Management of Reactive Power using Evolutionary Techniques

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Abstract— This paper presents an algorithm for minimizing the generator fuel cost and active power loss based on voltage stability using Genetic algorithm. The generator fuel cost and active power loss are mitigated by the management of reactive power via FACTs (UPFC). The optimal power flow is computed using N-R technique subjected to operational and stability constraints. The developed algorithm has been implemented on the modified IEEE 30-bus system and compared with Particle swarm optimization technique. The obtained results indicate that the Genetic algorithm (GA) provides better optimized solution than Particle swarm optimization technique (PSO).

Key words: Reactive Power Control Variable; Voltage Stability; Power Flow; Unified Power Flow Compensator; Genetic Algorithm

I. INTRODUCTION

In the present day scenario, transmission systems are becoming increasingly stressed, more difficult to operate, and more insecure with unscheduled power flows and higher losses because of growing demand and tight restrictions on the construction of new lines. The purpose of the transmission network is to pool power plants and load centers in order to supply the load at a required reliability, maximum efficiency and at lower cost. As the demand for the power transfer increases, the power system becomes increasingly more difficult to operate and insecure with unscheduled power flows and thus handling the losses. Therefore there is a renewed interest in developing optimal power flow (OPF) models that incorporate additional constraints and new objective functions to enhance the security of electricity markets. As several blackouts around the world have been related to voltage phenomena much more interest has been devoted by planning engineers to the voltage stability problem. The present paper deals with the voltage stability issue in the optimal power flow to effectively improve system voltage stability as well as to reduce power generation cost and losses.

Rapid development of power semiconductor devices has made it possible to design power electronic based equipment, well known as flexible AC transmission system (FACTS) which has been introduced by Hingorani [1]. The objective of FACTS devices is to control power flow so that it flows through the designated routes, and increase transmission line capability to its maximum thermal limit, and improve the security of transmission system with minimal infrastructure investment and environmental impact. Gyugyi *et al.* [2] proposed UPFC for the control of both the transmission real power and independently, the reactive power flows at the sending and the receiving end of the transmission lines. The UPFC provides flexibility for AC power transmission control and therefore it automatically counteract power oscillations and can adapt almost instantaneously to new P and Q demands to enhance the transient behaviour of the system and optimize its performance under transmission contingency conditions. Yang et al. [3] presents the Optimal setting of reactive compensation devices with an improved voltage stability index for voltage stability enhancement. By using FACTS devices [4] it is possible to control voltage magnitude and phase angle at chosen buses and/or line impedance of a transmission system. But the existing conventional optimal power flow (OPF) algorithms have to be modified such that power system analysis is possible for modern power system with FACTS devices.

The OPF [5] mainly aims to optimize the selected objective function such as fuel cost, active power loss with the help of optimal adjustment of power system control variables, keeping the equality and inequality constraints in limit. For last two decades researchers developed algorithms to solve optimal power flow problem incorporating FACTS devices. The Modelling of Optimal Unified Power Flow Controller (OUPFC) for optimal steady-state performance of power systems is presented by Lashkar *et al.* [6]. Incorporation of SSSC and SVC devices for real power and voltage stability limit enhancement through shuffled frog leaping algorithm under stressed Conditions is presented by Jebaraj *et al.* [7]. OPF control in electric power system by using UPFC, TCSC, and thyristor controlled phase shifter transformer (TCPS) is presented by Noroozian *et al.* [8]. The capability of UPFC in OPF application was demonstrated and compared with that of a phase shifting transformer (PST). A method to incorporate FACTS devices in the power flow control for optimal active power flow dispatch described by Ge and Chung [9]. They used the linearized DC network model and three types of FACTS devices such as TCSC, TCPS and UPFC were considered. Chung *et al.* [10] represented an optimal active power flow model with FACTS devices by a load-equivalent model. Ambriz-Perez *et al.* [11] solved the OPF incorporating advanced SVC and UPFC using Newton’s method, leading to obtain the minimum of total generation cost solutions. A particle swarm optimisation for multi-objective optimal power flow considering the cost, loss, emission and voltage stability is presented by Niknam et al. [12]. A multi objective differential evolution to optimize cost of generation, emission and active power loss with facts devices is presented by Basu [13]. Genetic algorithm based reactive power dispatch for voltage stability improvement is presented by Devaraj and Roselyn [14].

