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Use of Unified Power Flow Controller for Power Flow Control

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Abstract: **This paper presents the introduction of Unified Power Flow Controller (UPFC) for solving power flow control problem in power system. The Unified Power Flow Controller is a typical FACTS (Flexible AC Transmission Systems) device which is the most sophisticated and complex power electronic equipment and has emerged for the control and optimization of power flow and also to regulate the voltage in electrical power transmission system. The aim of this paper is to examine the ability of Unified Power Flow Controller for power flow control in a power system. Unified Power Flow Controller is able to control both the real and reactive power flows at the sending-end and the receiving-end of the transmission line. When no UPFC is installed, real and reactive power through the transmission line cannot be controlled.**

Keywords: FACTS, UPFC, AC transmission

I. INTRODUCTION

In the late 1980's the Electric Power Research Institute (EPRI) introduced a concept of technology to improve the power flow, improve the system stability and reliability with the existing power systems. This technology of power electronic devices is termed as Flexible Alternating Current Transmission Systems (FACTS) technology. It provides the ability to increase the controllability and to improve the transmission system operation in terms of power flow, stability limits with advanced control technologies in the existing power systems.

A Unified Power Flow Controller (UPFC) is a type of FACTS devices used for providing fast-acting reactive power compensation on high-voltage electricity transmission networks. It uses a pair of three-phase controllable bridges to produce current that is injected into a transmission line using a series transformer. The controller can control active and reactive power flows in a transmission line. The UPFC uses solid state devices, which provide functional flexibility, generally not attainable by conventional thyristors controlled systems. The UPFC is a combination of a static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC) coupled via a common DC voltage link. The main advantage of the UPFC is to control the

active and reactive power flow in the transmission line. If there is any disturbances or faults in the source side, the UPFC will not works. The UPFC operates only under balanced sine wave source. The controllable parameters of the UPFC are reactance in the line, phase angle and voltage. The UPFC concept was described in 1995 by L. Gyugyi of Westinghouse. [1] The UPFC allows a secondary but important function such as stability control to suppress power system oscillations improving the transient stability of power system.

II. FACTS CONTROLLERS

FACTS controllers are used for the dynamic control of voltage, impedance and phase angle of high voltage AC transmission lines. FACTS controllers can be divided into four categories:

1. Series controllers.
2. Shunt controllers.
3. Combined series-series controllers.
4. Combined series-shunt controllers.

2.1 Series Controllers

Series controllers inject voltage in series with the line. In this a variable impedance multiplied by the current flow through it, which represents an injected series voltage in the line.

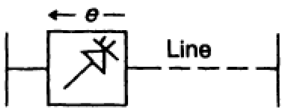

Fig.-1. Series Controller

2.2 Shunt Controllers

All shunt controllers inject current into the system at the point of connection. As long as the injected current is in phase quadrature with the line voltage, the shunt controller only supplies or consumes variable reactive power. Any other phase relationship will involve handling of real power as well.

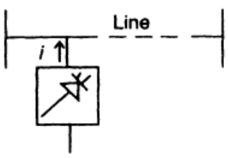

Fig.-2. Shunt Controller

2.3 Combined Series-Series Controllers

This is a series combination of separate series controllers, which are controlled in a coordinated manner, in a multilane transmission system. Or it could be a unified controller, in which series controllers provide independent series reactive compensation for each line but also transfer real power among the lines via the power link.

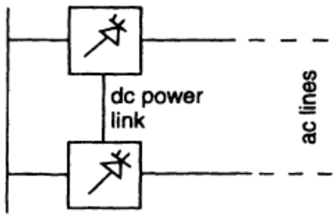

Fig.-3. Combined Series-Series Controller

2.4 Combined Series-Shunt Controllers

This could be a combination of separate shunt and series controllers, which are controlled in a coordinated manner, or a unified power flow controller with series and shunt elements. In principle, combined shunt and series controllers inject current into the system with shunt part of the controller voltage in series in the line with the series part of the controller. However, when the shunt and series controllers are unified, there can be a real power exchange between the series and shunt controllers via the power link.

