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Line loss minimization and voltage regulation using UPFC

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ABSTRACT

This paper presents a method for achieving line loss minimization and voltage regulation in the given power system. In order to achieve these two objectives simultaneously, the Unified Power Flow Controller (UPFC) is used. UPFC can be used for load voltage regulation and total active power loss minimization in electric power systems at the same time. In this paper, the injection model of UPFC (Unified Power Flow Controller) is used to investigate its effects on bus voltages and loss reduction in a power system.

Introduction

The possibility of controlling power flow in an electric power system without generation rescheduling or topology changes can improve the power system performance . By use of controllable components, the line flows can be changed in such a way that thermal limits are not exceeded, losses minimised, stability margins increased, contractual requirements fulfilled, etc. without violating the economic generation dispatch. Investigating the power through a transmission line shows that reactance and phase angle control of a transmission line are effective means for power flow control in AC transmission systems.

Alternating current transmission systems incorporating power electronic-based and other static controllers to enhance controllability and increase power transfer capability are called Flexible AC Transmission Systems (FACTS). In principle, FACTS devices like thyristor switched series capacitors (TCSC) and thyristor switched phase shifting transformer (TCPST) could provide fast control of active power through a transmission line. Both devices exert a voltage in series with the line. For a series capacitor, the inserted voltage lags the line current by 90 degrees. For a phase shifting transformer, the inserted voltage is in quadrature to the bus voltage. Recent advances in high power technology has made it possible to implement all solid state power flow controllers using power switching converters.

The *unified power flow controller* (UPFC) is a device in FACTS family which consists of series and shunt connected converters. The *unified power flow controller* (UPFC) can provide the necessary functional flexibility for optimal power flow control. This approach allows the combined application of phase angle control with controlled series and shunt reactive compensation.

The family of FACTS devices relevant to this paper are Static Synchronous(shunt) Compensator (STATCOM) [1],Static Synchronous Series Compensator (SSSC) [2] and Unified Power Flow Controller (UPFC)[3]. Whereas the STATCOM and SSSC are usually employed as reactive compensators, the UPFC could be considered as a comprehensive real and reactive power compensator capable of independently controlling both real and reactive power flow in the line.

UPFC is a versatile FACTS (Flexible AC Transmission Systems) controller with all encompassing capabilities of voltage regulation, series compensation & phase shifting. It can independently & rapidly control both real & reactive power flows in a transmission line.

This paper investigates the performance of the UPFC for power flow control. A mathematical model for UPFC which will be referred as *UPFC injection model* is derived. This model is helpful in understanding the impact of the UPFC on power system. Furthermore, the UPFC injection model can easily be incorporated in the steady state power flow model.

The proposed model is used to demonstrate some of the features of UPFC for optimal power flow control (OPF) applications. This paper shows that a UPFC has the capability of regulating the power flow and minimising the losses at the same time. This outstanding feature can be utilised for various power flow control applications, for example, overload relief, loop flow minimisation, etc.

This paper is organised as follows: Section II describes the operating principle of UPFC. Section III describes the UPFC injection model. Section IV describes the UPFC injection model for load flow studies. Section V describes the MATLAB simulation results. Section VI describes the conclusion.

Operating Principle of UPFC

The unified power flow controller consists of two voltage source converters (VSC).These converters are operated from a common dc link provided by a dc storage capacitor as shown in Fig 1.

Converter 2(Series converter) provides the main function of the UPFC by injecting an ac voltage with controllable magnitude and phase angle in series with the transmission line via a series transformer. The basic function of converter 1 is to supply or absorb the real power demand by converter 2 at the common dc link. It can also generate or absorb controllable reactive power

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and provide independent shunt reactive compensation for the line. Converter 2 supplies or absorbs locally the required reactive power and exchanges the active power as a result of the series injection voltage. Here $V_i \langle \theta_i$ and $V_j \langle \theta_j$ are bus voltage magnitude and phase angles at bus i & j respectively. P and Q are real and reactive power flow in the line.

Converter 1(shunt converter) maintains constant voltage of the DC bus. It functions like a STATCOM & independently regulates the terminal voltage of the interconnected bus by generating /absorbing a requisite amount of reactive power.

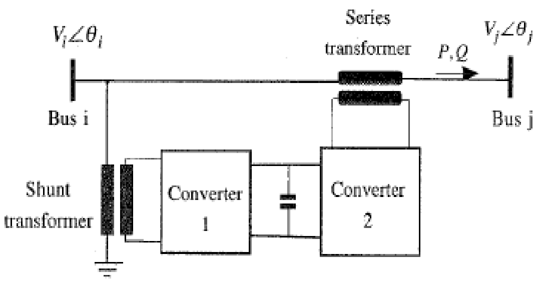

Fig1. Basic UPFC circuit arrangement

Whereas the STATCOM and SSSC are usually employed as reactive compensators, the UPFC could be considered as a comprehensive real and reactive power compensator capable of independently controlling both real and reactive power flow in the line .The UPFC concept provides a powerful tool for the cost-effective utilization of individual transmission lines by facilitating the independent control of both the real and reactive power flow and thus the maximization of real power transfer at minimum losses in the line.

