IJIREEICE

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 4, Issue 3, March 2016

Transmission Loss and TCSC Cost Minimization in Power System using Particle Swarm Optimization

Rahul Agrawal[1], Dr. S.K. Bharadwaj, Member IEEE[2], Dr. D. P. Kothari, Fellow IEEE[3]

Research Scholar, Department of Energy, MANIT Bhopal (M.P.), India[1]

Professor, Department of Electrical Engineering, MANIT Bhopal (M.P.), India[2]

Director Research, Gaikwad-Patil Group of Institutions, Wardha Road Nagpur (M.H.), India[3]

Abstract: The economical perspective of Flexible AC Transmission System (FACTS) installation and performance has been a crucial issue since inception and increasing every day due to strategic, technical and market constraints. The optimization of these issues plays an important role in the success of any utility and ultimately low cost availability of power at the user end. This paper presents the optimal location of Thyristor Controlled Series Capacitor (TCSC) in power system to minimize the transmission loss using Particle Swarm Optimization technique. The simulations are performed on the IEEE-14 bus system, IEEE 30 bus system and Indian 75 bus system with Newton Raphson load flow algorithm including TCSC.

Keywords: FACTS, TCSC, Transmission Loss, PSO.

I. INTRODUCTION

Current power systems, which are growing in dimension and complexity, are characterized by long distance bulk power transmissions and wide area interconnections. In the day by day operation of modern power system the most important thing is to supply steady and reliable power along with the minimum transmission loss and to take care of the load demand. The term stable and reliable is an indication of keeping up the voltage profile within an acceptable limit. This is a common objective for all utilities to minimize of power losses and maximize the quality and quantity of the power. For transmission of the maximum quantity of power either the existing transmission lines must be utilized more efficiently, or new lines should be added to the system. Therefore, it is unavoidable to employing new techniques and erecting new transmission lines. On the other hand, erecting new transmission lines is not economical and environmental issues must be considered. One of the solutions to this problem is the utilization of the current transmission lines more effectively with the use of FACTS devices. FACTS devices are solid state converters which have the ability of controlling various electrical parameters in transmission circuits. FACTS devices are one of the most common devices used in the transmission line [1]. FACTS devices can be broadly classified into two groups based on their distinct operation and performance characteristics. The first group of FACTS devices has produced the SVC, TCSC, and TCPS. The second group has resulted in the STATCOM, SSSC, UPFC and IPFC [2].

In [3] Genetic Algorithms (GA) is presented for the optimal location and optimal value of TCSC to improve Total transfer Capability (TTC). The algorithm is tested on the 4-bus test systems and it is found that result of GA method is better as compared with Repetitive Power Flow (RPF) method. The Differential Evolution (DE) to determine the optimal location, number and parameter setting of TCSC to enhance the loading capacity of the system and minimize the investment cost of the IEEE-6 bus and the IEEE-14 bus power system has been proposed by Rashed et al. [4]. To alleviate security in an IEEE-6 bus and IEEE-30 bus system using Differential Evolution and Genetic Algorithm to find the optimal location of TCSC is reported in [5]. Result show that DE is better than GA. Banu and Devaraj [6] investigate the optimal location of TCSC is using Genetic Algorithms to solve the optimal power flow problem and it is verified on IEEE-30 bus system. GA method with TCSC shows its effectiveness to increase the security margin for overload line minimization. Nguyen and Yousefi [7] proposed a Non-dominated Sorting Genetic Algorithm-II [NSGA-II], to discover the optimal location and size of TCSC. It is examined and tested on the modified IEEE 30- bus system. In [8] Sidhartha Panda presents an approach for the improvement of power system stability through the modelling, simulation and optimal setting of parameters of a thyristor controlled series compensator (TCSC) controller. For the searching of optimal controller parameters Differential Evolution is used. In [10] Differential Evolution (DE) and Genetic Algorithm is presented for the optimal allocation of TCSC for the simulation of the IEEE 5 bus and IEEE 24 bus RTS system using MATPOWER. It is shown that the results obtained from Differential Evolution are better compared to Genetic Algorithm. In [12], a PSO technique has been developed for enhancing the loadability, minimization the TCSC device cost and active power losses of the Java-Bali 24-Bus Indonesian system.

