



AENSI Journals

Australian Journal of Basic and Applied Sciences

ISSN:1991-8178

Journal home page: www.ajbasweb.com

Transmission Line Loss Minimization in Power System Network Using TCSC and UPFC

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ARTICLE INFO

Article history:

Received 25 December 2013

Received in revised form 22

February 2014

Accepted 26 February 2014

Available online 15 April 2014

Keywords:

Transmission line loss, CPF, FACTS,

TCSC, UPFC

ABSTRACT

This paper presents a method to reduce the transmission line losses in the power system network using FACTS devices. The FACTS devices TCSC and UPFC only are used to minimize transmission line losses in the system. Identification of suitable location of these FACTS devices is proposed in this paper. This not only reduces the losses in the system but also maintains the power system network stability. In addition, it increases the loadability of the transmission line. The effectiveness of the proposed work is analyzed using IEEE 14-bus test system. The proposed method identifies suitable devices, on suitable lines at suitable location. The simulation confirms the proposal.

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To Cite This Article: A.Anbarasan, M.Y. Sanavullah and S. Ramesh., Transmission Line Loss Minimization in Power System Network Using TCSC and UPFC. *Aust. J. Basic & Appl. Sci.*, 8(3): 564-569, 2014

INTRODUCTION

The main objective of power system engineer is to operate the power system network up to its maximum limits economically to improve the system efficiency. This is achieved by reducing real power losses in the line and in turn will improve the reliability of the system to supply power to the consumers. Because of rapid growth of industries and infrastructural facilities, the electric power demand will be going on increasing. Nowadays number of private power producers are increasing rapidly to meet out this increased demand of electricity. All the power producers are utilizing the common existing transmission line network. Due to this, the magnitudes of the power flow in some of the transmission lines reaches closer to their maximum limits, while some other lines may be under loaded compared to their maximum rating.

To meet out these new challenges, existing generation or transmission facilities must be utilized more efficiently or new facilities should be added to the existing power system. The development of new generation facility and the new transmission system need more investments and time. Alternatively, loadability of existing can be improved by reducing real power loss in the line with the help of Flexible AC Transmission System (FACTS) devices.

A new power frequency model for Unified Power Flow Controller (UPFC) with its DC link capacitor dynamics is suggested in Huang, Z., *et al.*, 2000. Four principal control strategies for UPFC series element main control and their impacts on system stability are discussed. The main control of UPFC series element can be realized as a combination of the four control functions. The supplementary control of UPFC is added for damping power oscillation. The integrated UPFC model has then been incorporated into the conventional transient and small signal stability programs with a novel UPFC-network interface. A Genetic Algorithm (GA) is presented in Gerbex, *et al.*, 2001. to seek the optimal location of multi-type FACTS devices in a power system. The optimizations are performed on three parameters: the location of the devices, their types and their values. The system loadability is applied as a measure of power system performance. Four different kinds of FACTS controllers are used and modeled for steady-state studies, such as Thyristor Controlled Series Compensators (TCSC), Thyristor Controlled Phase Shifting Transformer (TCPST), Thyristor Controlled Voltage Regulator (TCVR) and Static VAR Compensator (SVC).

A method to determine the suitable locations of TCSC and Thyristor Controlled Phase Angle Regulator (TCPAR) based on the real power flow performance index sensitivity has been suggested in Verma, K.S., *et al.*, 2001., for enhancing the total transfer capability of the interconnected power system. An approach for selection of a suitable location of UPFC considering normal and network contingencies after evaluating the degree of severity of the contingencies is presented in Visakha, K.K., *et al.*, 2003. The ranking is evaluated using

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composite criteria based fuzzy logic for eliminating masking effects. The selection of suitable locations for UPFC uses the criteria on the basis of improved system security/stability. A GA based method to use TCSC in power systems in order to increase system loadability and to decrease the total loss is presented in Kazemi, A., *et al.*, 2006. Optimizations are done on two parameters: the location of TCSC and their values. A sensitivity analysis is used and the most sensitive lines are chosen to be compensated by TCSC. For this purpose, the steady state model of TCSC is utilized. A method to determine the optimal location of TCSC has been suggested in Hadi Besharat, and Seyed Abbas Taher, 2008. based on a real Power Performance Index (PPI) and reduction of total system VAR power losses.

