International Journal of Engineering Research and Development
e-ISSN: 2278-067X, **p**-ISSN: 2278-800X, www.ijerd.com
Volume 5, Issue 11 (February 2013), PP. 01-08

Allocation of SSSC FACTS Device for Optimal Power Flow Solution Using DE Approach

D. Bharath kumar[1], P.Ramesh[2], K.Padma[3]
[1,2]P.G. Scholar, Department of Electrical Engineering, A.U.C.E (A), A.U., Visakhapatnam-530003
[3]Assistant Professor, Department of Electrical Engineering, A.U.C.E (A), A.U., Visakhapatnam-530003

Abstract:- In this paper, the DE optimization technique is effectively used to solve the optimal power flow problem by incorporating Facts device i.e. SSSC to enhance the performance of the power system. The standard IEEE 30-bus test system is considered to examine proposed approach without and with SSSC FACTS device. Results show that proposed DE algorithm gives better solution than other algorithms to enhance the system performance with SSSC device.

Keywords:- Differential Evolution (DE), FACTS device, Newton Raphson method, Optimal Power Flow solution, SSSC FACTS device.

I. INTRODUCTION

In today's highly complex and interconnected power systems, there is a great need to improve electric power utilization while still maintaining reliability and security. While power flows in some of the transmission lines are well below their normal limits, other lines are overloaded, which has an overall effect on deteriorating voltage profiles and decreasing system stability and security. Because of all that, it becomes more important to control the power flow along the transmission lines to meet the needs of power transfer. On the other hand, the fast development of solid-state technology has introduced a series of power electronic devices that made FACTS a promising pattern of future power systems. Power flow is a function of transmission line impedance, the magnitude of the sending end and receiving end voltages and the phase angle between voltages. By controlling one or a combination of the power flow arrangements, it is possible to control the active as well as the reactive power flow in the transmission line [1]. With FACTS technology [2], such as Static Var Compensators (SVCs), Static Synchronous Compensators (STATCOMs), Static Synchronous Series Compensators (SSSCs) and Unified Power Flow Controller (UPFC) etc., bus voltages, line impedances and phase angles in the power system can be regulated rapidly and flexibly. Thus, FACTS can facilitate the power flow control, enhance the power transfer capability, decrease the generation cost, and improve the security and stability of the power system.

In this paper, SSSC FACTS controller are incorporated to solve an optimization problem with different objectives such as minimization of cost of generation, real power loss, voltage profile enhancement and improvement of voltage stability L-index as these are the basis for improved system performance. The Differential Evolution (DE) algorithm is used effectively to solve the optimal power flow problem, it results great characteristics and capability of determining global optima, by incorporating a set of constraints including voltage stability and FACTS device. In order to calculate the power losses and check the system operating constraints such as voltage profile, a load flow model is used. An existing Newton-Raphson load flow algorithm is introduced [2]. This model is further modified to incorporate SSSC *FACTS* device into the network and *DE* technique is applied to the modified model to enhance the performance of the power system. Thus, effectiveness of the proposed method was tested on standard IEEE 30-bus test system and comparison was made on the performance of system with other OPF methods.

The organization of this paper is as follows. Section 2 addresses the Computation of Voltage Stability Index (L-index). FACTS controller is explained in Section 3. Mathematical formulation of optimal power flow problem is given in section 4. Differential Evolution Algorithm Optimization Process is represented in section 5. The overall computational procedure is given in the section 6. The simulation results on test system are illustrated in section 7. Finally, the conclusion is given in section8.

This document is a template. An electronic copy can be downloaded from the conference website. For questions on paper guidelines, please contact the publications committee as indicated on the website. Information about final paper submission is available from the website.

II. VOLTAGE STABILITY INDEX (L-INDEX) COMPUTATION

The voltage stability L-index is a good voltage stability indicator with its value change between zero (no load) and one (voltage collapse) [3]. Moreover, it can be used as a quantitative measure to estimate the voltage stability margin against the operating point. For a given system operating condition, using the load flow (state estimation) results, the voltage stability L-index is computed as [4]:

$$L_j = \left| 1 - \sum_{i=1}^{g} F_{ji} \frac{V_i}{V_j} \right| \quad j = g+1,\ldots,n \tag{1}$$

All the terms within the sigma on the RHS of equation (1) are complex quantities. The values of F_{ji} are btained from the network *Y*-bus matrix.