In this paper the generator fuel cost and transmission losses are minimised with the adjustment of available reactive power through UPFC subjected to stability constraints. The proposed methodology is tested on modified IEEE-30 bus system and compared with obtained results through Particle swarm optimization (PSO).

II. MODELLING OF UPFC

UPFC is a combination of static synchronous compensator (STATCOM) and a static series compensator (SSSC), which are coupled via a common DC link, to allow bi-directional flow of real power between the series output terminals of the SSSC and the shunt output terminals of the STATCOM, and are able to control the transmission line voltage, impedance, and angle, and the real and reactive power flow in the line with line compensation without an external electric energy source [15]. The network model of UPFC is shown in Fig.1.

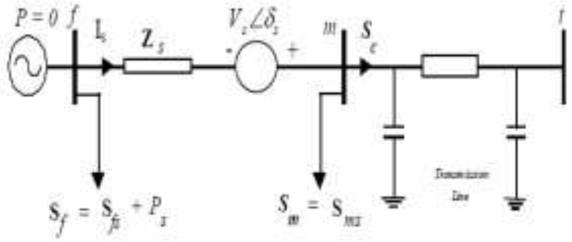

Fig. 1: UPFC model representation in transmission line.

The proposed UPFC model consists of a synchronous condenser (with $P = 0$), two fictitious loads (S_f and S_m), and an impedance (Z_s) is shown in the network model in Fig.1. Note that the fictitious loads in Fig.1 are not constant and need to be updated regularly during the iteration process using the computed values of V_f and V_m. All of these elements can easily be incorporated into any standard load flow and optimal power flow programs. Active and reactive power flows of the line with UPFC are given as;

$$P_{ft} = G'_{ff}\left(V_f^2 + V_fV_scos\delta_{fs}\right) + G'_{ft}\left(V_fV_tcos\delta_{ft}\right) + G'_p\left(V_fV_pcos\delta_{fp}\right) - B'_{ff}\left(V_fV_ssin\delta_{fs}\right) - B'_{ft}\left(V_fV_tsin\delta_{ft}\right) - B'_p(V_fV_psin\delta_{fp})$$

$$Q_{ft} = G'_{ff}\left(V_fV_ssin\delta_{fs}\right) + G'_{ft}\left(V_fV_tsin\delta_{ft}\right) + G'_p\left(V_fV_psin\delta_{fp}\right) + B'_{ff}\left(V_f^2 + V_fV_scos\delta_{fs}\right) + B'_{ft}\left(V_fV_tcos\delta_{ft}\right) + B'_p(V_fV_pcos\delta_{fp}) \quad (1)$$

Similarly,

$$P_{tf} = G'_{tf}\left(V_tV_fcos\delta_{tf} + V_tV_scos\delta_{tf}\right) + G'_{tt}V_t^2 - B'_{tf}\left(V_tV_fsin\delta_{tf} + V_tV_ssin\delta_{ts}\right)$$

$$Q_{tf} = -G'_{tf}\left(V_tV_fsin\delta_{tf} + V_tV_ssin\delta_{ts}\right) + B'_{tt}V_t^2 + B'_{tf}\left(V_tV_fcos\delta_{tf} + V_tV_scos\delta_{ts}\right) \quad (2)$$

The injected real power at bus-*f* (P_{finj}) and reactive power (Q_{finj}) of a transmission line having a UPFC are as follows,

$$P_{finj}^{UPFC} = V_f^2G''_{ff} + V_fV_t(G''_{ft}cos\delta_{ft} + B''_{ft}sin\delta_{ft}) + V_fV_s\left(G'_{ff}cos\delta_{fs} - B'_{ff}sin\delta_{fs}\right) + V_fV_p(G'_pcos\delta_{fp} - B'_psin\delta_{fp})$$

$$Q_{finj}^{UPFC} = V_f^2B''_{ff} + V_fV_t(G''_{ft}sin\delta_{ft} + B''_{ft}cos\delta_{ft}) + V_fV_s\left(G'_{ff}sin\delta_{fs} + B'_{ff}cos\delta_{fS}\right) + V_fV_p(G'_pcos\delta_{fp} + B'_pcos\delta_{fp}) \quad (3)$$

