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Modeling, Analysis and Optimal Location of UPFC for Real Power Loss Minimization

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Abstract

A new concept of Flexible AC Transmission system (FACTS) brought radical changes in the power system operation and control. A new technique using FACTS devices linked to the improvements in semiconductor technology opens new opportunities for controlling power and enhancing the usable capacity of existing transmission lines The UNIFIED POWER FLOW CONTROLLER is devised for the real time control and dynamic compensation of transmission systems, providing multifunctional flexibility required solving many of the problems facing the power delivery industry. Within the framework of traditional power transmission concepts, the UPFC is able to control, simultaneously or selectively all the parameters affecting power flow in the transmission line and this unique capability is signified by the adjective "unified" in its name. UPFC can independently control both active and reactive power in the line.

Key words- UPFC, Reactive power, Facts

1. INTRODUCTION

Over the years, it has become clear that the maximum safe operating capacity of the transmission system is often based on voltage and angular stability rather than on physical limitations. And also In the recent years ecological concerns and high installation costs have put constraints over construction of new plants and overhead lines in many countries, thereby forcing existing system to be used more efficiently rather than constructing new lines, industry has tended towards the development of technologies or devices that increase transmission network capacity while maintaining or even improving grid stability.[1]

Our main objective is to meet the electric load demand reliably while simultaneously satisfying certain quality constraints imposed on the power supply. Generally, this specified level of system reliability and quality is insured in terms of the capacity of the system to meet the aggregate load demand and the ability of the system to withstand the impact of disturbance.

An increase of the unplanned power exchanges causes some lines located on particular paths may get overloaded, which causes a phenomenon called congestion, and thus full capacity of the transmission interconnections may not be fully utilized. Therefore, it became effective to have a way of permitting a more efficient use of the transmission lines by controlling the power flows. Until a few years ago, the only means of carrying out this function were electromechanical devices such as switched inductors or capacitor banks and phase shifting transformers, however, specific problems related to these devices make them not very efficient in some situations they are not only relatively slow, but they also cannot be switched frequently, because they tend to wear out quickly.[1,2]

2. VOLTAGE CONTROL OF POWER SYSTEM

A power system is said to be well designed if it gives a good quality of reliable supply. By good quality is meant the voltage levels within the reasonable limits. Practically all the equipment on the power systems are designed to operate satisfactorily only when the voltage levels on the system correspond to their rated voltages or at the most the variations are within say 5%.If the voltage variation is more than a prescribed value, the performance of the equipments suffers and the life of most of the equipments suffers and the life of most of the equipment also is sacrificed.

When power is supplied to a load through a transmission line keeping the sending end voltage constant, the receiving end or load voltage undergoes variations depending upon the magnitude of the load and the power factor of the load. The higher the load with smaller power factor the greater is the voltage variation. The voltage variation at a node is an indication of the unbalance between the reactive power generated and consumed by that node. If the reactive power generated is greater than consumed, the voltage goes up and vice versa. Whenever the voltage level of a particular bus undergoes variation this is due to the unbalance between the two vars at that bus.[4]

3. UNIFIED POWER FLOW CONTROLLERS

The Unified Power Flow Controller (UPFC) is a member of this latter family of compensators and power flow controllers which utilize the synchronous voltage source (SVS) concept of controllers for providing a uniquely comprehensive capability for transmission system control. Within the framework of traditional power transmission concepts, the UPFC is able to control, simultaneously or selectively, all the parameters affecting power flow in the transmission line (i.e., voltage impedance, and phase angle). Alternatively, it can provide the unique functional capability of independently controlling both the real and reactive power flow in the line. These basic capabilities make the most powerful device presently available for transmission system control.

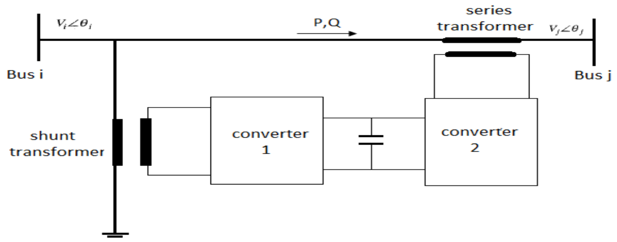


Figure 1 Basic circuit arrangement of UPFC

3.1 CONVENTIONAL TRANSMISSION CONTROL CAPABILITIES

Viewing the operation of the Unified Power Flow Controller from the standpoint of traditional power transmission based on reactive shunt compensation, series compensation, and phase shifting, the UPFC can fulfil all these functions and thereby meet multiple control objectives by adding the injected voltage Vpq, with appropriate amplitude and phase angle, to the (sending-end) terminal voltage Vs.