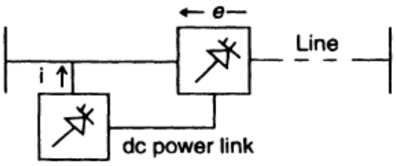

Fig.-4. Combined Series-Shunt Controller

III. THE PROPOSED SYSTEM FOR POWER FLOW CONTROL USING UNIFIED POWER FLOW CONTROLLER (UPFC)

3.1 The Operating Principal of UPFC

From the conceptual viewpoint, the UPFC is a generalized synchronous voltage source (SVS), represented at the fundamental (power system) frequency by voltage phasor *Vpq* with controllable magnitude *Vpq* and angle *p*, in series with the transmission line, as illustrated for the usual elementary two machine system (or for two independent systems with a transmission link intertie) in Figure. In this functionally unrestricted operation, which clearly includes voltage and angle regulation, the SVS generally exchanges both reactive and real power with the transmission system. Since, as established previously, an SVS is able to generate only the reactive power exchanged, the real power must be supplied to it, or absorbed from it, by a suitable power supply or sink. In the UPFC arrangement the real power exchanged is provided by one of the end buses (e.g., the sending-end bus), as indicated in figure.

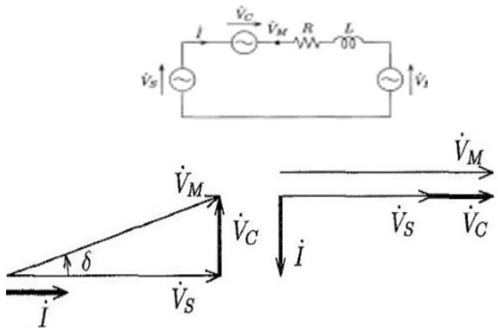

Fig 5: Active power control Reactive power control

The basic components of the UPFC are two voltage source inverters (VSIs) sharing a common dc storage capacitor, and connected to the power system through coupling transformers. One VSI is connected to in shunt to the transmission system via a shunt transformer, while the other one is connected in series through a series transformer.

3.2 UPFC Working

In the presently used practical implementation, the UPFC consists of two voltage-.sourced converters, as illustrated in Figure. These back-to-back converters, labeled "Converter 1" and "Converter 2" in the figure, are operated from a common de link provided by a de storage capacitor. As indicated before, this arrangement functions as an ideal ac-to-ac power converter in which the real power can freely flow in either direction between the ac terminals of the two converters, and each converter can independently generate reactive power at its own ac output terminal. Converter 2 provides the main function of the UPFC by injecting a voltage *Vpq* with controllable magnitude *Vpq* and phase angle *p* in series with the line via an insertion transformer. This injected voltage acts essentially as a synchronous ac voltage source. The transmission line current flows through this voltage source resulting in reactive and real power exchange between it and the ac system. The reactive power exchanged at the ac terminal is generated internally by the converter. The real power exchanged at the ac terminal is converted into de power which appears at the de link as a positive or negative real power demand. The basic function of Converter 1 is to supply or absorb the real power demanded by Converter 2 at the common de link to support the real power exchange resulting from the series voltage injection. This de link power demand of Converter 2 is converted back to ac by Converter 1 and coupled to the transmission line bus via a shunt connected transformer. In addition to the real power need of Converter 2, Converter 1 can also generate or absorb controllable reactive power, if it is desired, and thereby provide independent shunt reactive compensation for the line. It is important to note that whereas there is a closed direct path for the real power negotiated by the action of series voltage injection through Converters 1 and 2 back to the line, the corresponding reactive power exchanged and therefore does not have to be transmitted by the line. Thus, Converter 1 can be operated at a unity power factor or be controlled to have a reactive power exchange with the line independent of the reactive power exchanged by Converter 2. Obviously, there can be no reactive power flow through the UPFC de link.

