Optimal Location of UPFC for ATC Enhancement Under Contingencies for Bilateral Transaction

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Abstract- **This paper focuses on the evaluation of the impact of Unified Power Flow Controller (UPFC) on available transfer capability (ATC) enhancement through optimal location of UPFC. Placement of FACTS controller may be quite effective for enhancing the ATC of power system due to the capability to improve line voltage and control power flow through lines. Technical merits of UPFC technology on ATC boosting are analyzed. The application of this paper lies within the new de-regulation of power systems where a great deal of emphasis has been put on transmission open access, leading to more efficient utilisation of the existing facilities. The effectiveness of the proposed method for the placement of UPFC in voltage stability margin enhancement has been validated on a IEEE-14 bus system.**

Index Terms– **Unified power flow controller (UPFC), available transfer capability (ATC), total transfer capability (TTC), static var compensator (SVC).**

I. INTRODUCTION

Key task of electric power industry restructuring is to encourage competition for electricity trading. Under new environment, major consequences of deregulation are increasing uncertainties associated with risks of decision making. An important responsibility of transmission system operators (TSO) is facilitating non-discriminatory open-access to transmission network. TSO should procure such services to ease transferring more power using the existence facilities in an economic fashion. Required reliability as well as adequate available transfer capability (ATC) is needed to ensure all economic transactions, while sufficient ATC is required to guarantee competitive electricity trading [1].

Based upon the report of North American Electric Reliability Council (NERC)—ATC is defined as "a measure of the transfer capability remaining in the physical transmission network for further commercial activities over and above already committed uses". The main part of ATC is total transfer capability (TTC), which is the largest flow increase between the selected source/sink that transfers without violation of thermal limits, voltage limits as well as dynamic stability limits. ATC enhancement focus on the possible -ways by which such constraints can be alleviated [2].

FACTS controllers can be effectively used to improve the utilization of the power systems in order to improve stability as well as security. FACTS devices may enhance transmission functionality in order to fully utilize existing transmission systems [3]. Static VAR compensator (SVC) and thyristor controlled series capacitor (TCSC) are some of the commonly used FACTS controllers. The improvements on the field of power electronics developed a new family of versatile FACTS controllers namely static synchronous compensator (STATOM), static synchronous series compensator (SSSC) and the unified power flow controller (UPFC).

The advent of Flexible AC Transmission Systems (FACTS) Controllers [3] has created new opportunities for increasing power system stability margin including voltage stability margin. However, due to high cost and, for maximum enhancement in voltage stability margin, these are to be optimally placed in the system. Out of different types of FACTS controllers, Unified Power Flow Controller (UPFC) seems to be more effective in voltage stability enhancement [4] due to its ability to control series and shunt variables, simultaneously. The selection of optimal bus based on combination of continuation power flow and optimal power flow for the placement of UPFC has been suggested in [5].

The aim of the optimization problem is to find the best location and the optimum capacity of UPFC with regards to satisfying technical and economical constraints. A linear programming based optimal power flow algorithm for the placement of UPFC has been proposed in [6] to reduce overloads and voltage violations. However, reduction of loads and voltage violations may not always be helpful in improving voltage stability margin. Particle Swarm Optimization (PSO) technique has been used [7] to achieve maximum system loadability with minimum cost of installation. Particle swarm optimization technique has been 8] to maximize the loadability of transmission system using Unified Power Flow Controller under line outages. employed in [8] to maximize the loadability of transmission system using Unified Power Flow Controller under line outages.

The work on UPFC placement has mainly concentrated to see its impact for the system intact case and under line outage cases. However, outage of some of the generators may also cause voltage instability in the power system. In this paper a sensitivity based approach has been presented to study impact of UPFC placement in loading margin enhancement under critical contingencies considering line outage cases. The effectiveness of the proposed method of UPFC placement has been established on a IEEE 14-bus system.

A number of methods have been developed for calculating ATC. Amongst the proposed methods three of them seem to be applicable for large-scale applications. The three methods are Repeated Power Flow (RPF) method, Continuation Power Flow (CPF) method and Transfer-based security constrained method [9].