A new method for locating multi-type FACTS devices is presented in Benabid, R., *et al.*, 2009. in order to optimize multi-objective voltage stability problem. The proposed methodology is based on a new variant of Particle Swarm Optimization (PSO) specialized in multi-objective optimization problem known as Non-Dominated Sorting Particle Swarm Optimization (NSPSO). The Crowding Distance Technique (CDT) is used to maintain the Pareto front size at the chosen limit, without destroying its characteristics. To aid the decision maker choosing the best compromise solution from the Pareto front, the fuzzy-based mechanism is employed for this task. NSPSO is used to find the optimal location and setting of two types of FACTS namely: TCSC and SVC that maximize Static Voltage Stability Margin (SVSM), reduce Real Power Losses (RPL), and Load Voltage Deviation (LVD). Mark Ndubuka Nwogu, 2010. presents an approach to find and choose the optimal location of UPFC based on the sensitivity of the total system active power loss with respect to the control variables of the UPFC. Bhattacharyya, A.B., and B. S.K.Goswami, 2011. presents a GA based approach for the allocation of FACTS devices for the improvement of Power transfer capacity in an interconnected Power System. The optimal power flow solution and enhancement of system performance without sacrificing the security of the system via optimal location and sizing of TCSC is presented in Shanmukha Sundar, K., and H.M.Ravikumar, 2012, when the system is operating under normal and network contingency conditions.

In the above literature it is found that the normal state of the system for placement of FACTS devices is only considered. But voltage instability problem is usually occurs in stressed conditions. Hence the analysis of FACTS devices under heavily stressed condition is very important. In this paper, FACTS devices is installed at the different locations of the power system network and system performance is analyzed without and with FACTS devices under maximum loadability condition. The locations of FACTS devices are determined based on the weak bus in the system and loadability of the transmission line. The main objective of this paper is to reduce the real power loss under maximum loadability conditions and to maintain the bus voltage within the security level by suitable location of TCSC and UPFC.

Modelling of Thyristor Controlled Series Compensator (TCSC):

A TCSC is a capacitive reactance compensator, which consists of a series capacitor bank shunted by a thyristor-controlled reactor in order to provide a smoothly variable series capacitive reactance. The basic idea behind power flow control with the TCSC is to decrease or increase the overall lines effective series transmission impedance, by adding a capacitive or inductive reactance correspondingly. Fig. 1 show the basic structure of a TCSC. (Acha, E., *et al.*, 2006, Hingorani, N.G., and L. Gyugyi, 2001)

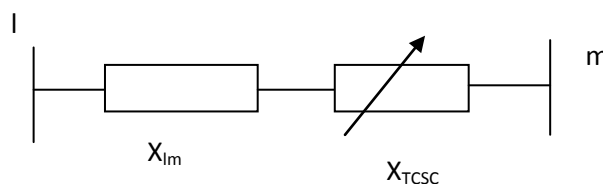


Fig. 1: Basic structure of TCSC

Modelling of Unified Power Flow Controller (UPFC):

A UPFC is a combination of Static Synchronous Compensator (STATCOM) and a Static Series Compensator (SSSC), which is coupled via a common DC link, to allow bidirectional flow of real power between the series output terminals of the SSSC and the shunt output terminals of the STATCOM. UPFC are controlled to provide coordinated real and reactive series line compensation without an external electric energy source. In addition to providing a supporting role in the active power, exchange that takes place between the series converter and the shunt converter generate or absorb reactive power in order to provide independent voltage magnitude regulation at its point of connection with the AC system. Fig. 2 shows the basic structure of a UPFC. (Acha, E., *et al.*, 2006, Hingorani, N.G., and L. Gyugyi, 2001)

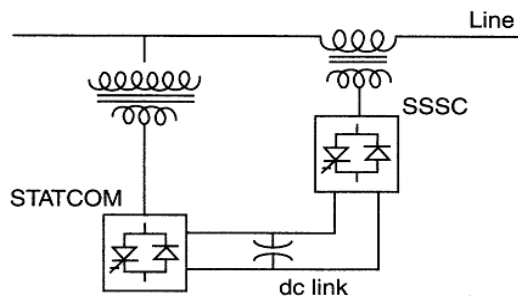


Fig. 2: Basic structure of UPFC

Case Studies:

