OPTIMAL LOCATION OF UPFC FOR CONGESTION RELIEF IN DEREGULATED POWER SYSTEMS

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Abstract: *The power system operation and its security management has become one of the typical tasks to system operator under competitive market environment. The economic efficiency of energy market is mainly dependent on strategic bidding of the market participants and network capability to drive market driven schedule. In order to avoid congestion state and its consequences, the traditional approaches for security management have been replacing by modern technologies like flexible ac transmission system devices, distributed generation etc. This paper addressing the congestion relief approach using unified power flow controller (UPFC). The location and its parameters are optimized with an objective of social welfare maximization. The results on IEEE 30-bus test system are validating the proposed deterministic approach based on contingency ranking for optimal location of UPFC in deregulated power systems.*

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Key words: *Deregulated Power System, Congestion Management, Unified Power Flow Controller, Contingency Ranking.*

1. Introduction

The traditional approach of power system generation scheduling has been changed in different ways in the present deregulated environment. The dispatch of competitive electricity market driven schedule becomes one of the typical operational tasks to the system operator in addition to the general security and reliability concerns. The preventive and corrective actions for transmission security margin have also been changed tremendously with the market gamming. Due to geographical and economic issues, the transmission system expansion becomes difficult to implementation. Under these circumstances, the planning and control actions should validate the adoption and integration of emerging technologies as a long-term solution to satisfy the system operational constraints as well as economic issues. One of the factors which influence the market economics greatly is transmission congestion and has been addressing by the many researches at present. Different techniques and studies have been used to resolve this problem.

According to Ashwani Kumar et al. [1], the existing congestion management (CM) approaches have been categorized in to four major groups i.e. sensitivity factors based, auction based, pricing based approaches and re-dispatch & willingness to pay approach. Many researchers have been focused on the emerging technologies like flexible ac transmission system (FACTS) devices to explore their impact on various congestion relief approaches. Naresh Acharya et al. [2], [3], S.K.Joshi et al. [4], Srinivasa Rao Pudi et al. [5] and Seyed Abbas Taher et al. [6] have addressed the influence of TCSC on market economics under congestion state. You Shi et al. [7] present FACTS validation for CM instead of re-dispatch in hybrid market environment. Sudipta et al. [8] adopt optimal re-scheduling of generators to obtain minimum absolute mismatch to the actual schedule. J. Sridevi et al. [9] explore the FACTS devices impact on zonal congestion management.

From all these works, FACTS can be a promising solution to the CM as well as system security. In this paper, the effect of unified power flow controller (UPFC) on a voluntary pool based day-ahead (DAEM) energy market economics under congestion state is presented. Based on the impact of UPFC on critical loading margin enhancement under N-1 contingency, its optimal location is determined. Finally with the suitable parameter control of UPFC, the economic loss which will incur due to congestion management actions can overcome.

The rest of the paper is organized as follows: Section 2 reviews the UPFC steady state modeling and Section 3 presents the proposed approach for UPFC location. Section 4 addresses the single-sided auction based DAEM settlement and in Section 5, congestion relief with UPFC is presented. The numerical results of case studies on IEEE 30-bus test system are presented in Section 6. Finally, Section 7 concludes the paper.

2. Static Modeling of UPFC

Since UPFC can be used for many technical issues or application in the system hence its modeling is depended on the particular application. Seungwon An et al. [10] has developed an ideal transformer model of UPFC suitable for sensitivity approach to identify its optimal location. Bhowmick *et al.* [11] has proposed an indirect UPFC model to enhance reusability of Newton power-flow codes. Similarly Alomoush [12] has proposed a model of lossless UPFC-embedded transmission lines including the effect of line charging susceptance. The most popular model is power injection (PIM) and it can be found in Palma-Behnke et al. [13], Jun-Yong Liu et al. [14], H.C. Leung et al. [15], K. S. Verma et al. [16], Wei Shao et al [17], Sun-Ho Kim et al [18], Hongbo Sun et al [19], Jung-Uk Lim et al [20], Ying Xiao et al [21], are some of the works which has adopted PIM approach.

Some other specific models can be found in literature. A novel approach of setting for the state variables of an UPFC by incorporation of a UPFC model into the Newton–Raphson power flow algorithm has been presented by Arnim Herbig et al. [22]. Kwang M. Son et a. [23] present Newton-type current injection model, C. R. Foerte-Esquivel et al. [24] present a comprehensive Newton-Raphson UPFC Model for the Quadratic Power Flow Solution of Practical Power Networks, Saeed Arabi et al. [25] was introduced power flow representation of UPFC using auxiliary capacitors. Marcos Pereira et al. [26] present current based model considering the current in the series converter as a variable.