II. MODELING OF BILATERAL CONTRACTS

The conceptual model of bilateral dispatch in a competitive electricity market is such that sellers and buyers enter into transactions where the quantities traded and the associated prices are at the discretion of these parties and not a matter for system operators (SO_s). If there is no static and dynamic security violation, the SO simply dispatches all requested transactions and charges for the transmission service. Mathematically, each bilateral transaction between a seller at bus-p and power purchaser at bus-q satisfies the following power balance relationship: $P_{Gp} - P_{Dq} = 0$[10].

III. UPFC MODEL

In the present work, UPFC has been represented by steady-state injection model [5]. The UPFC consists of two switching converters operated from a common DC link, as shown in fig. 1. In this figure, Converter 2 performs the main function of the UPFC by injecting an AC voltage with controllable magnitude and phase angle in series with the line.

The basic function of Converter 1 is to supply or absorb the active power demanded by Converter 2 at the common DC link. This is represented by the current Ip.

Converter 1 can also generate or absorb controllable reactive power and provide independent shunt reactive compensation for the line. This is represented by the current, Iq. A UPFC can regulate active and reactive power simultaneously. In principle, a UPFC can perform voltage support, power flow control and dynamic stability improvement in one and the same device.

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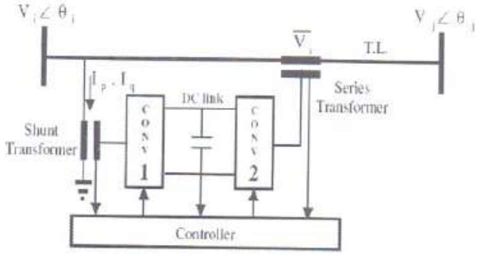

Fig. 1.UPFC schematic diagram

The UPFC circuit arrangement has been shown in fig. 2. The series converter is represented by an AC voltage source $\overline{V}_s$ in series with a reactance X_s. The shunt converter has been represented as an independently controllable reactive power Q_{conv1} injected to or absorbed from bus-i. In addition, this converter also supplies or absorbs real power P_{conv1} to the series converter through the common DC link. I_{ij} and I_{ji} represent current flowing from bus-i to bus-j and from bus-j to bus-i respectively. $\overline{V}_i'$ represents complex voltage of a fictitious bus-i'.

The series voltage source is controllable in magnitude and phase and can be given by

$$\overline{V}_i = r\,\overline{V}_i\,e^{j\gamma}$$

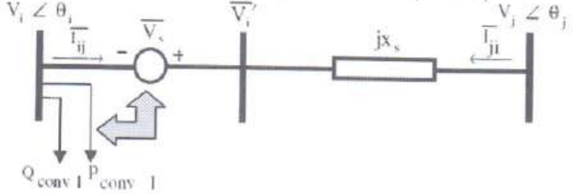

Fig. 2. UPFC circuit arrangement

Where, $0 < r < r_{max}$ and $0 < \gamma < 2\pi$, Variables r and γ are the control magnitude and phase angle of injected voltage $\overline{V}_s$ r_{max} represents maximum limit of variable r.

The steady-state injection model of UPFC has been derived from fig. 2. [5] and has been shown in fig. 3. In this UPFC has been represented as controllable loads connected at buses i and j.

In [4], shunt converter has been represented as a constant voltage variable reactive power source, whereas series converter has been considered as a variable reactance in the line. This model of UPFC ignores phase-shifter action of series converter. Steady-state injection model of UPFC overcomes this limitation.

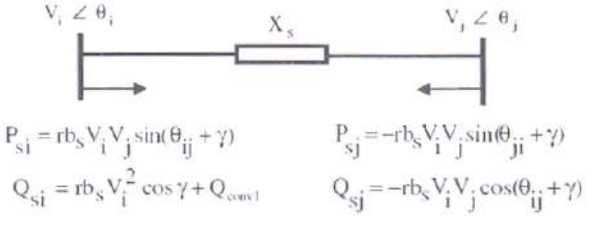

Fig. 3. UPFC injection model

IV. CASE STUDY

The suggested algorithm is applied to the IEEE 14-bus test system. It consists of five synchronous machines, three of which are synchronous compensators used only for reactive power support. There are 11 loads in the system totaling 259 MW and 81.3 MVAR.

The loading margin for the system intact case & contingency cases (considering line and generator outages) were obtained using continuation power flow based software package UWPFLOW [11].