For stability, the index L_j must not be violated (maximum limit=1) for any of the nodes j. Hence, the global indicator L_j describing the stability of the complete subsystem is given by maximum of L_j for all j (load buses). An L_j-index value away from 1 and close to 0 indicates an improved system security. The advantage of this L_j-index lies in the simplicity of the numerical calculation and expressiveness of the results.

III. FACTS CONTROLLERS

FACTS controllers are able to change in a fast and effective way, the network parameters in order to achieve better system performance. FACTS controllers [5,6] such as phase shifter, shunt, or series compensation and the most recent developed converter-based power electronic controllers, make it possible to control circuit impedance, voltage angle and power flow for optimal operation performance of power systems, facilitate the development of competitive electric energy markets, stimulate the unbundling the power generation from transmission and mandate open access to transmission services, etc. The benefit brought about by FACTS includes improvement of system behavior and enhancement of system reliability. However, their main function is to control power flows.

3.1. Static Synchronous Series Compensator (SSSC):

A SSSC [7] usually consists of a coupling transformer, an inverter and a capacitor. The SSSC is series connected with a transmission line through the coupling transformer.

It is assumed here that the transmission line is series connected via the SSSC bus *j*. The active and reactive power flows of the SSSC branch *i-j* entering the bus *j* are equal to the sending end active and reactive power flows of the transmission line, respectively. In principle, the SSSC can generate and insert a series voltage, which can be regulated to change the impedance (more precisely reactance) of the transmission line. In this way, the power flow of the transmission line or the voltage of the bus, which the SSSC is connected with, can be controlled.

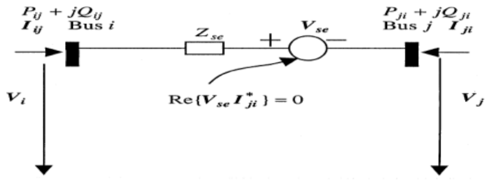

Fig. 1: Equivalent Circuit of SSSC

The equivalent circuit of SSSC is as shown in the Fig.1. From the equivalent circuit the power flow constraints of the SSSC can be given as:

$$P_{ij} = V_i^2 g_{ii} - V_i V_j (g_{ij}\cos\theta_{ij} + b_{ij}\sin\theta_{ij}) - V_i V_{se}(g_{ij}\cos(\theta_i - \theta_{se}) + b_{ij}\sin(\theta_i - \theta_{se})) \tag{2}$$

$$Q_{ij} = -V_i^2 b_{ii} - V_i V_j (g_{ij}\sin\theta_{ij} - b_{ij}\cos\theta_{ij}) - V_i V_{se}(g_{ij}\sin(\theta_i - \theta_{se}) - b_{ij}\cos(\theta_i - \theta_{se})) \tag{3}$$

$$P_{ji} = V_j^2 g_{ji} - V_i V_j (g_{ij}\cos\theta_{ji} + b_{ij}\sin\theta_{ji}) + V_j V_{se}(g_{ij}\cos(\theta_j - \theta_{se}) + b_{ij}\sin(\theta_j - \theta_{se})) \tag{4}$$

$$Q_{ji} = -V_j^2 b_{jj} - V_i V_j (g_{ij}\sin\theta_{ji} - b_{ij}\cos\theta_{ji}) + V_j V_{se}(g_{ij}\sin(\theta_j - \theta_{se}) - b_{ij}\cos(\theta_j - \theta_{se})) \tag{5}$$

where $g_{ij} + jb_{ij} = 1/Z_{se}, g_{ii} = g_{ij}, b_{ii} = b_{ij}, g_{jj} = g_{ij}, b_{jj} = b_{ij}$ (6)

The active and reactive power flow constraints is:

$$P_{ji} - P_{ji}^{specified} = 0 \tag{7}$$

$$Q_{ji} - Q_{ji}^{specified} = 0 \quad (8)$$

where $P_{ji}^{specified}$ and $Q_{ji}^{specified}$ are specified active and reactive power flows.