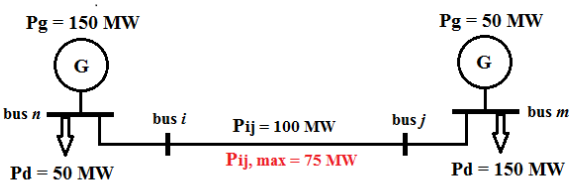

Fig. 1. Congested transmission line.

For better exploration on decoupled modeling of UPFC [20], [21], its application for congestion relief can be understood with the following example. From the Fig. 1, the line connected between buses *i* to bus *j* is subjected congestion state. If that line is integrated with UPFC as shown in Fig. 2, the decoupled model and its required power injections at buses *i* and *j* are given in Fig. 3. The model modified the bus *i* as PQ bus and bus *j* as PV bus. If power direction is from bus *j* to *i*, then bus *j* should become PQ bus and bus *i* should become PV bus. The observable thing is, if the injected power is further increased to 50 MW, then the power flow will also further decreased to 50 MW in the line. So the required power control can easily be possible through this modeling.

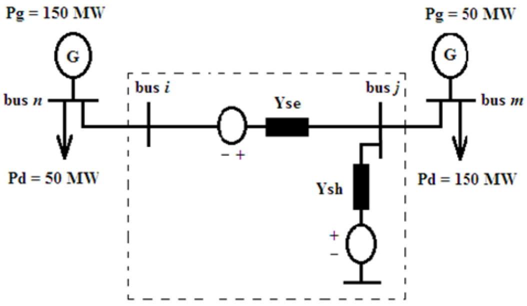

Fig. 2. UPFC in congested transmission line.

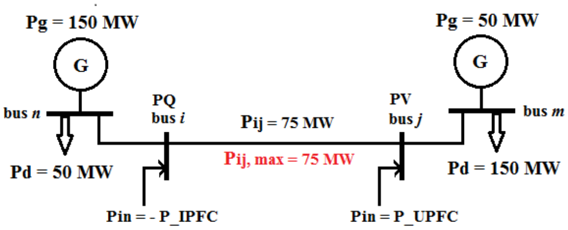

Fig. 3. Decoupled PIM of UPFC in transmission line.

3. Optimal Location of UPFC

The best choice of FACTS devices and their optimal location is not a simple optimization problem due to their distinguished advantages and disadvantages of each device. So, the solution is mainly dependent on the concerned objective function. Reza Sirjani et al. [27] use novel global harmony search algorithm for SVC location with a multi-criterion objective function defined to enhance voltage stability, voltage profile improvement and power loss minimization while minimizing the total cost. Roberto Minguez et al. [28] proposed a multi-start Benders decomposition procedure to identify the optimal location of SVC for loading margin enhancement. Similarly Ya-Chin Chang [29] adopted SVC integration in to the system optimally based on multi-objective particle swarm optimization (MOPSO) problem and finally solved for loading margin enhancement. P.Ramasubramanian el al. [30] has been used evolutionary program (EP) based optimal power flow (OPF) for optimal location of TCSC for congestion management. Lijun Cai et al. [31] and J.

Baskaran et al. [32] use genetic algorithm (GA) to find optimal choice and allocation of FACTS devices to minimize economics saving cost and Vilmair E. Wirmond et al. [33] use OPF and GA for optimal location of TCPST to minimize overload in the transmission system.

Similarly, some of the works focused on technical benefits with FACTS application. Ying Xiao et al. [34], N. Schnurr et al. [35], Harinder Sawhney et al. [36] and P. Gopi Krishna et al. [37] for available transfer capability (ATC) enhancement, Wang Feng et al. [38] for total transmission capacity enhancement, Ya-Chin Chang et al. [39] for transmission system loadability enhancement, P.S.Venkataramu et al. [40] for voltage stability margin enhancement, Chonhoe Kim et al. [41] for transient stability enhancement, A. Rajabi-Ghahnavieh et al. [42] for system reliability, A.V.Naresh babu et al. [43], M.H.Haque et al. [44] and Ch. Chengaiah et al. [45] for load flow control are some of the examples of FACTS application in deregulated environment.

As a long-term solution for technical issues in the system, this paper has been proposed a novel approach for UPFC location in the network. To validate UPFC function clearly during the abnormalities, the (N-1) line contingency (*i.e. also only the lines which are not incident to any generator bus in the network*) has been imposed in the network. Based on the reduced critical loading margin [46], the line was opted as a best location for UPFC installation.