In order to calculate ATC, bilateral transactions were considered between seller bus 2 & buyer bus 13. Real power demands were calculated at the base case operating point and at the maximum load ability point for the system intact case and critical contingency cases for each of these transactions. The difference between real power demands at the nose point and at the base case operating point were calculated for the system intact case and critical contingency cases, and were considered as ATC for the corresponding cases.

The minimum out of intact case ATC and ATCs for critical contingency cases was considered as static ATC of the system.

Table I, shows ATCs for the system intact case and critical contingency cases for the bilateral transactions between seller bus 2 and buyer bus 13. It is observed from Table I that static ATC of the system for the bilateral transactions between seller bus 2 and buyer bus 13 is 78.9589 MW corresponding to outage of line 5-6.

TABLE I
Static ATC for bilateral transactions between seller bus 2 and buyer bus 13 (IEEE 14-bus system)

Outage	ATC (MW)
Intact	224.7204
2-3	201.2324
1-5	199.5984
5-6	78.9589
2-4	189.2618
7-9	167.9844
4-5	225.6988
2-5	190.0637
4-7	184.9947
3-4	216.6868

It is observed from Table III, that placement of UPFC in line 4-9 (towards bus-9) causes maximum enhancement in ATC for bilateral transactions between seller bus-2 and buyer bus-13. The enhancement in ATC is from **78.9589** MW to **96.6859** MW.

TABLE II
Static ATC with UPFC in line 14 (8-7) for bilateral transactions between seller bus-2 and buyer bus-13 (ieee 14-bus system)

Outage	ATC (MW) with UPFC in line 14 (8-7)
Intact	225.8631
2-3	201.5567
1-5	199.8864
5-6	79.19939
2-4	189.5934
7-9	168.4624
4-5	225.9417
2-5	190.3721
4-7	186.7851
3-4	218.3206

TABLE III
static ATC with UPFC in line 9 (4-9) for bilateral transactions between seller bus-2 and buyer bus-13 (ieee 14-bus system)

Outage	ATC (MW) with UPFC in line 9 (4-9)
Intact	244.1564
2-3	227.9427
1-5	222.0763
5-6	96.6859
2-4	215.2525
7-9	211.1933
4-5	245.3801
2-5	213.5361
4-7	211.7837
3-4	218.3206

TABLE IV
static ATC with UPFC in line 18 (10-11) for bilateral transactions between seller bus-2 and buyer bus-13 (ieee 14-bus system)

Outage	ATC (MW) With UPFC in line 18 (10-11)
Intact	233.0346
2-3	212.7592
1-5	209.5007
5-6	88.8602
2-4	200.0242
7-9	187.629
4-5	234.7395
2-5	199.679
4-7	197.01
3-4	225.7569

Comparing percentage enhancement in static ATC for bilateral transactions, optimal location of UPFC was considered as line 4-9 (towards bus-9). Fig. 4 shows a bar chart showing static ATC without UPFC and with UPFC at optimal location for bilateral transactions. It is observed from table V, that placement of UPFC in line 4-9 (towards bus-9) causes considerable enhancement in static ATC for bilateral transactions.

TABLE V
enhancement of static ATC for bilateral transactions between seller bus-2 and buyer bus-13 (IEEE 14-bus system)

Outage	ATC(MW) without UPFC	Percentage enhance-ment in ATC with UPFC in line 8-7 (towards bus-7)	Percentage enhance-ment in ATC with UPFC in line 4-9 (towards bus-9)	Percentage enhance-ment in ATC with UPFC in line 11-10 (towards bus-10)
Intact	224.720	0.5085	8.6489	3.6998
2-3	201.232	0.1611	13.2733	5.7281
1-5	199.598	0.1442	11.2615	4.9610
5-6	78.958	0.3045	22.4509	12.5397
2-4	189.261	0.1752	13.7326	5.6865
7-9	167.984	0.2845	25.7219	11.6942
4-5	225.698	0.1076	8.7201	4.0056
2-5	190.063	0.1622	12.3497	5.0589
4-7	184.994	0.9678	14.4809	6.4949
3-4	216.686	0.7539	0.7539	4.1858

