle." Each particle is represented by its position and velocity and is referred to as a potential solution in n-dimensional search space of the problem. The particle has memory, and every particle keeps track of its earlier best position and the comparable fitness value.

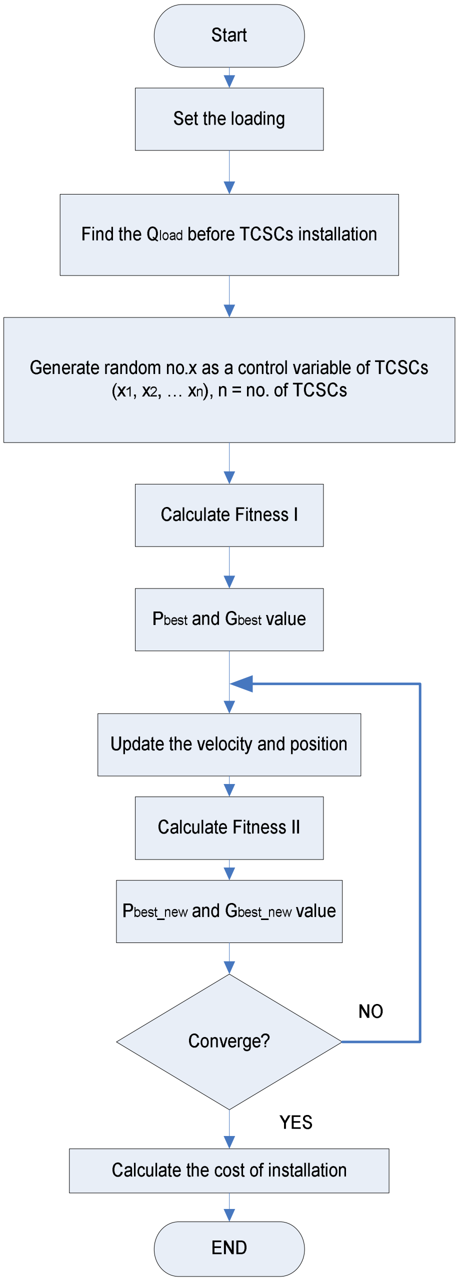

Fig. 2. Flowchart of Particle Swarm Optimization (PSO) algorithm for TCSC parameters.

The earlier best value is titled p_{best} and it is combined to a specific particle. G_{best} is the best value of all the particles’ p_{bests} in the swarm. Velocity of each particle can be modified by (4) [4, 10, 12]:

$$v_i^{k+1} = w \times v + c_1 \times rand_1 \times (P_{best\,i} - s_i^k) + c_2 \times rand_2 \times (G_{best\,i} - s_i^k) \qquad (4)$$

where

v_i^{k+1} : velocity of particle *i* at iterations.
w : weight function.
c_1 and c_2 : weight coefficient
$rand_1$ and $rand_2$: random number between 0 and 1
$s_i^{\,k}$: current position of particle *i* at iteration k.
P_{best} : best position of particle *i* th up to the current iteration
G_{best} : best overall position found by the particles up to the current iteration.

Weight function is given by (5) [6, 9, 10, 14]:

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{iter_{\max}} \times iter \quad (5).$$

where
w_{max} : maximum weight equal to 0.9
w_{min} : minimum weight equal to 0.4
$iter_{\max}$: maximum iteration number, and
$iter$: current iteration number

The new position can be modified (6)

$$s_i^{k+1} = s_i^{k} + v_i^{k+1} \quad (6).$$

The first benefit of swarm intelligence techniques is that they are excellently resistant to the local optimal problem. Additionally, PSO is employed usually because it is ordinary in concept, it is easy to implement; it is dominant, and it is a flexible mechanism to enhance global and local exploration abilities. From [13], the principal merits of PSO are ease in concept implementation, computationally efficient, and validity to control parameters. Figure 2 illustrates the flow chart for PSO algorithm in implementing TCSC installation.