Minimization of loss is very important because it can lead to more economic operation of power system. The power can be consumed more efficiently if losses are to be minimized as possible. In this paper an objective function is formulated to find the optimal location and size of TCSC device using Particle Swarm Optimization for minimizing the transmission loss and improving the voltage profile, subjected to various equality and inequality constraints of the power system.

II. MODELING OF TCSC

TCSC is defined as "A capacitive reactance compensator which is made up of a series capacitor bank, parallel with an inductor which is thyristor controlled and shunted by the series capacitor". Thyristor Controlled Series Capacitor (TCSC) provides a powerful means of increasing and controlling power transfer level of a transmission line by varying the apparent impedance of the same transmission line. As an important component for transmission system losses and voltage control, it is usually installed on the line where the tap - setting transformer is not connected. The modelling of TCSC as a controllable reactance X_{TCSC} is shown in Fig. 1.

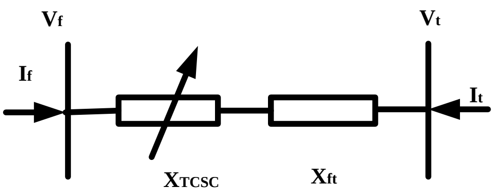

Fig. 1- The Variable reactance model of TCSC

The total reactance of the transmission line can be expressed mathematically as:

$$X_{line} = X_{TCSC} + X_{ft} \tag{1}$$

Where,

X_{ft} = Reactance of a transmission line between bus 'f' and 't'. X_{TCSC} = Reactance of the TCSC

X_{line} = Total reactance of line after placing the TCSC.

The reactance of the TCSC in term of degree of compensation of the line 'a' is expressed as

$$X_{TCSC} = a \times X_{line} \tag{2}$$

Eq. (1) is modified as

$$X_{line} = a \times X_{ft} + X_{ft} \tag{3}$$

$$X_{line} = (a+1) X_{ft} \tag{4}$$

III. OBJECTIVE FUNCTION

Power flow is an important tool of electric power system. A multi-objective function is executed utilizing Newton Raphson power flow to discover an answer comprising of both the location and size of TCSC that minimizes the aggregate power loss and keep up the voltage profile at all buses, described as follows

A. Minimize the Active Power Loss-Transmission losses in the network constitute economic loss providing no benefits. The magnitude of these losses needs to the accurately estimated and practical steps taken to minimize them. The total real power loss in an electric power system is expressed mathematically as,

$$\min f_1 = P_{loss} = \sum_{\substack{k=1 \\ j\neq i}}^{nline} G_{kj}[V_k^2 + V_j^2 - 2V_kV_j\cos(\delta_k - \delta_j)] \tag{5}$$

Where,
nline= total number of transmission lines,
G_{kj} = conductance between the bus 'k' and 'j'
V_k = voltage of the bus 'k'
V_j = voltage of the bus 'j'
δ_k = angles of bus 'k'
δj = angles of bus 'j'

B. Voltage Profile Improvement-The second objective is formulated as the minimization of the voltage deviation given as

$$\min f_2 = \sum_{i=1}^{nk} \left| V_{iref} - V_i \right| \tag{6}$$

Where V_i is the voltage magnitude at bus 'i', V_{iref} is the reference value of the voltage of bus 'i' and 'nk' is the number of load buses.

C. Minimize the Installation Cost-The total TCSC cost in US$/ KVAr is given as

$$C_{TCSC} = 0.0003S_{TCSC}^2 - 0.3051S_{TCSC} + 127.38 \tag{7}$$

Where
C_{TCSC}= the cost of TCSC devices in [US$/ KVAr]
S_{TCSC}= Operating range of TCSC
The expense of establishing of TCSC devices has been numerically formulated and given by the accompanying mathematical statement

$$\min f_3 = IC_{TCSC} = C_{TCSC} \times S_{TCSC} \times 1000 \tag{8}$$

Where,
IC_{TCSC}=the installation cost of TCSC in [US$].