The power extraction (i.e. reduced generation level) at *bus-i* and insertion (i.e. reduced load level) at *bus-j* should be equal for lossless UPFC operation. The reactive power generated at *bus-i* is to maintain the desired voltage by PV bus model. In order to maintain constant power factor at *bus-j*, not only real power but also reactive should be adjust properly.

4. Day-Ahead Energy Market Modeling

The day-ahead energy market and with mandatory pool operation has been considered in this work. All the generator buses are treated as generation companies (GENCOs) and load buses as distribution companies (DISCOs) and the entire transmission network as a single entity (TRANSCO) and is functioned under independent system operator (ISO) regulatory body. Single-sided auction mechanism [47] has been considered in the market model. The objective function is to minimize the generation cost at unconstrained case. The bids submitted by any GENCO will arrange in a sequence from lower to higher cost. The aggregated supply curve will be the combination of all GENCOs' bids arranged from lower to higher cost basis. The intersecting point of forecasted demand and aggregated supply curve will give the market clearing price (MCP). The market cleared quantity (MCQ) for any GENCO can be obtained from its bid curve at this MCP as explained in case studies. If this schedule is not subjected to any operational constraints, then that market settlement will be the perfect market equilibrium point.

Mathematically, the DA market objective function is as follows:

$$\min\left(\sum_{i=1}^{NG} C_{G,i}\left(P_{G,i}\right)-\sum_{i=1}^{ND} C_{D,i}\left(P_{D,i}\right)\right) \tag{1}$$

In single sided auction market model, only GENCOs will submit bids and then the objective function will become as:

$$\min\left(\sum_{i=1}^{NG} C_{G,i}\left(P_{G,i}\right)\right) \tag{2}$$

As explained in [48], the perfect competitive energy market can also simulate as a traditional economic load dispatch problem [49]. Under this assumption, the generation schedule at any bus and market clearing price can obtained using equations (3) and (4) respectively.

$$MCP=\frac{P_D+\sum\limits_{i\in NG}\frac{b_i}{2a_i}}{\sum\limits_{i\in NG}\frac{1}{2a_i}} \tag{3}$$

$$P_{G,i}=\frac{MCP-b_i}{2a_i} \tag{4}$$

The equality and inequality constraints to the objective function of equation (2) are as follows:

$$\Delta P_i=\sum_{j=1}^{NB}\left|V_i\right|\left|V_j\right|\left|Y_{ij}\right|\cos\left(\delta_i-\delta_j-\theta_{ij}\right) \tag{5}$$

$$\Delta Q_i=\sum_{j=1}^{NB}\left|V_i\right|\left|V_j\right|\left|Y_{ij}\right|\sin\left(\delta_i-\delta_j-\theta_{ij}\right) \tag{6}$$

5. Congestion Relief using UPFC

The solution of the system can be obtained using Newton-Raphson method. The network loading and its security level can easily understand with performance index [49] which can calculate using equation (7). The higher value of *PI* indicates overloading of one or more lines.

$$PI = \sum_{lk} \left(\frac{f_{lk}}{f_{lk,\max}} \right)^{2x} \tag{7}$$

As explained Section 2.2, the UPFC has been installed at its optimal interface between *bus-i* to *bus-j*. The residual powers at these buses modify with UPFC control factors as follows:

$$\Delta P_i = \left(P_{G,i} - P_{upfc} \right) - P_{D,i} \tag{8}$$

$$\Delta P_j = P_{G,j} - \left(P_{D,j} - P_{upfc} \right) \tag{9}$$

$$\Delta Q_j = Q_{G,j} - \left(Q_{D,j} - Q_{upfc} \right) \tag{10}$$

$$P_{upfc} + jQ_{upfc} = \tau \left(P_{D,j} + jQ_{D,j} \right) \tag{11}$$

where $\tau\left(0 \le \tau \le 1\right)$ is the UPFC control parameter which will adjust up to congestion problem overcome by the network.

6. Case Studies

(A) Contingency Analysis for Optimal Location

The IEEE-30 bus system data can be found in [50, 51]. The base load on the system is 283.4 MW and it is shared among all the generators in proportional to their maximum generation limit. By performing NR load flow, the system suffers with 4.040 MW loss and all the lines are under their MVA ratings. In order to identify the severe line outage, the (N-1) line contingency has been performed at base case and the corresponding system performance index (SPI), real power loss (Loss), and minimum voltage bus with its magnitude among all the buses are given in Table 1 and Table 2 based on SPI values in two categories like severe and normal respectively. The results of incredible contingencies (not solvable cases) of line numbers 13, 16 and 34 are not listed.