Similarly, the real power and reactive power injections at bus-*t* are,

$$P_{tinj}^{UPFC} = V_t^2G''_{tt} + V_fV_t(G''_{tf}cos\delta_{tf} + B''_{tf}sin\delta_{ft}) + V_tV_s\left(G'_{tf}cos\delta_{ts} - B'_{tf}sin\delta_{ts}\right)$$

$$Q_{tinj}^{UPFC} = V_t^2B''_{tt} + V_fV_t(G''_{tf}sin\delta_{tf} + B''_{tf}cos\delta_{tf}) + V_tV_s\left(G'_{tf}sin\delta_{ts} - B'_{tf}cos\delta_{ts}\right) \quad (4)$$

Where,

$$G_{ff}' + jB_{ff}' = -\frac{{Y_{ff}}^2}{1+Z_sY_{ff}} + \frac{1}{Z_s}$$

$$G_{tt}' + jB_{tt}' = -\frac{Y_{ft}Y_{tf}Z_s}{1 + Z_sY_{ff}}$$

$$G_{ft}' + jB_{tf}' = -\frac{Y_{ff}Y_{ft}Z_s}{1 + Z_sY_{ff}}$$

III. PROBLEM FORMULATION

The objective function is to minimize the total fuel cost and transmission loss. Therefore the OPF problem is with flexible ac transmission system is expressed as follows:

$$J = Min\sum_{\boldsymbol{i=1}}^{\boldsymbol{n_G}}(a_iP_{Gi}^2 + b_iP_{Gi} + c_i) + \lambda\left(\sum_{\boldsymbol{i=1}}^{\boldsymbol{n_L}}Re(I_i^2R_i)\right) \quad (5)$$

Subject to following Inequality constraints:

$$P_{gi}^{min} \le P_{gi} \le P_{gi}^{max}\ \forall i \in n_g$$
$$Q_{gi}^{min} \le Q_{gi} \le Q_{gi}^{max}\ \forall i \in n_g$$
$$V_{gi}^{min} \le V_{gi} \le V_{gi}^{max}\ \forall i \in n_g$$
$$V_i^{min} \le V_i \le V_i^{max}\ \forall i \in n$$
$$T_i^{min} \le T_i \le T_i^{max}\ \forall i \in n_T$$
$$|S_i| \le S_i^{max}\ \forall \in n_L \quad (6)$$

UPFC constraints:

$$V_{sUPFC}^{min} \le V_{sUPFC} \le V_{sUPFC}^{max}$$
$$\delta_{sUPFC}^{min} \le \delta_{sUPFC} \le \delta_{sUPFC}^{max}$$
$$\delta_{pUPFC}^{min} \le \delta_{pUPFC} \le \delta_{sUPFC}^{max} \quad (7)$$

Where, n_L no. of lines, n is set of bus indices, n_t is set of transformer indices, n_g is set of generation bus indices, n_b is set of branch indices, Y_{ij} and θ_{ij} are magnitude and phase angle of element in admittance matrix, P_{gi} is real power generation at bus i, Q_{gi} is reactive power generation at bus i, P_{di} is real power load at bus i, Q_{di} is reactive power load at bus i, S_i is calculated apparent power flow at line i (from bus-*f* to bus-*t*) T_i is tapping ratio at transformer i, V_i is voltage magnitude at bus i, θ_i is load angle at bus i and V_{sUPFC}, $\delta_{s\ UPFC}$, $\delta_{p\ UPFC}$ are the voltage magnitude and angle of series inserted voltage and voltage angle of shunt inserted voltage respectively of the UPFC. The function of equality and inequality constraints is given by the following equations.