The multi objective optimization problem with mathematical statement (5, 6 and 8) is change over into a single objective optimization problem with the fitness function expressed as

$$J = h_1f_1 + h_2f_2 + h_3f_3 \tag{9}$$

Where h_1, h_2 and h_3 are the scaling factor selected between 0 and 1.
The eq. (9) is subjected to the following equality and inequality constraints

Equality constraints:
The real and reactive power balance equations for n-bus power system is

$$P_i^G - P_i^D = P_i^c \tag{10}$$

$$Q_i^G - Q_i^D = Q_i^c \tag{11}$$

Where,
P_i^G = real power generation at the bus 'i'
P_i^D = real power demand at the bus 'i'
Q_i^G = reactive power generation at the bus 'i'
Q_i^D = reactive power demand at the bus 'i'

P_i^c And Q_i^c are the calculated real power and reactive power at the bus 'i'

Inequality constraints: Real power generation, reactive power generation, voltage limit, tap setting transformer limit and TCSC reactance limit considered as inequality constraints.

IV. IMPLEMENTATION OF PSO FOR THE OPTIMAL PLACEMENT OF TCSC

Particle swarm optimization (PSO) is an optimization method that gives the optimal solution for the given problem. It is a kind of algorithm utilized to discover the best solution by simulating the movement and flocking of birds. The algorithm works by initializing a flock of birds randomly over the searching space, where each bird is called a 'particle'. These 'particles' move in the search space with a certain velocity and find the best global position after some cycle. When a particle is moving through the search space, it compares its fitness value at the current position to the best fitness value it has ever reached at any cycle up to the current cycle. The best position that is associated with each individual particle is called pbest. The best position of the group achieved so far is called gbest.

This section presents the step by step implementation of the proposed algorithms to the objective function described by eq. (9)
Step-I: - Enter the line data, bus data, shunt data and generator data.
Step-II: - Set the location and sizing of single TCSC as particles.
Step-III: - Read the line data, bus data, shunt data and generator data. Run the load flow and determine voltage for all the buses.
Step-IV: - Evaluate Transmission losses before TCSC is placed.
Step-V: - Initialization of PSO parameter as per Table-1
Step-VI: - Generate the particle position randomly.
Step-VII: - Generate the particle velocity randomly.
Step-VIII: - Run the load flows by placing a particle 'i' at the buses.
Step-IX: - Evaluate the fitness function.
Step-X: - Determine pbest value and then identify gbest value.
Step-XI:-Update the velocities and position of particle.

$$V_i^{k+1} = wV_i^k + c_1 rand_1 * \left(pbest_i^k - x_i^k\right) + c_2 rand_2 * \left(pbest_i^k - x_i^k\right) \quad (10)$$

$$x_i^{k+1} = x_i^k + V_i^{k+1} \quad (11)$$

Where,
w= Weighting factor
c_1= Cognitive constant
c_2= Social acceleration constant
$rand_1$= Uniformly distributed random numbers between (0, 1)
$rand_2$= Uniformly distributed random numbers between (0, 1)
x_i^k= Current position of the particle 'i' at the iteration k
V_i^k= Constant velocity of the particle 'i' at iteration k
x_i^{k+1}= Current position of particle 'i' at the iteration k+1
V_i^{k+1}= Current velocity of particle 'i' at the iteration k+1
Step-XII: - Update the pbest and gbest value.
Step-XIII: -If maximum iteration number is reached, then go to next step else go to step II.
Step-XIV:-Evaluate transmission losses after TCSC is placed.
Step-XV: - Stop

The flow chart of the PSO algorithms with optimal location and sizing of TCSC is given in Fig. 2.