All the lines listed in Table 1 are suitable for UPFC location since they are having significant impact on system loadability. In the second steps, among these lines the first 10 lines are considered to investigate their impact on (CLM) or maximum loading capability (MLC). For each contingency, the reduced MCL from base case i.e. reduced security margin (RSM) and critical bus which constrained to NR method fails to convergence as well as its voltage magnitude have been given in Table 3.

Table 1
Severe line outage contingencies

Line #	Loss	SPI	Vmin	Bus
base	4.646	0.8089	0.9921	30
36	6.787	8.4462	0.8674	30
25	5.117	2.5946	0.9883	20
5	10.101	2.1438	0.97	5
14	5.302	1.7896	0.9901	30
24	4.931	1.6388	0.9919	30
38	5.151	1.5264	0.937	30
9	6.607	1.452	0.9758	7
40	4.698	1.398	0.9906	30
37	5.025	1.3246	0.9469	29
18	5.324	1.2193	0.9864	30
28	4.712	1.1858	0.9909	30
27	5.01	1.1757	0.9874	30
30	4.761	1.1559	0.987	30
17	4.885	1.1528	0.9911	30
15	4.595	1.1335	0.994	30
26	4.798	1.0101	0.9932	30

Table 2
Normal line outage contingencies

Line #	Loss	SPI	Vmin	Bus
31	4.776	0.9747	0.9853	30
35	4.764	0.9647	0.9849	30
39	4.777	0.9518	0.9744	30
19	4.761	0.9385	0.991	30
1	6.145	0.8975	0.9917	30
10	4.887	0.8801	0.9966	30
12	4.686	0.8701	0.9929	30
32	4.652	0.8679	0.99	30
20	4.653	0.8535	0.9919	30
21	4.664	0.8488	0.9916	30
29	4.649	0.8451	0.9927	30
22	4.735	0.7761	0.992	30
7	4.86	0.7597	0.9894	30
23	4.648	0.7596	0.9921	30
33	4.609	0.7434	0.9871	30
8	4.798	0.7001	0.9914	30
41	4.771	0.6921	0.9793	30
11	4.68	0.6711	0.9939	30
2	5.38	0.6603	0.9893	30
4	5.243	0.6532	0.9896	30
3	4.828	0.6154	0.9901	30
6	4.939	0.5983	0.9889	30

Table 3
Impact of severe line outages on CLM

Line #	**CLM**	**RSM**	**Critical Bus**	**Vcri**
Base	2.899	-	30	0.562
36	1.485	1.414	30	0.539
25	2.596	0.303	20	0.586
5	2.625	0.274	30	0.621
14	2.438	0.461	30	0.586
24	2.865	0.034	30	0.565
38	1.928	0.971	30	0.566
9	2.918	-0.019	30	0.568
40	2.808	0.091	30	0.574
37	2.115	0.784	29	0.531
18	2.688	0.211	30	0.561

From results, the high reduced CLM has happened for the contingency of line 36, 38 and 37. Hence, these three lines are considered most suitable locations for UPFC installation. Under these contingencies, the buses 30 and 29 are subjected to voltage instability hence these locations can opt for shunt compensation devices like SVC, STATCOM and TCVR etc.

(B) Simulation of Day-Ahead Energy market

The cost curve coefficients and maximum generation capacities of each generator are given in Table 4. Since the market settlement is only based on incremental costs hence, the initial cost has been neglected. Similarly the minimum generation limits are also omitted to avoid mandatory participation of the produces in market.

For the base case load of 283.4 MW, the market has been cleared at 4.3724 \$/MWh and for this MCP, the production cost is 949.62 \$/h. The load flow has been performed with the market driven schedule $P_{G,i}$ and the results are framed in Table 4. The system is subjected to congestion with line # 10 overloaded to 110.01%. The SPI and losses are 2.189 and 4.577 MW respectively.

Table 4
Cost curve coefficients and Market schedule

Gen #	a_i	b_i	$P_{Gi,\max}$	$P_{G,i}$
1	0.02	2	80	62.335
2	0.0175	1.75	80	78.383
5	0.0625	1	50	27.947
8	0.00834	3.25	55	55
11	0.025	3	30	29.868
13	0.025	3	40	29.868

(C) UPFC Function at Stressed Conditions

The best suitable locations of UPFC have been tested in this section. At first, UPFC has been inserter in line 36 i.e. connected between buses 28 to 27. As explained in section 2, the UPFC configuration is formulated by modifying *bus-28* as a PV bus and *bus-27* remains as a PQ bus. The reactive power limits for PV bus are considered as -15MVAr to 50MVAr. The severe contingencies are imposed one after one with UPFC in line 36 and the corresponding changes in SPI, losses, voltage at critical bus given in Table 5. As compared with base case results i.e., Table 1, all the parameters are changed significantly. The voltage profile at all buses is illustrated in figure 4.