IV. RESULTS AND DISCUSSION

In order to verify its feasibility, the PSO is applied to optimal placement and sizing of TCSC on the IEEE-30 bus system. The busdata and the linedata of the IEEE-30-bus system are given in [6]. The parameters of the optimization algorithms for this research are listed in Table I.

A. Transmission Loss Minimization using TCSC Installation

Result for transmission loss minimization at buses 26, and 29 are tabulated in Table II and III. The results for the location and sizing of TCSC to achieve the loss minimization at several loading conditions can be referred to the same table. For example, at loading condition is 20MVar the transmission loss has been decreased from 20.3393MW to 19.8915MW. In order to get this, the location of TCSC is line 35 and the sizing of TCSC is -0.5474p.u. The cost of installation at this scenario is US$330,590. From the Table II it is observed that the value of transmission losses decreased and the cost of installation increased accordingly as the reactive power loading is increased. Figure 3 illustrates the voltage profile at bus 26 when the load at this bus is gradually increased.

TABLE I
PARAMETER OF OPTIMIZATIONS TECHNIQUE USING PARTICLE SWARM OPTIMIZATION (PSO)

Parameters	Value
Population Size	10,20,30,50
Inertial Weight, *w*	0.4 and 0.9
Weight coefficient, $c_1 = c_2$	1, 2, 3
Number of iteration	50
Rand 1	0 to 1
Rand 2	0 to 1

TABLE II
TRANSMISSION LOSS MINIMIZATION LOAD VARIATION AT BUS 26

Loading Cond. Q_{d26} (MVar)	Loss (MW)		TCSC location	TCSC sizing	I_C (US$)
	without TCSC	with TCSC			
5	17.7175	17.6098	2	-0.0385	407,410
10	18.2785	18.0485	2	-0.0277	516,480
15	19.0625	18.8599	34	-0.4192	242,420
20	20.3393	19.8915	35	-0.5474	330,590
25	22.6325	21.2691	34	-0.3053	794,300
30	26.5184	22.6478	34	-0.4584	2,057,400

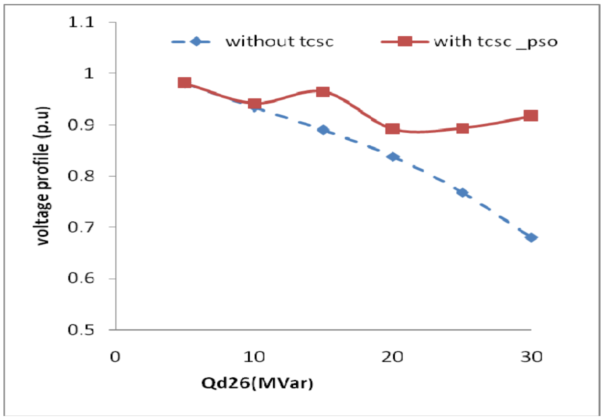

Fig. 3. Results for Voltage Profile Improvement Load Variation at Bus 26

The location and sizing of TCSC to achieve loss minimization when the load is subjected to bus 29 can be referred to Table III. For instance, at loading condition of 20MVar the transmission loss has been reduced from 19.4699MW to 19.0105MW. In order to get this, the location of TCSC is line 36 and the sizing of TCSC is -0.3445p.u. The cost of installation at this scenario is US$686,310. From the Table III it is studied that the value of transmission losses decreased, and the cost of installation raised accordingly as the reactive power loading is raised. Figure 4 illustrates the voltage profile at bus 29 when the load at this bus is gradually increased.

TABLE III
TRANSMISSION LOSS MINIMIZATION LOAD VARIATION AT BUS 29

Loading Cond. Q_{29} (MVar)	Loss (MW)		TCSC location	TCSC sizing	I_C (US$)
	without TCSC	with TCSC			
5	17.7284	17.6253	2	-0.3300	345,810
10	18.1682	17.9937	13	-0.1835	257,510
15	18.6839	18.5098	36	-0.3224	456,800
20	19.4699	19.0105	36	-0.3445	686,310
25	20.8433	19.8095	36	-0.3638	1,065,200
30	22.7158	20.6413	36	-0.3912	1,706,900