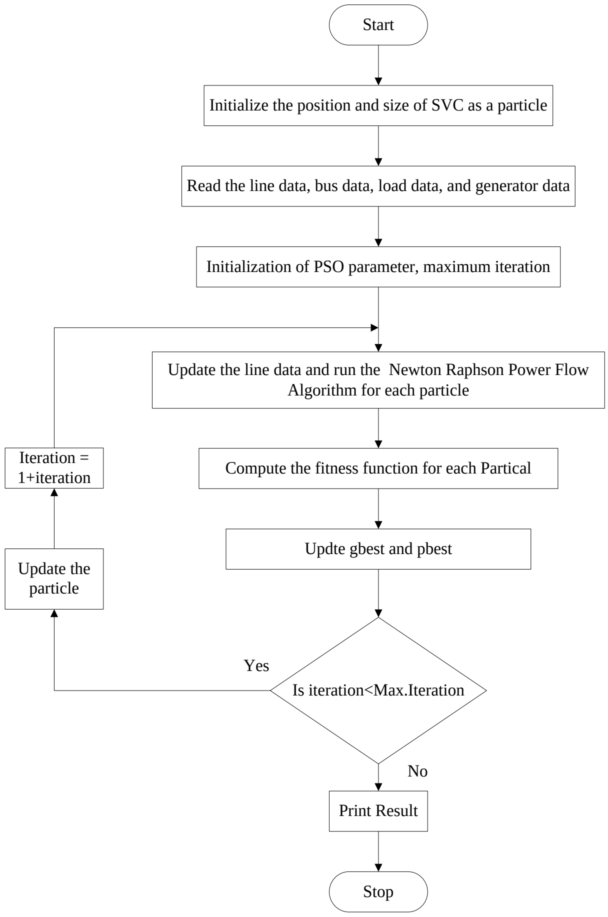

Fig. 2- Flow Chart of PSO Algorithm with TCSC

V. TEST RESULTS AND DISCUSSION

The simulation is performed on an IEEE 14 bus system [9], IEEE 30 bus system [9] and UPSEB 75 bus [11] system using MATLAB. The parameter value of the PSO is listed in Table 1.

Table 1-Parameter values for PSO

PSO Parameter	
Parameter	Value
Number of iterations	35
Number of design variable	2
Population size	20
Inertial Weight, w	0.88 to 0.38
Constant, C1	2
Constant, C2	2
rand1	0 to 1
rand2	0 to 1

 DOI 10.17148/IJIREEICE.2016.4360

The real power loss with TCSC and without TCSC is given in Table 2. The real power loss without TCSC for test systems 1, 2 and 3 are 11.165 MW, 6.8212 MW and 224.3341 MW respectively. From the Table 2 it is observed that with TCSC using PSO for test systems 1, 2 and 3 the real power losses are 7.8779 MW, 4.7883 MW and 168.4428 MW respectively.

Table-2 Real power Transmission loss in MW with TCSC using PSO

S.N.	Bus System	Without TCSC	With TCSC
1	IEEE-14 Bus System	11.165	7.8779
2	IEEE-30 Bus System	6.8212	4.7883
3	UPSEB-75 Bus System	224.3341	168.4428

The real power loss in the test system 1, 2 and 3 with 35 iterations are shown in Fig. 3, Fig.4 and Fig. 5. From the figures it is evident that with the iterations, the loss is reduced.

The optimal location, rating and installation cost of TCSC obtained from PSO is presented in Table 3. From the table 3 it is visible that if single TCSC with capacitive reactance of 0.178 p.u. is installed in line 9, for the test systems 1 the active power losses are decreasing. Also, if capacitive reactance of 0.148 p.u. and 0.067 p.u. is located in line number 6 and 48 for the test systems 2 and 3 respectively, the active power losses are decreased. The installation cost of the TCSC with PSO for the test system 1, 2 and 3 is 27457 US$, 22795 US$ and 10304 US$ respectively.