Table 5
Severe line outage contingencies with UPFC

Line #	**Loss**	**SPI**	**Vmin**	**Bus**
base	4.6587	0.8066	0.9893	30
36	6.3830	6.5186	0.9734	30
25	5.1294	2.5966	0.9881	30
5	10.0983	2.1424	0.9700	5
14	5.3073	1.7926	0.9889	30
24	4.9431	1.6393	0.9892	30
38	5.0473	1.4245	0.9637	30
9	6.6273	1.4265	0.9758	30
40	4.7055	1.3891	0.9890	30
37	4.9364	1.2460	0.9930	30
18	5.3164	1.2147	0.9881	30
28	4.7201	1.1887	0.9890	30
27	5.0061	1.1749	0.9883	30
30	4.7559	1.1499	0.9882	30
17	4.8946	1.1538	0.9891	30
15	4.6130	1.1262	0.9897	30
26	4.8149	1.0068	0.9895	30

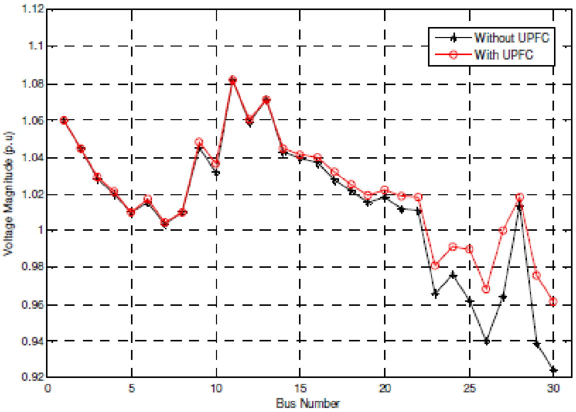

Fig. 4. Voltage profile without & with UPFC in line # 36.

(D) Congestion Relief by UPFC

In addition to the line 36, the lines 37 and 38 are also considered here. When UPFC is in line #37, *bus-29* and for line #38, *bus-28* are considered as PV buses. As UPFC control parameter τ changes, the congestion relief in the form of decrement in SPI and %loading in line #10 as well as transmission losses can observe in figures 5, 6 and 7 respectively.

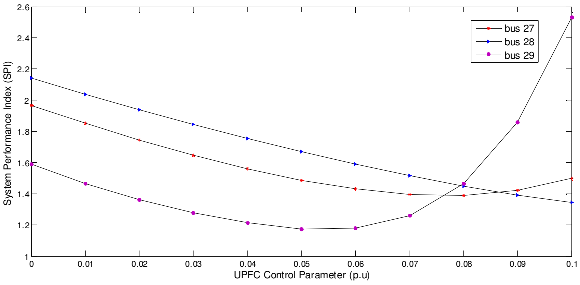

Fig. 5. SPI Vs UPFC Control Parameter.

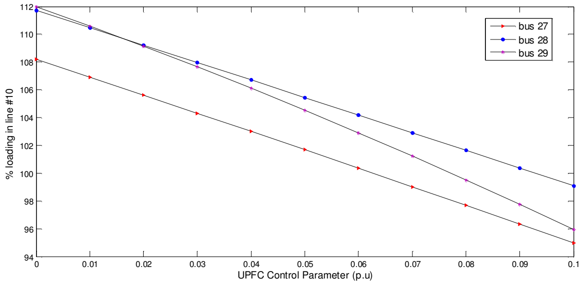

Fig. 6. % loading in line #10 Vs UPFC Control Parameter.

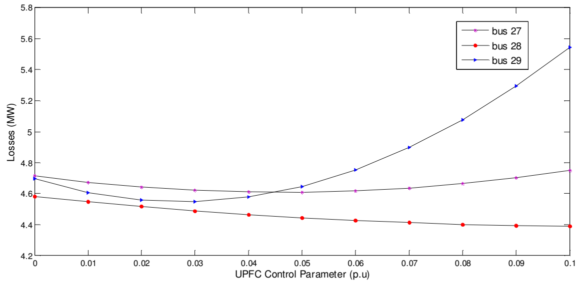

Fig. 7. Transmission losses Vs UPFC Control Parameter.