The equivalent voltage injection $V_{se}\angle\theta se$ bound constraints are as :

$$V_{se}^{\min} \le V_{se} \le V_{se}^{\max} \quad (9)$$

$$\theta_{se}^{\min} \le \theta_{se} \le \theta_{se}^{\max} \quad (10)$$

IV. MATHEMATICAL FORMULATION OF OPF PROBLEM

Mathematically, the OPF problem with FACTS is solved to minimize fuel cost of generation maintaining thermal and voltage constraints can be formulated as follows [14]-[22]:

Minimize $F = (\sum_{i=1}^{NG} (a_i P_{Gi}^2 + b_i P_{Gi} + C_i)$ (11)

The minimization problem is subjected to following equality and inequality constraints

4.1 Equality Constraints: These are the sets of nonlinear power flow equations that govern the power system:

$$P_{Gi} - P_{Di} - \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) = 0 \quad (12)$$

$$Q_{Gi} - Q_{Di} + \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) = 0 \quad (13)$$

where P_{Gi} and Q_{Gi} are the real and reactive power outputs injected at bus i, the load demand at the same bus is represented by P_{Di} and Q_{Di}, and elements of the bus admittance matrix are represented by $|Y_{ij}|$ and θ_{ij}.

4.2 Inequality Constraints: These are the set of constraints that represent the system operational and security limits like the bounds on the following:

1) generators real and reactive power outputs:

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max}, i = 1, \ldots, ng \quad (14)$$

$$Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max}, i = 1, \ldots, ng \quad (15)$$

2) voltage magnitudes at each bus in the network:

$$V_i^{\min} \le V_i \le V_i^{\max}, i = 1, \ldots, ng \quad (16)$$

3) transformer tap settings:

$$T_i^{\min} \le T_i \le T_i^{\max}, i = 1, \ldots, NT \quad (17)$$

4) reactive power injections due to capacitor banks:

$$Q_{Ci}^{\min} \le Q_{Ci} \le Q_{Ci}^{\max}, i = 1, \ldots, CS \quad (18)$$

5) transmission lines loading:

$$S_i \le S_i^{\max}, i = 1, \ldots, nl \quad (19)$$

6) voltage stability index:

$$Lj_i \le Lj_i^{\max}, i = 1, \ldots, NL \quad (20)$$

7) SSSC device constraints:

SSSC Series voltage source magnitude

$$V_{se}^{\min} \le V_{se} \le V_{se}^{\max} \quad (21)$$

Series voltage source angle

$$\theta_{se}^{\min} \le \theta_{se} \le \theta_{se}^{\max} \quad (22)$$

The equality constraints are satisfied by running the power flow program. The generator bus real power generations (P_{gi}), generator terminal voltages (V_{gi}), transformer tap settings (T_i), the reactive power generation of capacitor bank (Q_{Ci}), P_{ji} and Q_{ji} of SSSC are control variables and they are self-restricted by the representation itself. The active power generation at the slack bus (P_{gs}), load bus voltages (V_{Li}) and reactive power generation (Q_{gi}), line flows (S_i), and voltage stability (L_j)-index are state variables which are restricted through penalty function approach.

V. DIFFERENTIAL EVOLUTION ALGORITHM OPTIMIZATION PROCESS

A differential evolution algorithm (DEA) is an evolutionary computation method that was originally introduced by Storn and Price in 1995. DEA uses rather greedy selection and less stochastic approach to solve optimisation problems than other classical EAs. There are also a number of significant advantages when using DEA.

A Initialization:

In the first step of the DEA optimization process, the population of candidate solutions must be initialized. Typically, each decision parameter in every vector of the initial population is assigned a randomly chosen value from within its corresponding feasible bounds:

$$x_{j,i}^{(G=0)} = x_j^{\min} + rand_{[0,1]} \cdot \left(x_j^{max} - x_j^{\min}\right) \quad (23)$$

where $i = 1,\ldots,NP$ and $j = 1,\ldots,D$. $x_{j,i}^{(G=0)}$ is the initial value (G=0) of the jth parameter of the i^{th} individual vector. $x_j^{\min}$ and $x_j^{\max}$ are the lower and upper bounds of the j^{th} decision parameter, respectively. Once every vector of the population has been initialized, its corresponding fitness value is calculated and stored for future reference.