An IEEE 14-bus test system is used to analysis the proposed real power loss minimization problem and the test system as shown in fig. 3. The test system consists of five generators and eleven load bus. Weak bus in the test system is investigated using Continuation Power Flow (CPF) methods. The behaviour of the test system without and with FACTS devices under different loading conditions is studied. The locations of the FACTS controllers are determined based on weak bus and loadability of the system including voltage limits to minimize the real power losses in the system.

A typical PQ model is used for the loads and the generator limits are ignored. The analysis is performed by starting from an initial stable operating point and then increasing the loads by a factor λ until the singular point of power flow linearization is reached. The loads are defined as

$$P_L = P_{L0}(1 + \lambda) \quad (1)$$

$$Q_L = Q_{L0}(1 + \lambda) \quad (2)$$

Where, λ is the loading parameter, P_{L0} and Q_{L0} are the active and reactive power base loads, P_L and Q_L are the active and reactive loads at bus L for the current operating point as defined by λ .

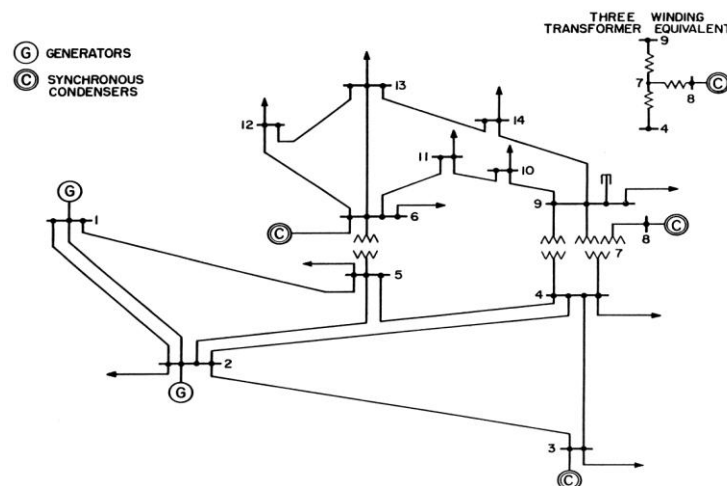


Fig. 3: The IEEE 14-bus test system

RESULTS AND DISCUSSIONS

The proposed work is analyzed using continuation power flow method suggested in Federico Milano, 2005 to study the maximum loadability of the system without violating their voltage limits. The analysis made based on the following three case studies.

A. Case -1 (Without FACTS devices):

The Table.1 shows the bus voltage magnitude without and with TCSC and UPFC under maximum loadability condition. When there is no FACTS device connected to the system, then the buses 4, 5, 7, 9,10,11,13 and 14 are violating their limits. Among these buses 4, 5, 9 and 14 identified as critical buses. The lines, which connect these buses, identified as the location for the FACTS devices.

B. Case-2 (With FACTS at line 7):

Based on the identified location of FACTS device, now the TCSC is included in the line 7 connected between the buses 4 and 5. The results shown in the table.1. From the result, it is notice that, when including TCSC between buses 4 and 5, the real power losses 5.8318 p.u. and maximum loadability of the system is 4.0022 p.u. Also, observe from the result that the buses 4, 5, 7, 9,10,11,13 and 14, are violating their voltage limits ($0.94 \text{ p.u.} \leq V_i \leq 1.06 \text{ p.u.}$).

Now, remove the TCSC and include the UPFC in the line 7 connected between the buses 4 and 5. The results are shown in the table .1. From the result, it is observed that, when including UPFC between buses 4 and 5, the real power loss is 6.01987 p.u. and maximum loadability of the system is 4.0297 p.u. Also, observe that the buses 4, 5,7,9,10,11 and 14 are violating their permissible voltage limits.