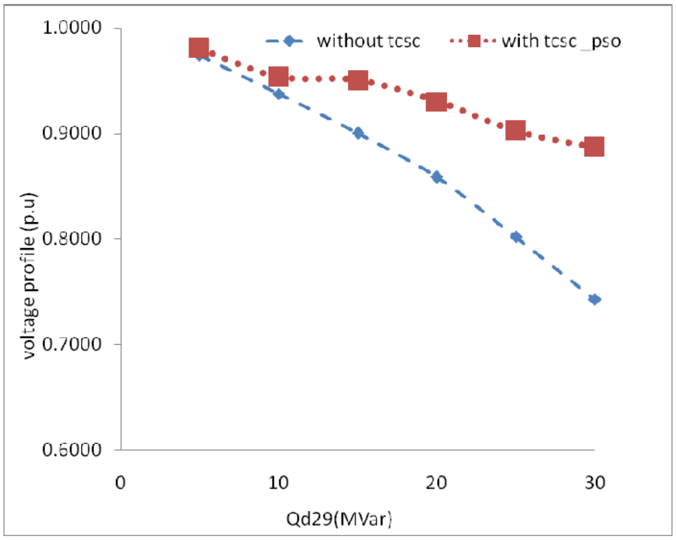

Fig. 4. Results for Voltage Profile Improvement Load variation at Bus 29

B. *Effect of weight coefficient, c_1=c_2*

The results for effect of weight coefficient, c_1 and c_2 to transmission loss minimization are tabulated in Table IV and V. In this case the value for c_1 and c_2 are adjusted between 1 and 3.

TABLE IV
RESULTS FOR THE EFFECT OF WEIGHT COEFFICIENT PERFORMED LOAD VARIATION AT BUS 26

Weight Coefficient (c_1 and c_2)	Transmission Loss for several Loading Conditions at Bus 26		
	Qd_{26}=10 (MVar)	Qd_{26}=20 (MVar)	Qd_{26}=30 (MVar)
1	18.0947	19.8922	22.6369
2	18.0419	19.5888	22.9680
3	18.0485	19.8915	22.6478

Table IV tabulates the effect of c_1 and c_2 to transmission losses when loading variation is subjected to bus 26. From the table, it is studied that the transmission loss raised consequently as the reactive power loading is increased. Large value of c_1 and c_2 gives the lowest transmission loss minimization in the system, and vice versa. For example, at Q_{d26}=20MVar with installation of TCSC, the losses value is 19.8922MW when the weight coefficient =1, while the transmission losses value is 19.5888MW when weight coefficient = 2. This indicates that higher value of the weight coefficients leads to better appearance. The same scenarios can also be practical at different loading conditions, From the results it is found that the large value of the weight coefficients has a relevant impact in completing process using the PSO method.

TABLE V
RESULTS FOR THE EFFECT OF WEIGHT COEFFICIENT PERFORMED LOAD VARIATION AT BUS 29

Weight Coefficient (c_1 and c_2)	Transmission Loss for Several Loading Condition at Bus 29		
	Qd_{29}=10 (MVar)	Qd_{29}=20 (MVar)	Qd_{29}=30 (MVar)
1	17.9948	19.0088	20.6437
2	17.9931	19.0160	20.6306
3	17.9937	19.0105	20.6413

The effect of weight coefficient to transmission loss minimization to bus 29 is tabulated in Table V. Similar phenomenon is observed as those for bus 26. For instance, at Q_{d29} = 30MVar with installation of TCSC, the losses value is 20.6437MW when the weight coefficient is 1, while the transmission losses value is 20.6306MW when the weight coefficient is 2.

C. *Effect of population size*

The results of effect of population size to transmission loss minimization are tabulated in Table VI and VII. Table VI tabulated the impact of population size to transmission loss when the reactive power loading variation is subjected to bus 26. From the table, it is studied that the transmission loss raised therefore as the reactive power loading is increased. Large population size gives the lowest transmission loss minimization in the power system, and vice versa. For instance, at Q_{d26} =10MVar with installation of TCSC, the losses value is 18.0406MW for population size of 30, while the transmission losses value is 18.0348MW when the population size is increased to 50. This shows that higher population sizes give best performance. The same scenario can also be studied at different loading conditions. Since the results, it is found that the large population size has a relevant impact in presenting optimization process using the PSO method.