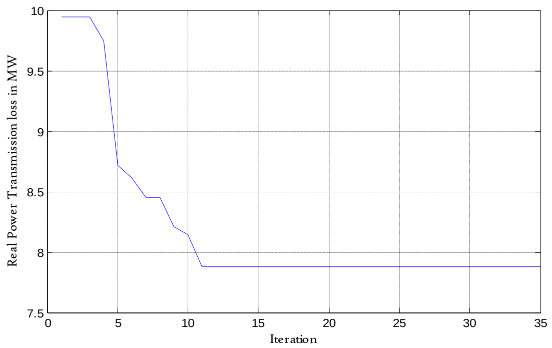

Fig.3-Real power transmission loss of IEEE 14 Bus system with PSO

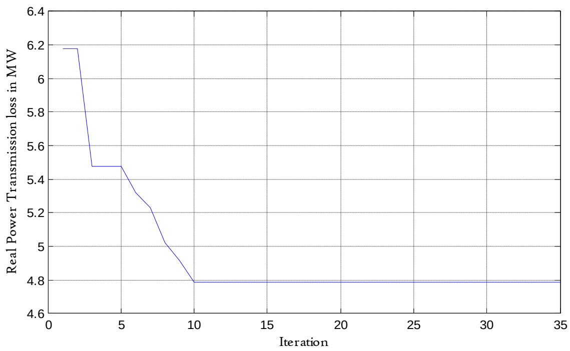

Fig.4-Real power transmission loss of IEEE 30 Bus system with PSO

This result shows that power transfer capacity of the test systems 1, 2 and 3 is also increased.

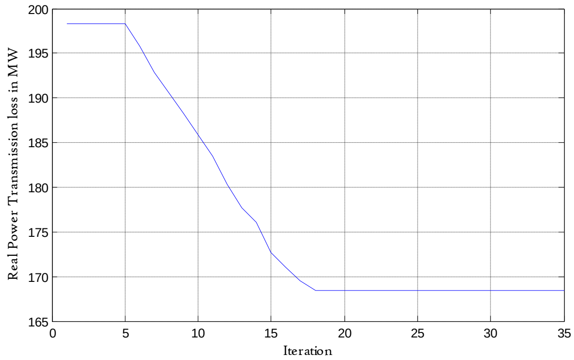

Fig.5-Real power transmission loss of UPSEB 75 Bus system with PSO

Table-3 Optimal Location and Sizing of TCSC with PSO

S.N.	Bus System	a	XTCSC (pu)	IC (US$)	Line Number
1	TS-1	-0.8	-0.1784	27457	9
2	TS-2	-0.8	-0.1482	22795	6
3	TS-3	-0.8	-0.067	10304	48

The real power line losses and reactive power line losses without TCSC and with TCSC for the test system 1 are given in Table 4. It is observed from the Table 4 that after position of TCSC in the line, the line losses are decreased.

Table-4 Line Losses of the line in MW with PSO

S.N	From Bus	To Bus	Real Power Line Losses		Reactive Power Line Losses	
			Without TCSC	With TCSC	Without TCSC	With TCSC
1	8	3	0	0	1.98294	1.829
2	9	6	0	0	0.8021	0.778
3	9	7	0	0	1.08253	1.024
4	1	8	2.015996	1.604	5.4772	4.235
5	2	8	0.618528	0.333	0.09396	-0.567
6	4	9	0.579853	0.005	-0.2926	-1.689
7	9	8	0.451873	0.244	0.76912	0.289
8	1	2	3.243583	3.771	6.99502	8.101
9	2	4	2.14406	0.409	6.7228	1.068
10	6	5	0	0	0.87675	0.967
11	2	9	1.243804	0.661	1.81189	0.506
12	6	7	0	0	1.17338	1.15
13	7	10	0.010945	0.01	0.02907	0.027
14	3	11	0.156103	0.155	0.3269	0.329
15	3	12	0.092391	0.089	0.19229	0.186
16	3	13	0.303495	0.292	0.59768	0.579
17	7	14	0.061237	0.064	0.13026	0.131
18	10	11	0.069418	0.071	0.1625	0.169
19	12	13	0.014901	0.015	0.01348	0.013
20	13	14	0.158736	0.154	0.32319	0.319

The bus voltage for the test system 1, 2 and 3 with TCSC using PSO is shown in Fig. 6, Fig. 7 and Fig. 8 respectively. From the figures it is observed that, after placement of TCSC the voltage of all the load buses is enhanced.