C. Case - 3 (With FACTS at line 20):

Now, the TCSC is included in the line 20 connected between the buses 13 and 14. The results are shown in the table 1. From the result, it is notice that, when including TCSC between buses 13 and 14 the total real power losses 6.0337 p.u. and maximum loadability of the system is 4.2654 p.u. Also, observed from the result that, the buses 4, 5, 7, 9,10,11,13 and 14 are violating their voltage limits, which will affect the stability of the power system network.

Next, the UPFC is included in the line 20 connected between the buses 13 and 14. The results are shown in the table .1. From the result, it is observed that, that the buses 4,5,7,9,10,11,13 and 14 are violating their voltage limits. When including UPFC between buses 13 and 14, the real power loss is 5.9661 p.u. and maximum loadability of the system is 4.0639 p.u.

Table 1: Bus voltage magnitude without and with TCSC and UPFC under maximum loadability

Bus no.	Without FACTS	With TCSC		With UPFC	
	V (p.u.)	at line 7	at line 20	at line 7	at line 20
1	1.000	1.000	1.000	1.000	1.000
2	1.045	1.045	1.045	1.045	1.045
3	1.010	1.010	1.010	1.010	1.010
4	0.639	0.685	0.641	0.765	0.678
5	0.608	0.641	0.612	0.684	0.655
6	1.070	1.070	1.070	1.070	1.070
7	0.761	0.779	0.770	0.812	0.797
8	1.090	1.090	1.090	1.090	1.090
9	0.665	0.679	0.682	0.706	0.714
10	0.694	0.705	0.707	0.725	0.735
11	0.818	0.867	0.868	0.877	0.882
12	0.975	0.975	0.985	0.976	1.003
13	0.922	0.922	0.932	0.923	0.978
14	0.661	0.665	0.711	0.672	0.751

From the study of case 1, 2, 3, it is understood that, some of the buses are violating their voltage limits under a maximum loadability limit condition without and with TCSC and UPFC. However, the main objective of the proposed work is to minimize the real power losses under maximum loadability condition without violating their voltage limits.

D. Comparison between without and with TCSC and UPFC at line 20:

Based on the number of buses violating their voltage limits, the line 20, which is connected between 13 and 14, is selected as the best suitable location for TCSC and UPFC. Now, the analysis again repeated including the bus voltage limits. The table .2 shows the bus voltage magnitude and a table. 3 shows the real power loss without and with TCSC and UPFC on line 20 under maximum loadability conditions including their voltage limits. From the table. 2 it is observed that, there are no buses violating their voltage limits.

Under this condition, the TCSC will improve the maximum loadability from 2.0774 p.u. to 2.42 p.u. and reduces the real power loss from 1.1675 p.u. to 0.9743 p.u. Similarly, the UPFC will improve the maximum loadability of the system from 2.0774 p.u. to 2.4196 p.u. and reduces the real power loss from 1.1675 p.u. to 0.9817 p.u. The table. 4 Shows the bus voltage magnitude without and with TCSC and UPFC under maximum loadability ($\lambda=2.07$) including voltage stability limit. From the table. 4. It is found that the TCSC and UPFC improve the bus voltages within the acceptable limits.

Table 2: Bus voltage magnitude without and with TCSC and UPFC under maximum loadability including voltage stability limit

Bus no.	Without FACTS	With TCSC at line 20	With UPFC at line 20
	V (p.u)	V (p.u)	V (p.u)
1	1.000	1.000	1.000
2	1.045	1.045	1.045
3	1.010	1.010	1.010
4	0.967	0.949	0.948
5	0.974	0.955	0.955
6	1.070	1.070	1.070
7	1.009	0.994	0.993
8	1.090	1.090	1.090
9	0.973	0.955	0.952
10	0.974	0.956	0.953
11	1.013	1.003	1.002
12	1.033	1.023	1.018
13	1.017	1.003	0.992
14	0.951	0.942	0.933
Maximum load ability	2.0774	2.42	2.4196

Table 3: Transmission line loss without and with TCSC and UPFC under maximum loadability including voltage stability limit