Voltage regulation with continuously variable in-phase anti-phase voltage injection, shown at ‘a’ for voltage increments $V_{pq}= \pm\Delta v(\rho=0)$. Functionally this is similar to that obtainable with a transformer tap-changer having infinitely small steps.

Series reactive compensation is shown at b where $V_{pq}=V_\sigma$ is injected in quadrature with the line current I. Functionally this is similar to, but more general than the controlled series capacitive and inductive line compensation. This is because the UPFC injected series compensating voltage can be kept constant, if desired, independent of line current variation, whereas the voltage across the series compensating impedance varies with the line current.

3.2 MODELING OF UPFC

The voltage at the bus i is taken as reference (all other angles are taken wrt this bus angle)

$$V_i = |V|\angle 0° \qquad (1)$$

And voltage upto UPFC is Vi’=Vi+Vse. The voltage sources,Vse and Vsh,are controllable in both magnitude and phase angles. the values of γ and r are defined with in the limits as

$0 \le r \le rmax \qquad 0\le \gamma \le 2$□□□

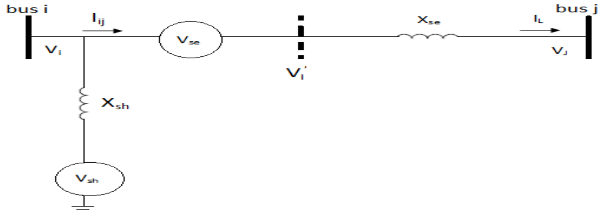


Figure 2 Two voltage source model of UPFC

V_{se} is defined in terms of reference bus voltage (i.e) ,Vi.

$$V_{se}= r*V_i *e\text{^}(j\gamma) \qquad (2)$$

For finding the power fed by the UPFC we go for superposition theorem. first considering the series voltage source and then the shunt one.

By considering the series source the circuit is as below

The steady-state UPFC mathematical model is developed by replacing Vse by a current source using duality principle. Which is connected in parallel with the transmission line, where bse =1/X_{se}.

$I_{se} = -j*b_{se}*V_{se}$ (3)

The convention for flow of current is if the current leaves the node it is negative and if it enters the node it is positive

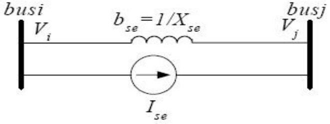


Figure 3 Replacement of voltage source by current source

As the power is equal to the product of voltage and current conjugate

$P+jQ = Vj*(I^{\sim})$. (4)

$Sis = Vi(-Ise)^{\sim}$ (˜ refers conjugate of the variable) (5)

$Sjs= Vj\ (I)$ (6)

The injected powers Sis Sjs can be simplified according to following operations

$Sis = Vi\ (\ jbse\ r\ Vi\ e\text{^}\ (j\gamma))^{\sim}$. (7)

From eulers identity $e\text{^}(j\gamma) = \cos\gamma+j\sin\gamma$.

$Sis= Vi(\ e\text{^}(-j\ (\gamma+90)\ x\ bse\ x\ r\ Vi^{\sim})$. (8)

So $Sis= -r\ x\ bse\ x\ Vi^{2}\ [\cos(-\gamma-90)+ j \sin (-\gamma-90)]$

As $\cos(-\gamma-90)=-\sin\gamma \quad \sin (-\gamma-90)=-\cos\gamma$.

$Sis = -r\ bse\ Vi^2\sin\gamma-j\ bse\ r\ Vi^2\cos\gamma$ (9)

Since $Sis=Pis+jQis$

Comparing above equations

$Pis= -r\ bse\ Vi^2 \sin \gamma$. (10)

$Qis=-r\ bse\ Vi^2 \cos \gamma$. (11)

The voltage $Vj=Vj\angle\theta j$ and $Vi= Vi\angle\theta i$

$Sjs=Vj(Ise)^{\sim}$

$Sjs=Vj\angle\theta j(-j\ bse\ r\ Vi\ \angle\theta i\ e\text{^}(j\gamma))$ (12)

$Sjs= Vi\ Vj\ bse\ r\ \sin(\theta i-\theta j+\gamma)+j\ I\ Vj\ bse\ r\ \cos(\theta i-\theta j+\gamma)$.

And $Sjs= Pjs+Qjs$.