$$g(x,s) = \left[g_{P1}(x,s),\cdots g_{Pn}(x,s), g_{Q1}(x,s),\cdots g_{Q1}(x,s)\right]^T = \begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix} = 0 \quad (8)$$

$$h(x,u,s)\left\{= \begin{bmatrix}h(x,u)\\ h(s)\end{bmatrix}\right\} \le 0 \quad (9)$$

Where h (x, u) and h (s) may be arranged as in below;

$$h(x,u) = \begin{bmatrix}P_{Gi}^{min} - P_{Gi}\\ P_{Gi} - P_{Gi}^{max}\\ V_{Gi}^{min} - V_{Gi}\\ V_{Gi} - V_{Gi}^{max}\\ T_i^{min} - T_i\\ T_i - T_i^{max}\\ Q_{Gi}^{min} - Q_{Gi}\\ Q_{Gi} - Q_{Gi}^{max}\\ V_i^{min} - V_i\\ V_i - V_i^{max}\\ |S_i| \le S_i^{max}\end{bmatrix} \le 0 \quad (10)$$

$$h(s) = \begin{bmatrix} V_{sUPFC}^{min} - V_{sUPFC} \\ V_{sUPFC} - V_{sUPFC}^{max} \\ \delta_{sUPFC}^{min} - \delta_{sUPFC} \\ \delta_{sUPFC} - \delta_{sUPFC}^{max} \\ \delta_{pUPFC}^{min} - \delta_{pUPFC} \\ \delta_{sUPFC} - \delta_{sUPFC}^{max} \end{bmatrix} \quad (11)$$

The optimization algorithm comes to an end, when the differences between the specified and calculated apparent bus powers are less than a specified tolerance, as shown in equation below.

$$P_i = Re(V_i Y_{ij}^* V_j^* - S_i) \leq \in$$
$$Q_i = Im(V_i Y_{ij}^* V_j^* - S_i) \leq \in \quad (12)$$

IV. GENETIC ALGORITHM

Genetic algorithms (GAs) are well suited for solving such problems, and in most cases they can find the global optimum solution with a high probability. Although GAs was first presented systematically by Holland, the basic ideas of analysis and design based on the concepts of biological evolution can be found in the work of Rechenberg. Philosophically, GAs is based on Darwin's theory of survival of the fittest. Genetic algorithms are based on the principles of natural genetics and natural selection. The basic elements of natural genetics, reproduction, crossover, and mutation are used in the genetic search procedure [16]. There are three major differences between GAs and conventional optimization algorithms. First, GAs operates on the encoded string of the problem parameters rather than the actual parameters of the problem. Each string can be thought of as a chromosome that completely describes one candidate solution to the problem. Second, GAs uses a population of points rather than a single point in their search. This allows the GA to explore several areas of the search space simultaneously, reducing the probability of finding local optima. Third, GAs do not require any prior knowledge, space limitations, or special properties of the function to be optimized, such as smoothness, convexity, unimodality, or existence of derivatives. They only require the evaluation of the so-called *fitness function (FF)* to assign a quality value to every solution produced. The GA algorithm is described as follows:

A. Representation:

Each individual in the genetic population represents a candidate solution. In the binary coded GA, the solution variables are represented by a string of binary alphabets. The size of the string depends on the precision of the solution required. For problems with more than one decision variables, each variable is usually represented by a substring. All substring are concatenated together to form a bigger string.

B. Fitness Function:

The objective is to minimize the severity index value under contingency case satisfying the constraints. For each individual, the constraints are satisfied by running Newton Raphson algorithm and the constraints on the state variables are taken in to considerations by adding penalty function to the objective function.

C. Selection:

The selection of parents to produce successive generations plays an important role in the GA. The goal allows the fittest individuals to be selected more often to reproduce. Roulette-wheel selection scheme is used in this work. In this selection, individual strings are copied according to their objective function values (fitness function Values).Copying strings according to their fitness values means that strings with a higher value have a higher probability of contributing one or more offspring in the next generation. This operator is an artificial version of natural selection, as Darwinian survival of the fittest among string creatures.