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 4, Issue 3, March 2016

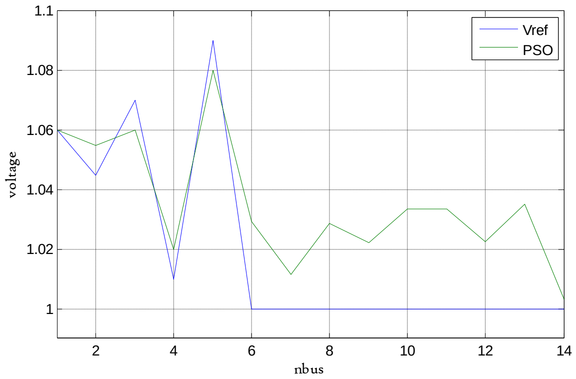

Fig.6- Bus Voltage of IEEE-14 Bus system with TCSC using PSO

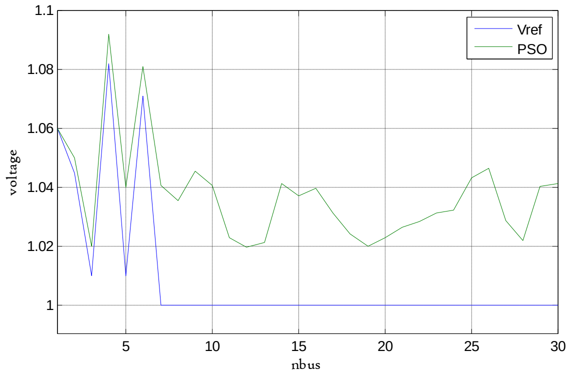

Fig.7- Bus Voltage of IEEE 30 Bus system with TCSC using PSO

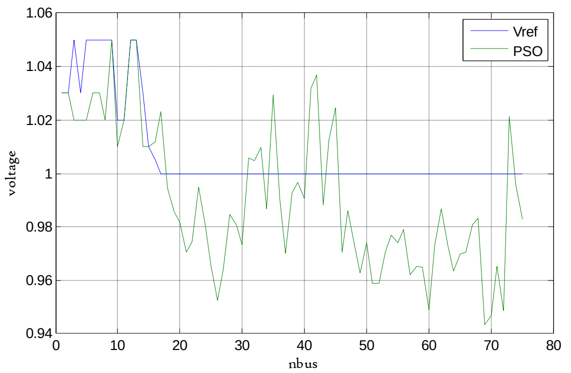

Fig.8- Bus Voltage of UPSEB 75 Bus system with TCSC using PSO

VI. CONCLUSION

This work proposes the optimal location of single TCSC using particle swarm optimization technique. The algorithms find the optimal location of single TCSC between the lines, among a large number of combinations by optimizing the objective function. From the results, it is observed that the installation cost and real power transmission losses are reduced in the power system. It is also shown that voltage of the buses is kept within ±5% limit of the corresponding bus voltage, while considering system constraints. The obtained results of the simulation on the considered test systems show the effectiveness and performance of the proposed PSO algorithms.