Line No.	Buses	Without FACTS	With TCSC at line 20	With UPFC at line 20
		Ploss (p.u)	Ploss (p.u)	Ploss (p.u)
1	1-2	0.3401	0.3307	0.3315
2	2-3	0.1852	0.1644	0.1646
3	2-4	0.1215	0.1122	0.1125
4	1-5	0.2011	0.1885	0.1889
5	2-5	0.0745	0.0635	0.0637
6	3-4	0.0462	0.0395	0.0397
7	4-5	0.0316	0.0303	0.0302
8	5-6	0.0000	0.0000	0.0000
9	4-7	0.0000	0.0000	0.0000
10	7-8	0.0000	0.0000	0.0000
11	4-9	0.0000	0.0000	0.0000
12	7-9	0.0000	0.0000	0.0000
13	9-10	0.0005	0.0004	0.0004
14	6-11	0.1200	0.0096	0.0099
15	6-12	0.0068	0.0055	0.0062
16	6-13	0.01900	0.0181	0.0216
17	9-14	0.0067	0.0063	0.0064
18	10-11	0.0061	0.0044	0.0046
19	12-13	0.0022	0.0011	0.0017
20	13-14	0.006	0.0000	0.0000
Total real power loss		1.1675	0.9743	0.9817
Maximum load ability		2.0774	2.42	2.4196
Voltage limit violating buses		0	0	0

Table 4: Bus voltage magnitude without and with TCSC and UPFC under maximum loadability ($\lambda=2.07$) including voltage stability limit

Bus no.	Without FACTS	With TCSC at line 20	With UPFC at line 20
	V (p.u)	V (p.u)	V (p.u)
1	1.000	1.000	1.000
2	1.045	1.045	1.045
3	1.010	1.010	1.010
4	0.967	0.968	0.967
5	0.974	0.975	0.974
6	1.070	1.070	1.070
7	1.009	1.011	1.009
8	1.090	1.090	1.090
9	0.973	0.978	0.974
10	0.974	0.978	0.974
11	1.013	1.015	1.013
12	1.033	1.035	1.020
13	1.017	1.020	1.018
14	0.951	0.965	0.952

The fig. 4. shows the total transmission losses in the system with and without TCSC and UPFC. The fig. 5 shows the loadability of the line with and without TCSC and UPFC. From the graph, it is clear that TCSC will reduce the transmission losses and improve the loadability compared to UPFC and without FACTS devices.

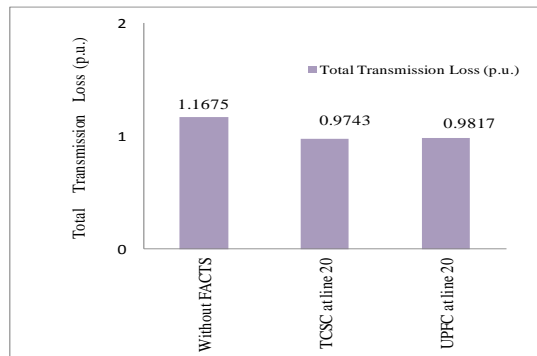


Fig. 4: Total transmission losses in the system

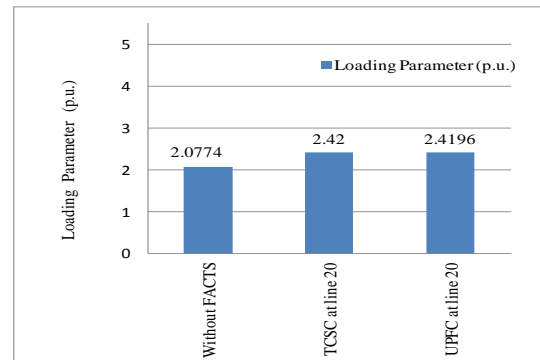


Fig. 5: Loadability of the system.

Conclusion:

The minimization of transmission line loss is analyzed in this paper without and with TCSC and UPFC. The continuation power flow method is used to identify weakest bus in the system. Based on the number of buses violating their voltage limits, while locating FACTS devices, the best suitable location for a FACTS device is selected. Then TCSC and UPFC are included in the identified best suitable line separately. From the analysis, the results are ensuring that, when locating either TCSC or UPFC at suitable lines will minimize the transmission line losses under maximum loadability condition. Hence, the existing transmission line facility will be utilized effectively and economically to transfer the power to the consumers.

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