7. Conclusions

The literature survey provides the basic understand on deregulated power system security problems which can change the physical and financial flows significantly in the network. In order to optimize the security level under competency, the optimal location of UPFC has been proposed based on a novel approach, i.e. reduced critical loading margin under (N-1) contingency condition. The control strategy of UPFC for security management in the competitive energy market has been addressed. Under congestion state, without deviating from market driven schedule, the UPFC parameters have been optimized. In some inevitable situations, the congestion management problem can be solvable with re-dispatch or load curtailment which causes to change power flows and economics of the market. The comparative study of this concept with UPFC will be the content of future work.

References

1. Ashwani Kumar, S.C. Srivastava, S.N. Singh, "*Congestion Management in Competitive Power Market: A Bibliographical Survey*", Electric Power Syst. Res., Vol. 76, pp. 153-164, July 2005.
2. Naresh Acharya, Nadarajah Mithulananthan, "*Influence of TCSC on Congestion and Spot Price in Electricity Market with Bilateral Contract*", Electric Power Syst. Res., Vol. 77, pp. 1010-1018, Oct. 2006.
3. Nadarajah Mithulananthan, Naresh Acharya, "*A proposal for Investment Recovery of FACTS Devices in Deregulated Electricity Markets*", Electric Power Syst. Res., Vol. 77, pp. 695-703, July 2006.
4. S.K Joshi, K.S. Pandya, "*Influence of TCSC on Social Welfare and Spot Price – A Comparative Study of PSO with Classical Method*", Int. J. of Engineering, Science and Technology, Vol. 2, No. 3, pp. 69-81, Special Issue 2010.
5. Srinivasa Rao Pudi, S.C. Srivastava, "*Optimal Placement of TCSC Based on a Sensitivity Approach for Congestion Management*", in Proc. of Fifteenth National Power Systems Conference (NPSC), IIT Bombay, December 2008, pp. 558-563, Dec. 2008.
6. Seyed Abbas Taher, Hadi Besharat, "*Transmission Congestion Management by Determining Optimal Location of FACTS Devices in Deregulated Power Systems*", American J. of Applied Science, Vol. 5, No. 3, pp. 242-247, 2008.
7. You Shi, Kennedy Mwanza, Le Anh Tuan, "*Validation of FACTS for Managing Congestion in Combind Pool and Bilateral Markets*", in Proc. of IEEE PES PowerAfrica 2007 Conference and Exposition, Johannesburg, South Africa, 16-20 July 2007.
8. Sudipta Dutta and S.P. Singh, "*Optimal Rescheduling of Generators for Congestion Management Based on Particle Swarm Optimization*", IEEE Trans. Power Syst. Vol 23, No. 4, pp. 1560-1569, Nov. 2008.
9. J. Sridevi, J. Amarnath, G. Govinda Rao, "*Impact of FACTS Devices on Zonal Congestion Management in Deregulated Power System*", Innovative Systems Design and Engineering, Vol. 3, No. 1, pp. 43-54, 2012.
10. Seungwon An, John Condren and Thomas W. Gedra, "*An Ideal Transformer UPFC Model, OPF First-Order Sensitivities, and Application to Screening for Optimal UPFC Locations*" IEEE Trans. Power Syst. Vol 22, No. 1, pp. 68-75, Feb. 2007.
11. Bhowmick S, Das B, Kumar N, "*An indirect UPFC model to enhance reusability of Newton power-flow*

codes," IEEE Trans. Power Delivery, Vol. 23, No. 4, pp. 2079-2088, Oct. 2008.