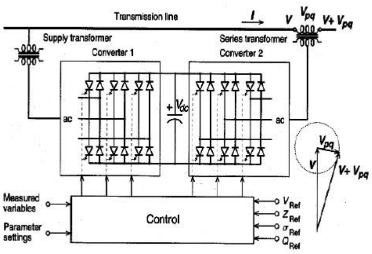

Fig.-6. Unified Power Flow Controller

IV. CONTROL SCHEMES

The UPFC control system divided functionally into internal control and functional operation control. The internal controls operate the two converters so as to produce the commanded series injected voltage and, simultaneously, draw the desired shunt reactive current. The internal controls provide gating signals to the converter valves so that the converter output voltages will properly respond to the internal reference variables, ipref , iqref and 'pqref, in accordance with the basic control structure shown in Figure .

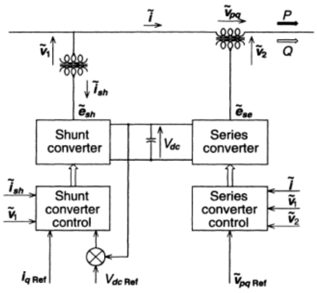

Fig.-7. Basic Control Scheme of UPF

As can be observed, the series converter responds directly and independently to the demand for series voltage vector injection. Changes in series voltage vector, *'19'* can therefore be affected virtually instantaneously. In contrast, the shunt converter operates under a closed-loop current control structure whereby the shunt real and reactive power components are independently controlled. The shunt reactive power responds directly to an input demand. However, the shunt real power is dictated by another control loop that acts to maintain a preset voltage level on the de link, thereby providing the real power supply or sink needed for the support of the series voltage injection. In other words, the control loop for the shunt real power ensures the required real power balance between the two converters. As mentioned previously, the converters do not exchange reactive power through the link. The external or functional operation control defines the functional operating mode of the UPFC and is responsible for generating the *internal* references, *Vpqref* and iqref for the series and shunt compensation to meet the prevailing demands of the transmission system. The functional operating modes and compensation demands, represented by external reference inputs, can be set manually by the operator or dictated by an automatic system optimization control to meet specific operating and contingency requirements.

4.1 Functional control of Shunt Inverter

The shunt inverter is used for voltage regulation at the point of connection injecting a reactive power flow in to the line and to balance the real power flow exchanged b/w the series inverter and transmission line. The shunt inverter is operating in such a way to inject a controllable current into the transmission line. This current consists of two components with respect to the line voltage.

- The real or direct component
- Reactive or quadrature component

The direct component is automatically determined by the requirement to balance the real power of series inverter. The quadrature component instead, can be independently set to ant desired reference level within the capability of inverter, to absorb or generate respectively reactive power from the line.

4.2 Functional control of Series Inverter

The series inverter can be used to control the real and reactive line power flow inserting a voltage with controllable magnitude and phase in series with the transmission line. The series voltage can be determined in different ways:

- Direct voltage injection mode: In this the reference inputs are directly the magnitude and phase angle of the series voltage.
- Phase angle shifter emulation mode: In this the reference input is phase displacement between the sending end voltage and the receiving end voltage.
- Line impedance emulation mode: In this the reference input is an impedance value to insert in series with the line impedance.
- Automatic power flow control mode: In this the reference inputs are values of P and Q to maintain on the transmission line despite system changes.

V. CONCLUSION

The Unified Power Flow Controller is an apparatus that can provide simultaneous, real-time control of all or any combination of the basic power system parameters such as transmission voltage, line impedance and phase angle. The proposed control scheme achieves quick response of active and reactive power without causing power swings and producing steady state errors. The important features of Unified Power Flow Controller and their ability to improve stability of the system is the prime concern for effective & economic operation of the power system.

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