D. Crossover:

Crossover is an important operator of the GA. It is responsible for the structure recombination (information exchange between mating chromosomes) and the convergence speed of the GA and it is usually applied with high probability (0.6-0.9).After selection operation, simple crossover proceeds. It is the primary genetic operator, which promotes the exploration of new regions in search space. Crossover is a structured, yet randomized mechanism of exchanging information between strings.

E. Mutation:

Mutation is a background operator, which produces spontaneous changes in various chromosomes. In artificial genetic systems the mutation operator protects against some irrecoverable loss. It is the occasional random alteration of the value in the string position. With a small probability, random bits of the offspring chromosomes flip from 0 to 1 and vice versa and give new characteristics that do not exist in the parent population. Mutation is needed because even though reproduction and crossover effectively search and recombine extent notions, occasionally they may become overzealous and lose some potentially useful genetic material.

V. RESULT AND DISCUSSIONS

The modified IEEE 30-bus system has been used to show the effectiveness of the proposed algorithm. The data used is given in Appendix. In this work, line no. 26 (between bus 10 and 17) near bus 10 and line no. 33 (between bus 24 and 25) near bus 24 are installed with UPFC. Voltage magnitude limits of generator buses are set to 0.95 pu < V <1.1 p.u. and load buses are set to 0.95 pu < V < 1.05 p.u. Voltage angle limits are taken as 14 < δ < 0 And the UPFC parameters are shown in Table I are considered for all cases and objectives.

X_s	X_p	V_s^{max}	V_p^{max}	S_s^{max}	S_p^{max}
0.02	0.02	0.5	1.0	1.0	1.0

Table 1: UPFC Device Parameters in pu.

The proposed algorithm has been implemented in MATLAB R2010a on a PC (Intel(R) Core TM i5 processor @1.7 GHz). The OPF problem with UPFC devices is solved using GA and PSO. The population size (NP), scaling factor (F) and crossover constant (CR) have been selected as 100, 1.1 and 1.0 for system under consideration in the proposed GA and PSO algorithm. Results obtained from GA and PSO are compared with stressed case results. Solutions and comparison of the total generation cost, transmission losses, total generation, and voltages of the IEEE 30 bus system have been determined and presented in Table II, III, and IV.

Parameters for the GA for optimal power flow Population size =40, Maximum no. of iterations=200, String length=155, Elitism probability = 0.15, Crossover probability = 0.95, Mutation probability = 0.001.

Total load: 384.860 + j174.360 at 135% increased loading.

	Load flow in stressed condition	Load flow with UPFC	OPF with PSO	**OPF with GA**
P_{G1} (MW)	228.839	227.288	240.12	**239.463**
P_{G2} (MW)	70	70	58.659	**58.456**
P_{G5} (MW)	40	40	22.571	**22.367**
P_{G8} (MW)	20	20	32.939	**32.732**
P_{G11} (MW)	20	20	16.000	**15.919**
P_{G13} (MW)	25	25	16.000	**15.919**
Total P_G (MW)	403.839	402.288	386.79	**384.856**
Cost (Rupees/hr)	67992.6	67992.6	65952.6	**64593**
P_{Loss} (MW)	18.979	17.568	16.689	**16.338**

Table 2: Solution and Comparison of Multi-Objective GA and PSO OPF with UPFC

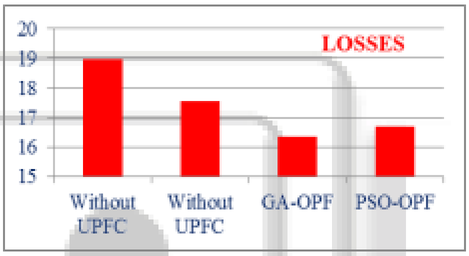

Fig. 2: Comparison of losses in different cases

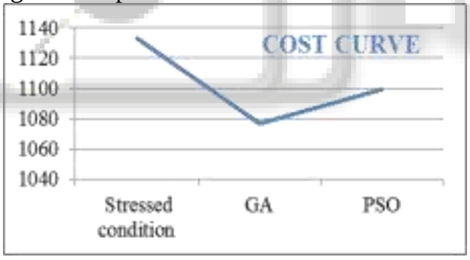

Fig. 3: Comparison generation cost

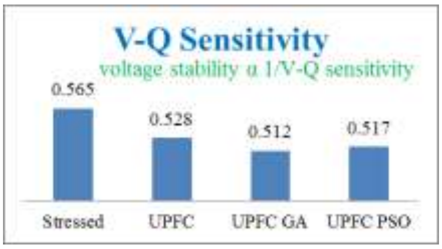

Fig. 4: Sensitivity analysis results for different cases.