12. Alomoush, M.I., "*Derivation of UPFC DC load flow model with examples of its use in restructured power systems*," IEEE Trans. Power Syst. Vol. 18, No. 3, pp. 1173-1180, Aug. 2003.
13. Palma-Behnke, R., Vargas, L.S., Perez, J.R., Nunez, .D., Torres, R.A., "*OPF with SVC and UPFC modeling for longitudinal systems*," IEEE Trans. Power Syst. Vol. 19, No. 4, pp. 1742-1753, Nov. 2004.
14. Jun-Yong Liu, Yong-hua Song, Mehta, P.A., "*Strategies for handling UPFC constraints in steady-state power flow and voltage control*," IEEE Trans. Power Syst. Vol. 15, No. 2, pp. 566-571, May. 2000.
15. Leung, H.C., Chung, T.S., "*Optimal power flow with a versatile FACTS controller by genetic algorithm approach*", in Proc. 2000 Int. Conf. on Advances in Power System Control, Operation and Management, 2000 (APSCOM-00), Vol. 1, pp. 178-183, Nov. 2000.
16. KS Verma, SN Singh and HO Gupta, "*Optimal Location of UPFC for Congestion Management*," Electric Power Syst. Res, Vol. 58 No.2, pp. 89-96, July 2001.
17. Wei Shao, Vittal, V., "*LP-Based OPF for Corrective FACTS Control to Relieve Overloads and Voltage Violations*", IEEE Trans. Power Syst. Vol. 21, No. 4, pp. 1832-1839, Nov. 2006.
18. Sun-Ho Kim, Jung-Uk Lim ; Seung-Il Moon, "*Enhancement of power system security level through the power flow control of UPFC*", IEEE Power Engineering Society Summer Meeting, pp. 38-43, July 2000.
19. Hongbo Sun, Yu, D.C. ; Chunlei Luo, "*A novel method of power flow analysis with unified power flow controller (UPFC)*", IEEE Power Engineering Society Meeting, vol.4, pp. 2800-2805, Jan. 2000.
20. Sung-Hwan Song, Jung-Uk Lim, Seung-Il Moon, "*FACTS operation scheme for enhancement of power system security*," in Proc. 2003 IEEE Bologna Power Tech Conference, Vol. 3, pp. 36-41, June 2003.
21. Ying Xiao, Song, Y.H., Chen-Ching Liu, Sun, Y. Z., "*Available transfer capability enhancement using FACTS devices*", IEEE Trans. Power Syst. Vol. 18, No. 1, pp. 566-571, Feb. 2003.
22. Arnim Herbig, "*On Load Flow Control in Electric Power Systems*", Doctoral Dissertation, Stockholm 2000.
23. Son, K.M., Lasseter, R.H., "*A Newton-type current injection model of UPFC for studying low-frequency oscillations*," IEEE Trans. Power Delivery, Vol. 19, No. 2, pp. 694-701, April 2004.
24. Fuerte-Esquivel, C.R., Acha, E. ; Ambriz-Perez, H., "*A comprehensive Newton-Raphson UPFC model for the quadratic power flow solution of practical power networks*," IEEE Trans. Power Syst. Vol. 15, No. 1, pp. 102-109, Feb. 2000.
25. Arabi, S., Kundur, P. ; Adapa, R., "*Innovative techniques in modeling UPFC for power system analysis*," IEEE Trans. Power Syst. Vol. 15, No. 1, pp. 336-341, Feb. 2000.
26. Pereira, M., Zanetta, L.C., "*A Current Based Model for Load Flow Studies with UPFC*," IEEE Trans. Power Syst. Vol. 28, No. 2, pp. 677-682, May. 2013.
27. Reza Sirjani, Azah Mohamed, Hussain Shareef, "*Optimal allocation of shunt Var compensators in power systems using a novel global harmony search algorithm*," Int. J. Electrical Power & Energy Systs, Vol. 43, No. 1, pp. 562–572, Dec. 2012.
28. Roberto Minguez, Federico Milano, Rafael Zarate-Minano, Antonio J. Conejo, "*Optimal Placement of SVC Devices*," IEEE Trans. Power Syst. Vol. 22, No. 4, pp. 1851-1860, Nov. 2013.
29. Ya-Chin Chang, "*Multi-Objective Optimal SVC Installation for Power System Loading Margin Improvement*," IEEE Trans. Power Syst. Vol. 27, No. 2, pp. 984-992, May. 2013.
30. P. Ramasubramanian, G. Uma Prasanna and K. Sumathi, "*Optimal Location of FACTS Devices by Evolutionary Programming Based OPF in Deregulated Power Systems*," British J. of Mathematics & Computer Science, Vol. 2, No. 1, pp. 21-30, Dec. 2012.
31. Lijun Cai and Istvan Erlic, Georgios Stamtsis, Yicheng Luo, "*Optimal Choice and Allocation of FACTS Devices in Deregulated Electricity Market using Genetic Algorithms*," in Proc. IEEE PES Power Systems Conference and Exposition, Vol. 1, pp. 201-207, Oct. 2004.
32. J. Baskaran, Dr. V. Palanisamy, "*Genetic Algorithm Applied to Optimal Location of FACTS Device in a Power System Network Considering Economic Saving Cost*," Academic Open Internet Journal, Vol 15, pp. 1-7, 2005.
33. Vilmair E. Wirmond, Thelma S.P. Fernandes, Odilon Luis Tortelli, "*TCPST allocation using optimal power flow and Genetic Algorithms*" Int. J. Electrical Power & Energy Systs, Vol. 33, No. 4, pp. 880–886, May 2011.
34. Ying Xiao, Y.H. Song, Chen-Ching Liu, Y.Z. Sun,"*Available Transfer Capability Enhancement Using FACTS Devices*", IEEE Trans. Power Syst. Vol. 18, No. 1, pp. 305-312, Feb. 2003.
35. N. Schnurr and W. H. Wellssow, "*Determination and Enhancement of the Available Transfer Capability in FACTS*," in Conf. IEEE Porto Power Tech Conference, Porto, Portugal, Vol. 4, Sept. 2001.
36. Harinder Sawhney, B. Jeyasurya, "*Application of Unified Power Flow Controller for Available Transfer Capability Enhancement*," Electric Power Syst. Res, Vol. 69 No.2-3, pp. 155-160, May 2004.
37. P. Gopi Krishna and T. Gowri Manohar, "*Voltage Stability Constrained ATC Computations in Deregulated Power System Using Novel Technique*", ARPN Journal of Engineering and Applied Sciences, Vol. 3, No. 6, pp. 76-81, Dec 2008.
38. Wang Feng, G. B. Shrestha, "*Allocation of TCSC devices to optimize total transmission capacity in a competitive power market*," in Proc. IEEE Power Engineering Society Winter Meeting, Vol. 2, pp. 587- 593, Feb. 2001.