B. Mutation:

The DEA optimisation process is carried out by applying the following three basic genetic operations; mutation, recombination (also known as crossover) and selection. After the population is initialised, the operators of mutation, crossover and selection create the population of the next generation $P^{(G+1)}$ by using the current population $P^{(G)}$. At every generation G, each vector in the population has to serve once as a target vector $X_i^{(G)}$, the parameter vector has index i, and is compared with a mutant vector. The mutation operator generates mutant vectors ($V_i^{(G)}$) by perturbing a randomly selected vector (X_{r1}) with the difference of two other randomly selected vectors (X_{r2} and X_{r3}).

$$V_i^{(G)} = X_{r1}^{(G)} + F\ X_{r2}^{(G)} - X_{r3}^{(G)}, \qquad i = 1,\ldots,N_p \quad (24)$$

Vector indices $r1$, $r2$ and $r3$ are randomly chosen, which $r1$, $r2$ and $r3$ {1,…,NP} and $r1 \neq r2 \neq r3 \neq i$. $Xr1$, $Xr2$ and $Xr3$ are selected anew for each parent vector. F is a user-defined constant known as the "scaling mutation factor", which is typically chosen from within the range [0, 1+] .

C. Crossover:

In this step, crossover operation is applied in DEA because it helps to increase the diversity among the mutant parameter vectors. At the generation G, the crossover operation creates trial vectors (U_i) by mixing the parameters of the mutant vectors (V_i) with the target vectors (X_i) according to a selected probability distribution:

$$U_i^{(G)} = u_{j,i}^{(G)} = \begin{cases} v_{j,i}^{(G)} \ \text{if}\ rand_j(0,1) \leq CR \ \text{or}\ j = s \\ x_{j,i}^{(G)} \ \text{otherwise} \end{cases} \quad (25)$$

The crossover constant CR is a user-defined value (known as the "crossover probability"), which is usually selected from within the range [0, 1]. The crossover constant controls the diversity of the population and aids the algorithm to escape from local optima. $rand_j$ is a uniformly distributed random number within the range (0,1) generated anew for each value of j. s is the trial parameter with randomly chosen index {1,…,D}, which ensures that the trial vector gets at least one parameter from the mutant vector.

5.4 Selection: Finally, the selection operator is applied in the last stage of the DEA procedure. The selection operator chooses the vectors that are going to compose the population in the next generation. This operator compares the fitness of the trial vector and the corresponding target vector and selects the one that provides the best solution. The fitter of the two vectors is then allowed to advance into the next generation according to equation (26):

$$X_i^{(G+1)} = \begin{cases} U_i^{(G)} \ \text{if}\ f\left(U_i^{(G)}\right) \leq f\left(X_i^{(G)}\right) \\ X_i^{(G)} \ \text{otherwise} \end{cases} \quad (26)$$

The DEA optimization process is repeated across generations to improve the fitness of individuals. The overall optimization process is stopped whenever maximum number of generations is reached or other predetermined convergence criterion is satisfied.

VI. OVERALL COMPUTATIONAL PROCEDURE FOR SOLVING THE PROBLEM

The implementation steps of the proposed DE based algorithm can be written as follows;

Step 1: Input the system data for load flow analysis
Step 2: Select FACTS device and its location in the system
Step 3: At the generation Gen =0; set the simulation parameters of DE and randomly initialize k individuals within respective limits and save them in the archive.
Step 4: For each individual in the archive, run power flow under the selected network contingency to determine load bus voltages, angles, load bus voltage stability indices, generator reactive power outputs and calculate line power flows.
Step 5: Evaluate the penalty functions
Step 6: Evaluate the objective function values and the corresponding fitness values for each individual.
Step 7: Find the new generation individuals and store them.
Step 8: Increase the generation counter Gen = Gen+1.
Step 9: Apply the DE operators to generate new k individuals
Step 10: For each new individual in the archive, run power flow to determine load bus voltages, angles, load bus voltage stability indices, generator reactive power outputs and calculate line power flows.
Step 11: Evaluate the penalty functions
Step 12: Evaluate the objective function values and the corresponding fitness values for each new individual.
Step 13: Apply the selection operator of DE and update the individuals.
Step 14: Update the new generation and store them.
Step 15: If one of stopping criterion have not been met, repeat steps 4-14. Else go to stop 16
Step 16: Print the results

VII. SIMULATION RESULTS

The proposed DE algorithm is employed to solve optimal power flow problem by incorporating SSSC FACTS device for enhancement of system performance on standard IEEE 30-bus test system. The DE parameters used for the simulation are summarized in Table I.