REFERENCES

[1] Hingorani, N. G. and Gyugyi, L., Understanding FACTS, Concepts and Technology of Flexible AC Transmission Systems, IEEE Press, 2000
[2] Y.H. Song & A.T. John, Flexible AC Transmission Systems (FACTS), IEE Power and Energy Series, 1999
[3] Manoj Fozdar, GA Based Optimizations of Thyristor Controlled Series Capacitor, IEEE UPEC, pp.-392-396, 2007
[4] Ghamgeen I. Rashed, Yuanzhang Sun, Kai-Pei Liu, Optimal Placement of Thyristor Controlled Series Compensation in Power System Based on Differential Evolution Algorithm, IEEE ICNC, Vol. 4, pp. 2204-2210, 2011
[5] Ghamgeen Izat Rashed, Yuanzhang Sun, Optimal Placement of Thyristor Controlled Series Compensation for Enhancing Power System Security Based on Computational Intelligence Techniques, Procedia Engineering, Vol. 15, pp. 908- 914, 2011
[6] R.Narmatha Banu and D.Devaraj, Genetic Algorithm Approach for Optimal Power Flow with FACTS devices, IEEE Conference Intelligent Systems, Vol. 23, pp. 11-16, 2008
[7] T.T Nguyen, Ashkan Yousefi, Multi-Objective approach for optimal location of TCSC using NSGA II, IEEE International Conference on Power System Technology, pp 1-7, 2010
[8] Sidhartha Panda, "Differential evolutionary algorithm for TCSC-based controller design", Simulation Modelling Practice and Theory, pp 1618-1634, 2009.
[9] Satish Joshi, Voltage Stability and Contingency Selection Studies in Electrical Power System, Ph. D. Thesis, IIT Kanpur, 1995
[10] Bongkoj Sookananta, Determination of FACTS Placement using Differential Evolution Technique, International Conference on Electrical Engineering and Informatics 5-7 August 2009, Selangor, Malaysia, pp. 672-675, 2009
[11] Mitresh Kumar Verma, Voltage Stability Considered Power System Security Assessment and its Enhancement Using FACTS Controllers, Ph. D. Thesis, IIT Kanpur, 2005
[12] I M Wartana, J G Singh, Werakorn Ongsakul, Ni Putu Agustini, Optimal Placement of A Series FACTS Controller in Java-Bali 24-bus Indonesian System for Maximizing System Loadability by Evolutionary Optimization Technique, IEEE ISMS, pp. 516-521, 2012

BIOGRAPHIES

Rahul Agrawal was born in Hoshangabad, (MP), India in 1978. He obtained his B.E. Degree in Electrical Engineering from JIT Khargone, India in 2001, and M.E. in Power Electronics from SGSITS Indore, India in 2008. Presently, he is an Assistant Professor with the Department of Electrical Engineering, Vindhya Institute of Technology & Science Indore, and pursuing a Ph.D. at Maulana Azad National Institute of Technology Bhopal, India. He has 14 years of teaching experience. He has many research publications in various International and national conferences and journals. His current research interests are in the areas of power electronics, HVDC and FACTs. He is a student member of IEEE and life member of ISTE, India.

Dr. S. K. Bharadwaj is a professor in the Department of Electrical Engineering, MANIT, BHOPAL, MP, India. He obtained his B. Tech. Degree from IIT, BHU Varanasi, UP, India in 1975, M. Tech. From NIT Kurukshetra in 1979 and then PhD in 1999. He has a vast experience of teaching Power System, Electrical Machines, Instrumentation and Digital

DOI 10.17148/IJIREEICE.2016.4360

Control to UG & PG students. He is a fellow of the Institution of Engineers (India), Life Member of ISTE, Life Member of CSI, Life Member of System Society of India and Life Member of Solar Society of India. He has been nominated as member of expert team of National Board of Accreditation, AICTE New Delhi, India. He has published papers in National and International Conferences & Journals.

D.P Kothari (Fellow IEEE-2011) received the B.E degree in electrical engineering in 1967, the M.E. degree in power systems in 1969, and the Ph.D. in 1975 from Birla Institute of Technology and Science, Pilani, India. He was a Professor with the Centre for Energy Studies at IIT Delhi (1995-1997) and Principal, Visvesvarya Regional Engineering College, Nagpur (1997-1998). He has also been Director I/C of the Indian Institute of Technology (IIT) Delhi (2005), New Delhi, India, and the Vice Chancellor of Vellore Institute of Technology, Vellore, India. He has published/presented over 760 papers in national and international journals/ conferences. He has authored/ co-authored 40 books. He has recipient of many awards and he is a fellow of IEEE, Fellow of Institute of Engineers (FIE), Fellow of Indian National Academy of Science (FNASc) and Fellow of Indian Academy of Engineers. His fields of specialization include optimal hydrothermal scheduling, unit commitment, maintenance scheduling, energy conservation, and power quality.