39. Ya-Chin Chang, Rung-Fang Chang, Tsun-Yu Hsiao and Chan-Nan Lu, "*Transmission System Loadability Enhancement Study by Ordinal Optimization Method*", IEEE Trans. Power Syst. Vol. 26, No. 1, pp. 451-459, Feb. 2011.
40. P.S.Venkataramu and T. Ananthapadmanabha, "*Installation of Unified Power Flow Controller for Voltage Stability Margin Enhancement under Line Outage Contingencies*," Iranian Journal of Electrical and Computer Engineering, Vol. 5, No. 2, pp. 90-95, Summer-Fall 2006.
41. Chonhoe Kim, Jungsoo Park, Gilsoo Jang , Son, K.M., Tae-Kyun Kim, "*Modeling of Unified Power Flow Controllers Using a Current Injection Method for Transient Stability Analysis*", in Proc. IEEE/PES Transmission and Distribution Conference & Exhibition: Asia and Pacific Dalian, China, pp. 1-7, 2005.
42. A. Rajabi-Ghahnavieh, M. Fotuhi-Firuzabad, M. Shahidehpour, R. Feuillet, "*UPFC for Enhancing Power System Reliability*," IEEE Trans. Power Delivery. Vol. 25, No. 4, pp. 2881-2890, Oct. 2011.
43. A.V.Naresh Babu, T. Ramana, S. Sivanagaraju, "*Effect of Unified Power Flow Controller Parameters in Power Flow Studies*," Elektrika -UTM Journal of Electrical Engineering, Vol. 13, No. 2, pp. 57-66, 2011.
44. M.H. Haque, C.M.Yam, "*A Simple Method of Solving the Controlled Load Flow Problem of a Power System in the Presence of UPFC*," Electric Power Syst. Res, Vol. 65 No. 1, pp. 55-162, April. 2003.
45. Ch. Chengaiah, G. V. Marutheswar, R. V. S. Satyanarayana, "*Control Setting of Unified Power Flow Controller through Load Flow Calculation*," APRN Journal of Engineering and Applied Sciences, Vol. 3, No. 6, pp. 6-10, Dec. 2008.
46. J. Vara Prasad, K. Chandra Sekhar, "*Optimal Allocation of FACTS Controllers for Critical Loading Margin Enhancement*," in Proc. 2013 Int. Conf. on Power, Energy and Control, Dindigul, India, pp. 86-91, Feb. 2013.
47. Anastasios G. Bakirtzis, Nikolaos P. Ziogos, Athina C. Tellidou and Gregory A. Bakirtzis, "*Electricity Producer Offering Strategies in Day-Ahead Energy Market with Step-Wise Offers*," IEEE Trans. Power Syst. Vol. 22, No. 4, pp. 1804-1818, Nov. 2007.
48. T. Li and S. M. Shahidehpour, "*Strategic Bidding of Transmission Constrained GENCOs with Incomplete Information*," IEEE Trans. on Power Systems", Vol.20, No. 1, pp. 437-447, Feb. 2005.
49. Allen J. Wood and Bruce F. Wollenberg: *Power Generation, Operation, and Control*, J. Wiley & Sons, Feb. 1996.
50. www.pserc.cornell.edu/matpower/
51. Hadi Saadat: *Power System Analysis*, PSA Publishing, 2010.