Table I: Optimal Parameter Settings for DE

S.No.	Parameters of Differential evolution	
	Parameter	**values**
1.	Population size	50
2.	Number of iterations	250
3.	Scaling mutation factor, F	0.5
4.	Crossover Factor, CR	0.9

The network and load data for this system is taken from [22]. To test the ability of the proposed DE algorithm one objective function is considered that is minimization of cost of generation. In order to show the affect of power flow control capability of the FACTS device in proposed DE OPF algorithm, two sub case studies are carried out on the standard IEEE 30-bus system.

Case (a): power system normal operation (without FACTS devices installation),

Case (b): one SSSC device is installed in line connected between buses 9 and 10 with real and reactive power flows (P_{ji} , and Q_{ji}) as ± 1.25 times of base case values. The ratings of SSSC are: V_{se} is in the range [0.001, 0.2], θ_{se} is in the range [0,2 π].

The first case is the normal operation of network without using any FACTS device, in second case optimal location of device has been considered.

From the Table II, it can be seen that details of the control variables and the installation of SSSC in the network gives the best performance of the system in the network in terms of reduction in cost of generation, power loss reduction, maximum of voltage stability indices. It also gives that DE algorithm is able to enhance the system performance while maintaining all control variables and reactive power outputs within their limits.

Table II: Optimal settings of control variables for IEEE 30-bus system

Control Variables	Limits(p.u)		DE Without FACTS	DE With FACTS device SSSC
	Min	Max		

P_{G1}	0.50	2.000	1.7714	1.7615
P_{G2}	0.20	0.800	0.4869	0.4911
P_{G3}	0.10	0.350	0.2104	0.1431
P_{G4}	0.10	0.300	0.1183	0.1362
P_{G5}	0.15	0.500	0.2127	0.2523
P_{G6}	0.12	0.400	0.1200	0.1200
V_{G1}	0.9	1.10	1.083	1.0736
V_{G2}	0.9	1.10	1.0641	1.0601
V_{G3}	0.9	1.10	1.0365	1.0355
V_{G4}	0.9	1.10	1.0124	0.9987
V_{G5}	0.9	1.10	1.0339	1.0319
V_{G6}	0.9	1.10	1.0444	1.0344
Tap - 1	0.9	1.1	1.0471	1.0317
Tap - 2	0.9	1.1	0.9167	0.9009
Tap - 3	0.9	1.1	0.9529	0.9666
Tap - 4	0.9	1.1	0.9504	0.9444
Q_{C10}	0.0	0.10	0.0467	0.0000
Q_{C12}	0.0	0.10	0.1000	0.0373
Q_{C15}	0.0	0.10	0.0786	0.0394
Q_{C17}	0.0	0.10	0.0795	0.0549
Q_{C20}	0.0	0.10	0.1000	0.0076
Q_{C21}	0.0	0.10	0.0546	0.0988
Q_{C23}	0.0	0.10	0.0160	0.0381
Q_{C24}	0.0	0.10	0.0270	0.0525
Q_{C29}	0.0	0.10	0.0233	0.0463
Cost ($/h)			798.86	795.7573
Ploss (p.u.)			0.0857	0.0702
Ljmax			0.1281	0.1271

The convergence characteristic of the cost of generation DE without and with SSSC at optimal location is shown in Fig. 2.

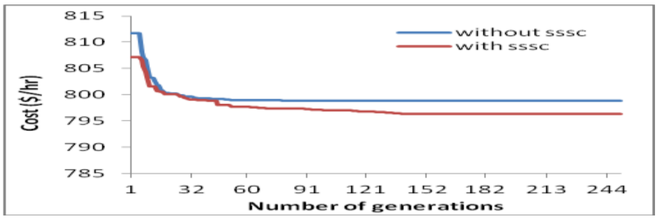

Fig. 2: Convergence of cost of generation without and with sssc using de for ieee 30-bus system

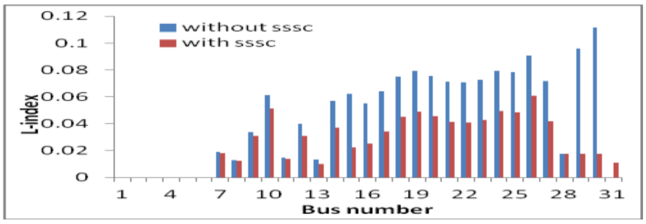

Fig. 3: L-index without and with SSSC device using DE for IEEE 30-bus system

The Figures 4-6 show the percentage MVA loading of the lines, voltage profiles and voltage angles indices of buses without and with SSSC at optimal location.