Comparing above equations we get

$Pjs= Vi\ Vj\ bse\ r\ \sin(\theta i-\theta j+\gamma)$ (13)

$Qjs= Vi\ Vj\ bse\ r\ \cos(\theta i-\theta j+\gamma)$ (14)

Now we will consider the shunt source, in UPFC, the shunt branch is used mainly to provide both the real power, Pse, which is injected to the system through the series branch, and the total losses within the UPFC. The total switching losses of the two converters is estimated to be about 2% of power transferred ,for Thyristor based PWM converters, if losses are included in real power injection of shunt connected voltage source at bus I , Psh is equal to 1.02 times the injected series real power through the series connected voltage source to the system.

$Psh = -1.02\ Pse$

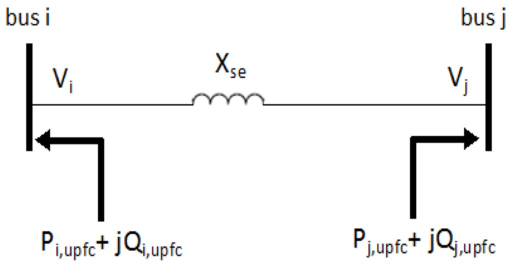
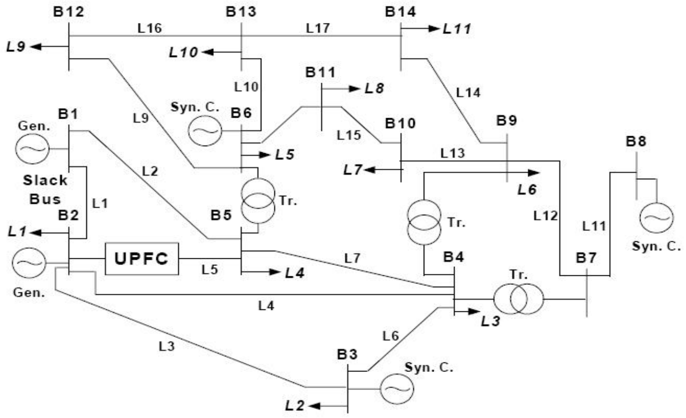


Fig 4 Steady state mathematical model

4. IMPLEMENTATION ON IEEE-14 BUS SYSTEM



5. RESULTS

Table 1: Power flows for IEEE-14 bus system with UPFC

Line no.	Active power flow (MW)	Reactive power flow (MVAR)
1	1.5696	-0.2042
2	0.7334	0.03549
3	0.5609	-0.0045
4	0.7544	0.0441
5	0.04152	0.019
6	-0.2318	0.0463
7	-0.6106	0.1269
8	0.4412	0.1191
9	0.2805	-0.1028
10	0	-0.1774
11	0.1606	-0.0067
12	0.2805	0.5732
13	0.052	0.0401
14	0.0737	0.0376
15	0.0779	0.0252
16	0.1776	0.0732
17	0.094	0.0347
18	-0.038	-0.0181
19	0.0162	0.0077
20	0.0566	0.0187

Table 2 Power flows for IEEE-14 bus system without placing UPFC

Line no.	Active power (MW)	Reactive power (MVAR)
1	1.557	-0.201
2	0.69	0.04
3	0.54	-0.367
4	0.788	-0.291
5	0.392	-0.398
6	-0.273	-0.317
7	-0.679	-0.066
8	0.445	-0.156
9	0.28	-0.522
10	-5.16E-17	-0.721
11	0.156	-0.15
12	0.28	0.139
13	0.049	0.034
14	0.076	0.043
15	0.078	0.026
16	0.179	0.075
17	0.092	0.031
18	-0.041	-0.024
19	0.017	0.008
20	0.059	0.022

The efficiency of the method is tested on IEEE 14- bus and 9-bus system. The optimal parameter of UPFC are evaluated which minimizes the system losses, fixing the location of line in which UPFC is placed. Power flows through lines also obtained. This process is carried out for all the lines. The line in which total losses are minimum is the optimal location. Each test system is studied for two cases. For 14-bus system optimal location is done at base case and

1.3 times the base load and for the 9-bus system optimal location is done at at base case and 1.1 times the base load. The losses are 30% less than the others power system control method.

6. CONCLUSIONS

In this study, an improved UPFC steady-state mathematical model for the implementation of the device in the conventional NR power flow algorithm has been developed from a two-voltage source equivalent of UPFC. An advantage of the model is that the model is capable of taking the losses of UPFC into account.

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