UPFC concept was devised for the real time control and dynamic compensation of ac transmission systems, providing multifunctional flexibility required to solve many of the problems facing the power delivery industry.

UPFC Injection Model

A. Series connected voltage source converter model

Suppose a series converter can be modelled as an ideal voltage source Vs in series with a reactance Xs as shown in the Fig 2 .Then Vi' represents a fictitious voltage behind the series reactance .We have Vi'=Vs+Vi, (1)

where Vi<θi & Vj <θj are bus voltage magnitude and phase angles at bus i & j respectively .Iij =current in the line, Vs =series injected voltage, Xs= line reactance.

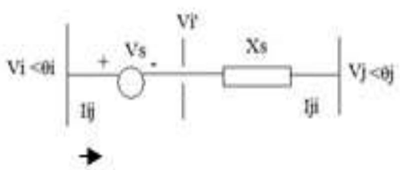

Fig 2. Representation of series connected VSC

Series voltage source

Vs=rVi exp(jγ) (2)

where $0<r<r_{max}$ and $0<\gamma<2\pi$,here r & γ are series voltage coefficient and angle .r_{max} is the maximum value of r. The injection model is obtained by replacing the voltage source by the current source Is=jbsVs in parallel with the line as shown in Fig 3, where bs=1/Xs=susceptance.

The current source corresponds to the injection powers Si & Sj, where

Si=Vi(-Is)*=Vi[-jbsrViexp(jγ)]* (3)

Sj=Vj(Is)*=Vj[jbsrVi exp(jγ)]* (4)

Separating real & imaginary parts we get real & reactive power injections Pi, Qi & Pj, Qj at bus i & j respectively . θij=θi –θj , 0<= r <=1.

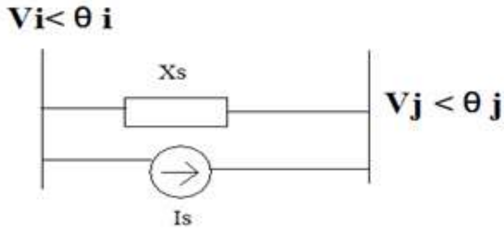

Fig3. Replacement of a series voltage source by a current source

Shunt converter model

The shunt branch is used to supply the active & reactive power which is injected into system. Hence this amount of active & reactive power must be added to Si to obtain the overall model of UPFC as shown in Fig 4.

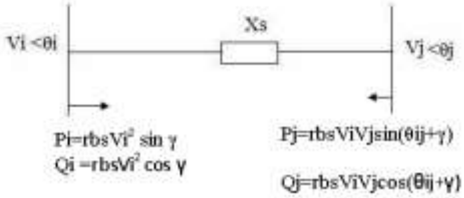

Fig 4. Overall UPFC injection model

UPFC Injection Model for Load Flow Studies

The UPFC injection model can easily be incorporated in a load flow program. If a UPFC is located between node i and node j in a power system, the admittance matrix is modified by adding a reactance equivalent to X_S, between node i and node j. The Jacobian matrix is modified by addition of appropriate injection powers.

If we consider the linearized load flow model as:

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix}=\begin{bmatrix}H & N\\ J & L\end{bmatrix}\begin{bmatrix}\Delta\Theta\\ \Delta V/V\end{bmatrix} \quad (5)$$

The Jacobian matrix is modified as given in Table I. (The superscript *o* denotes the Jacobian elements without UPFC).

Matlab Simulation Results

In this section ,the UPFC injection model is used to consider the effects of the UPFC on power flow and power losses .The simulated power system is an IEEE 14- bus system as shown in Fig.5 [6] . Simulations have been implemented in MATLAB and the IEEE 14-bus system has been used as a case study.

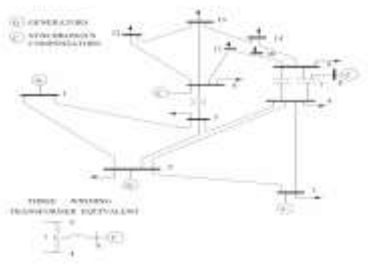

Fig 5. IEEE14-bus system

The possibility of controlling the magnitude and angle of the series voltage source in a UPFC, makes it a powerful device for Optimal Power Flow (OPF) control applications. Here the simulated system is an IEEE 14-bus system as shown in Fig 5.

When the complete transmission model is included in the development of generation schedules, the process is imbedded in a system of computer algorithms known as Optimal Power Flow

(OPF). OPF has many applications including the calculation of the optimum generation pattern, as well as all control variables, to achieve the minimum cost of generation together with meeting the transmission system limitations. A partial list of control variables are Generator voltage, Transformer tap position and DC line flow.