TABLE VI
RESULTS FOR THE EFFECT OF SIZE
PERFORMED LOAD VARIATION AT BUS 26

Population Size	Transmission Loss Value at Bus-26 for several Loading Condition		
	Qd_{26}=10 (MVar)	Qd_{26}=20 (MVar)	Qd_{26}=30 (MVar)
10	18.0566	19.8499	23.6266
20	18.0485	19.8915	22.6478
30	18.0406	19.4515	23.1217
50	18.0348	19.8083	22.0547

The effect of population size to transmission loss minimization to bus 29 is listed in Table VII. For example, at Q_{d29} = 20MVar with installation of TCSC the losses value is 19.0089MW for population size of 30, Besides that, with installation of TCSC the losses value is 19.0087MW and the population size is increased to 50. As of the table, it is determined that the optimal transmission loss can be seen as the population size of 50. Table VI and VII: 50 is population size as the mainly suitable to perform the best performance in transmission loss minimization optimized using PSO.

TABLE VII
RESULTS FOR THE EFFECT OF SIZE
PERFORMED LOAD VARIATION AT BUS 29

Population Size	Transmission Loss Value at Bus-29 for several Loading Condition		
	Qd_{29}=10 (MVar)	Qd_{29}=20 (MVar)	Qd_{29}=30 (MVar)
10	17.9959	19.0087	20.7795
20	17.9937	19.0105	20.6413
30	17.9931	19.0089	19.0089
50	17.9931	19.0087	20.6788

V. CONCLUSION

In this paper, the PSO approach is effectively and successfully implemented to choose optimal location and sizing of TCSC to minimize the transmission loss, increase the voltage profile and calculate the cost of installation. Tests are presented on the IEEE 30-bus system. Results shows that the implementations of PSO have reduce the transmission loss and increase the voltage profile of the system. For the future work, other technique such as Evolutionary Programming (EP), Artificial Immune System (AIS), and Evolutionary-PSO (EPSO) can be included together to complete the similar mission.

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VII. BIOGRAPHIES

Siti Amely Jumaat was born in Johor, Malaysia on March 12, 1979. She graduated from the Institut Tun Hussein Onn (ITTHO-UTM) with honours degree in BSc. Electrical Eng. in 2001 and MEng. (Power), UTM in 2004. She is currently pursuing PhD in power system at Universiti Teknologi MARA, Malaysia. Her research interests include power system stability, FACTS devices and Artificial Intelligent techniques.

Associate Professor Dr. Ismail Musirin obtained Diploma of Electrical Power Engineering in 1987, Bachelor of Electrical Engineering (Hons) in 1990; both from Universiti Teknologi Malaysia, MSc in Pulsed Power Technology in 1992 from University of Strathclyde, United Kingdom and PhD in Electrical Engineering from Universiti Teknologi MARA, Malaysia in 2004. His research interest includes power system stability, optimization techniques, distributed generator and artificial intelligence. He is also a member of IEEE, IEEE Power Engineering Society and Artificial Immune System Society (ARTIST).

Dr. Muhammad Murtadha bin Othman received his B.Eng. (Hons) from Staffordshire University, England in 1998; M.Sc from Universiti Putra Malaysia in 2000 and PhD from Universiti Kebangsaan Malaysia in 2006. He currently lectures at the Universiti Teknologi MARA, Malaysia. His area of research interests are artificial intelligence, transfer capability assessment and reliability studies in deregulated power system.

Dr. Hazlie Bin Mokhlis received M.Sc. degree from University of Malaya, Malaysia and Ph.D degree in 2009 from Manchester University, United Kingdom. His research interest is Electrical power system (Transmission and Distribution) Power quality, stability, EMC & Islanding.