Parameters	Line no.26(10-17)		Line no.33(24-25)	
	GA	PSO	**GA**	PSO
δ_p(degree)	**-11.01**	-11.97	**-7.83**	-7.91
δ_s(degree)	**145.1**	147.13	**156.58**	157.68
V_s(pu)	**0.1093**	0.1099	**0.1370**	0.1397

Table 3: Control Parameters of UPFC

Transformer No.	1	2	3	4
From/To Bus No.	6-9	6-10	4-12	27-28
Final Tap Position in case of PSO	0.936	1.145	1.035	1.079
Final Tap Position in case of GA	**1.056**	**1.096**	**1.082**	**0.971**

Table 4: Transformer-tap settings

As per the V-Q sensitivity analysis the voltage stability is improved with Genetic algorithm. The comparison of bus voltages and angles are given in Table V.

VI. CONCLUSION

The proposed algorithm for minimizing the generator fuel cost and transmission losses has been implemented. GA based methodology optimize better reactive power control variables via UPFC than well-established optimization technique namely; particle swarm optimization and also consume less computational time for computation of results. The proposed Genetic algorithm is simple, robust and efficient. This research work will be a very useful contribution in the field of optimal power flow (OPF) with FACTS devices in modern power systems and power industry.

Bus	**GA OPF**		**PSO OPF**		**In stressed condition (Without UPFC)**	
	V (pu)	**Phase Angle(degree)**	V (pu)	Phase Angle(degree)	V (pu)	Phase Angle(degree)
1	**1.060**	**0**	1.060	0	1.060	0.000
2	**1.033**	**-3.942**	1.033	-3.432	1.043	-4.503
3	**1.031**	**-5.792**	1.028	-4.177	1.004	-7.760
4	**1.025**	**-6.686**	1.024	-5.523	0.992	-9.292
5	**1.005**	**-8.393**	1.005	-9.081	1.010	-11.829
6	**1.023**	**-7.987**	1.023	-6.995	0.988	-10.743
7	**1.008**	**-8.691**	1.008	-8.382	0.981	-12.152
8	**1.023**	**-8.399**	1.023	-7.391	0.990	-11.165
9	**1.015**	**-8.313**	1.015	-7.259	1.009	-14.500
10	**1.017**	**-10.760**	1.016	-9.574	0.973	-17.850
11	**1.091**	**-7.076**	1.091	-5.586	1.082	-12.316
12	**1.015**	**-10.806**	1.016	-8.743	1.022	-16.758
13	**1.040**	**-9.877**	1.040	-7.351	1.071	-14.926
14	**1.002**	**-11.659**	1.003	-9.728	0.993	-18.360
15	**1.001**	**-11.694**	1.000	-9.900	0.978	-18.518
16	**1.009**	**-11.092**	1.009	-9.396	0.989	-17.687

17	**1.001**	**-11.086**	1.009	-9.476	0.967	-18.221
18	**0.994**	**-12.106**	0.993	-10.531	0.953	-19.649
19	**0.993**	**-12.146**	0.992	-10.697	0.944	-20.001
20	**0.998**	**-11.860**	0.997	-10.497	0.949	-19.575
21	**1.009**	**-11.144**	1.001	-10.237	0.948	-18.464
22	**1.011**	**-11.109**	1.001	-10.330	0.949	-18.730
23	**0.996**	**-11.974**	0.993	-10.513	0.949	-19.229
24	**1.000**	**-11.963**	0.993	-10.955	0.928	-19.476
25	**1.010**	**-12.221**	1.006	-11.315	0.937	-19.245
26	**0.992**	**-12.645**	0.988	-11.745	0.908	-19.998
27	**1.026**	**-12.095**	1.022	-11.247	0.957	-18.631
28	**1.017**	**-8.462**	1.017	-7.459	0.981	-11.594
29	**1.006**	**-13.315**	1.002	-12.479	0.920	-20.994
30	**0.995**	**-14.000**	0.991	-13.361	0.898	-22.835