The development of the OPF algorithm by Newton's method is based on the success of the Newton's method for the power flow calculations, called as Newton-Raphson algorithm.

Using this algorithm, all the bus voltages and the total transmission line losses are calculated for the IEEE 14-bus system with and without UPFC. The results of the simulation are tabulated below as shown in Table II and Table III. It is seen that bus voltages increase and line losses decrease after installing UPFC in all the lines of the IEEE 14-bus system. Most of the loads in IEEE 14-bus system are inductive loads.

Conclusion

Voltage source injection model is used to investigate the functioning of UPFC. This model is incorporated in Newton Raphson Algorithm for Optimal Power Flow studies. It is found that the UPFC regulates the voltage of the bus as well as the active and reactive power of the buses and the lines within the specified limits. The numerical results for the standard IEEE 14 bus network has been presented with and without UPFC and compared.

Thus it is seen that UPFC reduces the transmission line losses and regulates the bus voltages very well. It was shown that a UPFC can be controlled in a power system to satisfy the following objectives simultaneously

- Regulating power flow through a transmission line.
- Minimisation of power losses without generation rescheduling.

Reference

[1] G. Hingorani, *Understanding FACTS*, First Indian ed, Standard Publishers, New Delhi, India, 2001.
[2] L. Gyugyi, "Static Synchronous Series Compensator: A Solid-State Approach to the Series Compensation of Transmission Lines", *IEEE Transactions on Power Delivery*, vol. 12, no. 1, pp.569-571, Jan 1997.
[3] M. Noorzian and G. Anderson, "Use of UPFC for optimal power flow control", *IEEE Transactions on power delivery* , vol 12 , no 2, pp. 300-309, Oct. 1997.
[4] D. Gotham "Power flow control and power flow studies for systems with FACTS devices",*IEEE transactions on power systems* , vol 13 , no 3 , pp. 231-235, Nov 1999.
[5] Jun-Yong Liu, Yong-Hua Song and Mehta, "Strategies for handling UPFC constraints in steady-state power flow and voltage control in Power Systems", *IEEE Transactions on power systems*, vol 15, no 1, pp. 123-126, Jan 2003.
[6] S. Javed and A. Saeed, "Line Loss Minimization with UPFC", *CCECE conference*, vol 61,pp. 345-348,Sept 2004.
[7] K. Sen and E. Stacey, "UPFC - Unified Power Flow Controller: Theory, Modelling, and Applications", in *Proc ECOC'00,* 2000, paper 11.2.4 , p. 110 .
[8] Y. H. Song and A. T. Johns, *Flexible AC Transmission Systems (FACTS)*, IEE Press, London, 1999.
[9] C. Adamson and G. Hingorani, *High-Voltage Direct Current Power Transmission,* Garraway, 1960.
[10] K..R. Padiyar, *HVDC Power Transmission Systems*, Wiley Eastern Limited, New Delhi, India, 1990.
[11] C.E.Grund, "Dynamic Performance Characteristics of North American HVDC Systems for Transient and Dynamic Stability Evaluations", *IEEE Transactions on Power Apparatus and Systems*, vol. 7, no 2 , pp. 3356–3364, Jul 1981.
[12] M. Mathur and K. Varma, *Thyristor Based FACT Controllers for Electrical Transmission Systems*, John wiley, New Delhi, India, 2002.
[13] X. Wei, H.Chow and A. Edris "A common modelling framework of voltage sourced converters for load flow, sensitivity, and dispatch analysis", *IEEE Transactions on Power Systems*, vol 19, no 2, pp. 234-240, Jan 2004.
[14] L. Gyugyi , K. Sen and C. Schauder "The Interline Power Flow Controller: A New Approach to Power Flow Management in Transmission Systems", *IEEE Transactions on Power Delivery*, vol 14, no 3, pp. 1115–1123, Oct 2000.

Table I Modification of jacobian matrix

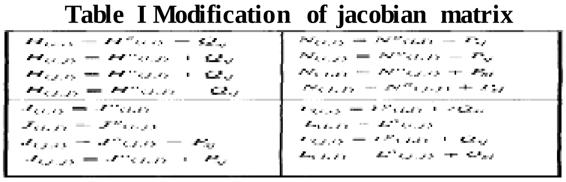

Table II Bus voltages

Bus No	Voltages (p. u)	
	Power flow study without UPFC	Power flow study with UPFC
1	1.00	1.00
2	0.99	1.00
3	0.9244	0.9437
4	0.9374	0.9601
5	0.9525	0.9734
6	0.8853	0.9282
7	0.8933	0.9288
8	0.8933	0.9288
9	0.8721	0.9126
10	0.8655	0.9023
11	0.8711	0.9156
12	0.8673	0.9149
13	0.8616	0.9089
14	0.8443	0.8913

Table III Total transmission line losses

Line losses (MW)	Power flow study without UPFC	Power flow study with UPFC
	16.3766	15.0095