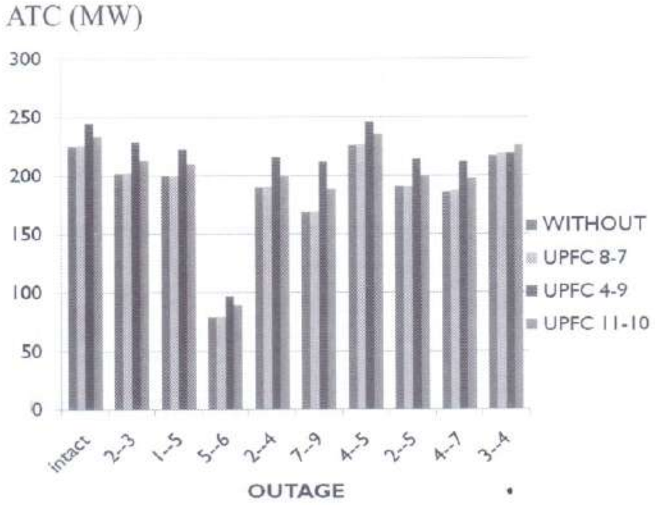

Fig. 4. Comparison of ATC (MW) without UPFC and with UPFC in line (8-7) (4-9) and (11-10) for bilateral transactions between seller bus 2 and buyer bus 13 under different outage conditions (IEEE 14-bus system)

V. CONCLUSION

A sensitivity based approach has been proposed in this paper for the optimal placement of UPFC in power system to enhance static ATC of the system. Based on the maximum absolute value of sensitivity factors, locations for UPFC placement have been obtained. The location causing maximum percentage enhancement in ATC for bilateral and transactions have been considered as the optimal location for the placement of UPFC controller.

From the case study performed on IEEE 14-bus-system, it is observed that a considerable enhancement occurred in ATC of the system after UPFC placement at the optimal location.

REFERENCES

[1] Y. H. Song and A. T. Johns, "Flexible AC Transmission Systems (FACTS)", Eds., *Inst. Elect. Eng. Power and Energy Series 30*, Chap.1, 1999.

[2] North American Electric Reliability Council (NERC), "Available Transfer Capability Definition and Determination," Rep., June 1996.

[3] N.G. Hingorani, L. Gyugi, *Understanding FACTS*, IEEE Press, NewYork, 2000.

[4] M.K.Verma and S.C.Srivastava " Enhancement of voltage stability margin under contingencies using FACTS controllers" *Proc. of the International Conference on Power System Operation in Deregulated Regime*, IT-BHU, Varanasi (India), pp. 139-149, March 6-7, 2006.

[5] H.A. Abdelsalam, G.E. M. Aly, M. Abdelkrim and K.M. Shebl "Optimal location of the Unified Power Flow Controller in electrical power system," *Proc. of the Large Engineering Systems Conference on Power Engineering – LESCOPE-2004*, Westin Nova Scotian, pp. 41-46, July 28-30, 2004.

[6] Weishao and Vijay Vittal, "LP based OPF for corrective FACTS control to relieve overloads and voltage violations", *IEEE Trans on Power Systems*, Vol. 21, No. 4, pp. 1832-1839, November 2006.

[7] M. Saravanan, S. Mary Raja Slochanal, P. Venkatesh, Prince Stephen Abraham. J "Application of PSO technique for optimal location of FACTS devices considering system loadability and cost of installation", *Power Engineering Conference*, Singapore, Vol- 2, pp. 716-721, Nov 29- Dec 2, 2005.

[8] S.T.Jaya Christa and P.Venkatesh, "Application of Particle Swarm Optimization for optimal placement of Unified Power Flow Controllers in electrical Systems with line outages", *International Conference on Computational Intelligence and* pp. 119-124, Dec.2007.*Multimedia Applications*, Sivakasi (India), Vol. 1, pp. 119-124, Dec.2007.

[9] H. Farahmand, M. Rashidinejad, A. A. Gharaveici, M.Shojaee, "An Application of Hybrid Heuristic Approach for ATC Enhancement", *Power Engineering*, 2006 Large Engineering Systems Conference on, pp. 125-130, July 2006.

[10] Ashwani Kumar, S.C. Srivastava and S.N. Singh,"Available transfer capability assessment in a competitive electricity market using a bifurcation Approach", *IEE Proc.-Gener. Transm. Distrib.*, Vol. 151, No. 2, March 2004.

[11] Software Package UWPFLOW available at http://www.power.uwaterloo.ca/~claudio/software/pflow.html

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