Table 5: Comparison of Bus Voltages and Angles of 30-bus system under stressed loading conditions with optimization techniques

REFERENCES

[1] Hingorani NG, Gyugyi L. Understanding FACTS: concepts and technology of flexible ac transmission systems. New York: IEEE Press; 1999.

[2] Gyugyi L, Schauder CD, I Williams S, Rictman TR, Torgerson DR, Edris A. The unified power flow controller, a new approach to power transmission control. IEEE Transactions on Power Delivery, vol.10No.2 pp.1085–1097, 1995.

[3] Yang, C.F., Lai, G.G., Lee, C.H., Su, C.T., Chang, G.W. 'Optimal setting of reactive compensation devices with an improved voltage stability index for voltage stability enhancement', Int. J. Electr. Power Energy Syst., 37, pp. 50–57, 2012.

[4] Xiao-Ping Zhang, Christian Rehtanz, Bikash Pal. Flexible AC Transmission Systems: Modelling and Control. Springer; 2006.

[5] Jizhong Zhu, Optimization of Power System Operation. IEEE Press Series. Published by John Wiley & Sons, Inc.; 2009.

[6] Lashkar Ara A, Kazemi A, Nabavi Niaki SA. Modelling of Optimal Unified Power Flow Controller for optimal steady-state performance of power systems. Energy Conver. Manage. Elsevier, vol.52; p. 1325–33, 2011.

[7] Jebaraj, L., Christober Asir Rajan, C., Sakthivel, S.: 'Incorporation of SSSC and SVC devices for real power and voltage stability limit enhancement through shuffled frog leaping algorithm under stressed conditions', Eur. J. Sci. Res., 79, (1), pp. 119–132,2012.

[8] Noroozian M. Angquist L., Ghandhari M. Anderson G. "Use of UPFC for Optimal Power Flow Control", IEEE Transactions on Power Delivery, vol.12, No.4, pp.1629-1634, 1997.

[9] Ge SY, Chung TS. Optimal active power flow incorporating power flow control needs in flexible AC transmission systems. IEEE Transactions on Power System, vol.14 No.2 pp.738–744, 1999.

[10] Chug TS, Qifeng D, and Bomina Z. Optimal active OPF with FACTS devices by innovative load-equivalent approach. IEEE Power Engineering Review, vol. 20 No.5 pp.63–66. 2000.

[11] Ambriz-Perez H, Acha E, Fuerte-Esquivel CR., Dela Torre A., "Incorporation of a UPFC in an Optimal Power Flow using Newton's method", IEEE Proceedings on Generation Transmission and Distribution,vol.145 No.3, pp.336-344, 1999.

[12] M. Basu, Multiobjective optimal power flow with FACTS devices, Energy conversion and Management 52 903-910, 2011.

[13] Niknam, T., Narimani, M.R., Aghaei, J., Azizipanah-Abarghooee, R.: 'Improved particle swarm optimisation for multi-objective optimal power flow considering the cost, loss, emission and voltage stability index', IET Gener. Transm. Distrib. 6, pp. 515–527, 2012.

[14] Devaraj, D., Roselyn, J.P.: 'Genetic algorithm based reactive power dispatch for voltage stability improvement', Int. J. Electr. Power Energy Syst., 2010, 32, pp. 1151–1156.

[15] R.M. Mathur, R.K. Verma, Thyristor-Based FACTS Controllers for Electrical Transmission Systems, Wiley, India, 2013.

[16] Singiresu S. Rao Engineering Optimization Theory and Practice. By John Wiley & Sons, Inc.; 2009.