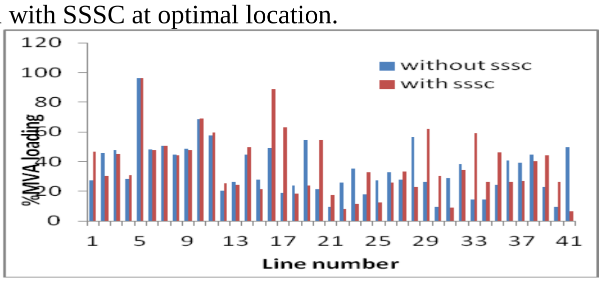

Fig.4: Percentage MVA line loadings of IEEE30-bus system after optimization without and with SSSC using DE

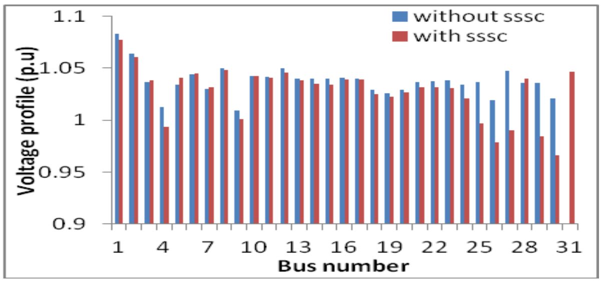

Fig. 5: Voltage profiles of IEEE 30-bus system after optimization without and with SSSC using DE

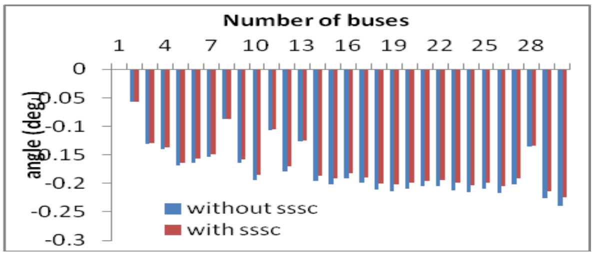

Fig. 6: Voltage angles of IEEE 30-bus system after optimization without and with SSSC using DE

A Comparison of fuel cost of generation without FACTS devices:

The comparison of fuel cost of the proposed method with those of the methods reported in the literature is given in Table III. It can be seen that DE algorithm gives less cost of generation compared with the cost of generation obtained with other OPF methods.

Table III: Comparison of fuel costs for IEEE 30-bus system

Method	**Fuel Cost ($/hr)**
EP [16]	802.907
TS [16]	802.502
TS/SA [16]	802.788
ITS [16]	804.556
IEP [16]	802.465
SADE_ALM [17]	802.404
OPFPSO [18]	802.410
MDE-OPF [19]	802.376
Genetic Algorithm ($/hr) [20]	803.050
Gradient method [21]	802.430
PSO (proposed) without FACTS	800.867
PSO (proposed) with SSSC	797.187
DE(proposed) without FACTS	798.860
DE(proposed) with SSSC	795.757

VIII. CONCLUSIONS

This paper has presented an OPF model incorporating FACTS controller SSSC using DE algorithm for enhancement of system performance. This model is able to solve power networks of any size and converges with any number of iterations and independent of initial conditions. The standard IEEE 30-bus system has been used to demonstrate the proposed method over a wide range of power flow variations in the transmission system. The results shows that proposed OPF with Static Series Synchronous Compensator (SSSC) scheme using DE is very effective compared to other methods in improving the security of the power system.

REFERENCES

[1]. N.Li, Y.Xu, and H.Chen (2000), "FACTS Based Power Flow Control in Interconnected Power Systems", IEEE Trans. on Power Systems, Vol.15, No.1, pp. 257-262, Feb.

[2]. N. G. Hingorani, L. Gyugyi, "Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems", IEEE Press, New- York, 2000.

[3]. Hsiao-Dong Chiang and Rene Jean Jumeau, “Toward a practical performance index for detecting voltage collapse in electric power systems”, IEEE Transactions on power systems, Vol.10, No.21, 1992, pp.584-592.

[4]. P Kessel and H Glavitsch, “Estimating the voltage stability of a power system”, IEEE Trans. on PD, Vol.1, No.3, pp.346-354, 1986.

[5]. IEEE Power Engineering Society/CIGRE, “FACTS Overview”, IEEE Service Centre, Piscataway, N.J., 1995, Special issue, 95TP108.

[6]. IEEE Power Engineering Society/CIGRE, “FACTS Applications”, IEEE Service Centre, Piscataway, N.J., 1996, Special issue,96TP116-0.

[7]. A. R. Messia, M. A. Perez, and E. Hernandez, "Co-ordinated application of FACTS devices to enhance study-state voltage stability," International Journal on Electrical Power and Energy Systems, vol. 25, no. 4, pp. 259-267, May 2003.

[8]. Enrique Acha, Claudio R. Fuerte-Esquivel, Hugo Ambriz-Perez, Cesar Angeles-Camacho. “FACTS modelling and simulation in power networks”

[9]. Alsac O., Stott B. “Optimal load flow with steady state security,” IEEE Trans Pwr Appar Syst 1974;PAS-93;745-51.

[10]. Dommel H, Tinny W. “Optimal power flow solution,” IEEE Trans Pwr Appar Syst 1968; PAS-87(10); 1866-76.

[11]. P. E. O. Yumbla, J. M. Ramirez, C. A. Coello Coello. “Optimal power flow subject to J. security constraints solved with a particle swarm optimizer,” IEEE Transactions on Power Systems, vol. 23, no. 1, Feb., 2008.

[12]. Abido MA. “Optimal power flow using particle swarm optimization,” Electric Power Energy Syst 2002; 24(7): 563-71

[13]. M.Noroozian, L.Angquist, M.Ghandhari, G.Anderson, "Use of UPFC for Optimal Power Flow Control", IEEE Trans. on Power Delivery, Vol.12, No.4, October 1997.

[14]. Roy Billinton, Mahmud Fotuhi-Firuzabad, Sherif Omar Faried, Saleh Aboreshaid, "Impact of Unified Power Flow Controllers om Power System Reliability", IEEE Trans. on Power Systems Vol.15, No.1, February 2000

[15]. Kennedy and R. Eberhart (1995), “Particle Swarm Optimization”, Proc. of IEEE Conf. on Neural Networks (ICNN), Vol. IV, pp. 1942-1948, Perth, Australia.

[16]. W. Ongsakul and T. Tantimaporn, “Optimal power flow by improved evolutionary programming”, Electric Power Components and Systems, 34:79-95, 2006.

[17]. Peerapol Jirapong and Weerakorn Ongsakul “Optimal placement of multi type FACTS devices for total transfer capability enhancement using hybrid evolutionary algorithm”, Electric power componenets and systems, 01 September 2007, 35:981-1005.

[18]. Abido MA. “Optimal power flow using particle swarm optimization,” Electric Power Energy Syst 2002; 24(7): 563-71.

[19]. Ramasubramanian Jayashree and Mohammed Abdullah Khan “A unified optimization approach for the enhancement of available transfer capability and congestion management using unified power flow controller”, Serbian journal of electrical engineering, Vol.5, No.2, November 2008, 305-324.

[20]. D.Devaraj and B.Yegnanarayana, “Genetic Algorithm-Based Optimal Power Flow for Security Enhancement”, IEE Proceedings on Generation, Transmission and Distribution” 2005, 152(6), pp 899-905.

[21]. X.P.Zhang, S.G.Petoussis and K.R.Godfrey “Nonlinear interior point optimal power flow method based on a current mismatch formulation”, IEE Proc.-Gener. Transm. Distrb. Vol.152, No.6, January 2005, 795-805.

[22]. IEEE 30-bus system (1996), (Online) Available at //www.ee.washington.ed