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Stability Enhancement Of Improve Power Quality Using Unified Power Flow Controller

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Abstract*: Flexible AC Transmission Systems (FACTS) technology is the most advanced tool for power flow control in electric network. Unified Power Flow Controller (UPFC) is the most versatile FACTS device for optimization and control of power flow in transmission system. It is a voltage source converter based FACTS controller for series and shunt compensation of the line which controls the real and reactive power independently. In this paper an attempt has been made to investigate the transient stability enhancement of system using UPFC controller. UPFC modeling has been done by measuring the parameters locally at the bus. The proposed controller is found to be suitable for operating in both voltage regulation and PQ mode. To mitigate the power oscillations in the system, the required amount of series voltage injected by UPFC controller has also been computed. It is also found that the proposed controller works effectively under low as well as high range of power rating of generator. The objective of this paper is to answer to the following question: How the unified power flow controller (UPFC) parameters should be controlled in order to achieve the maximal desired effect in solving first swing stability problem. This problem appears for bulky power systems with long transmission lines. Various methods of reference identification of the series part, in order to improve the transient stability of the system based on: optimal parameters, state variables and also injection models were studied. Finally, a new identification method based on state variables and using the local measurement was proposed. The controller have been designed and tested for controlling the real and reactive power flow of UPFC. Computer simulation by MATLAB/SIMULINK has been used to verify proposed control strategies.

Keywords: Flexible AC Transmission Systems, Unified Power Flow Controller, Simulink Model Circuit.

1. INTRODUCTION

Power systems in general are interconnected for economic, security and reliability reasons. Exchange of contracted amounts of real power has been in vogue for a long time for economic and security reasons. To control the power flow on tie lines connecting controls areas, power flow control equipment such as phase shifters are installed. They direct real power between control areas. The interchange of real power is usually done on an hourly basis. On the other hand, reactive power flow control on tie lines is also very important. Reactive power flow control on transmission lines connecting different areas is necessary to regulate remote end voltages. Though local control actions within an area are the most effective during contingencies, occasions may arise when adjacent control areas may be called upon to provide reactive power to avoid low voltages and improve system security. Document B-3 of Northeast Power Coordinating Council (NPCC) on Guidelines for Inter-Area Voltage Control provides the general principles and guidance for effective inter-area voltage control.

In this paper, the proposed controller is found to be suitable for operating in both voltage regulation and PQ mode. To mitigate the power oscillations in the system, the required amount of series voltage injected by UPFC controller has also been computed. It is also found that the proposed controller works effectively under low as well as high range of power rating of generator. The objective of this paper is to answer to the following question: How the unified power flow controller (UPFC) parameters should be controlled in order to achieve the maximal desired effect in solving first swing stability problem. This problem appears for bulky power systems with long transmission lines. Various methods of reference identification of the series part, in order to improve the transient stability of the system based on: optimal parameters, state variables and also injection models were studied. Finally, a new identification method based on state variables and using the local measurement was proposed. The controller have been designed and tested for controlling the real and reactive power flow of UPFC. Computer simulation by MATLAB/SIMULINK has been used to verify proposed control strategies.

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2. SYSTEM MODEL AND ASSUMPTIONS

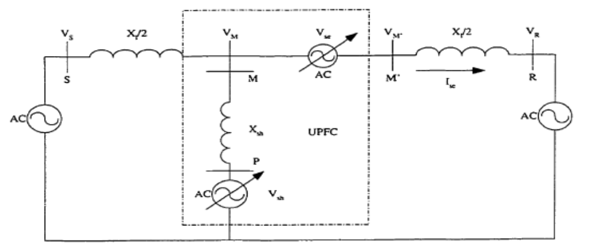

Fig.1.1 A power system with two machines connected by a transmission line with voltage sources V_{sh} and V_{se} representing the UPFC.

2.1. *Power flow controllers Vs Unified power flow controller*

Fixed series capacitors help in increasing stability limits in an interconnected power system. With transmission open access, each transmission system owning utility will increase their transmission capacity to attract more utilities to use its transmission facilities. Many existing power systems have already made the use of series compensation to increase their transmission capacity. By series compensation, the amount of reactive power consumed by the line is reduced thereby increasing the amount of reactive power transferred to the receiving end and improving the voltage profile at the receiving end. This is one of the secondary benefits of using series compensation. Under system disturbance conditions like three phase faults or line tripping, controllable series compensation helps in damping power system oscillations. Control of power flow by series compensation means that by changing the amount of impedance in the circuit, the current in individual transmission lines are varied thereby v q i n g the power flow in it. In essence, it controls only the magnitude of the current in a transmission line. Hence the reactive power demand at the end points of the line is determined by the transmitted real power in the same way as if the line was uncompensated but had a lower line impedance [Z].

The UPFC concept was proposed by Gyugyiet-al 121. To understand the unified power flow concept, consider a power system with two machines connected by a transmission line of reactance X, (purely inductive) along with two voltage sources V,and V, representing the UPFC as shown in Fig. 1.1. The voltage sources denoted by Vs, and V, in the Fig. 1.1 are connected in shunt and series respectively at the mid-point of the transmission line.

2.2. Unified power flow controller: Construction and Operation

The voltage sources V, and L mentioned in section 1.2 are obtained by converting DC voltage to AC voltage. The conversion from DC voltage to AC voltage is obtained by using standard bridge circuits. These bridge circuits use GTO as their building blocks. Since these circuits convert DC voltage to AC voltage, they are termed as voltage source converters (VSC).

2.3. Complexity in the design of a control system for UPFC:

The control aspect of a UPFC is an important area of research. As seen from the operation of a UPFC, it is a multi-variable controller. The control system design should be such that the UPFC is able to function in a stable manner, provide power flow control and power oscillation darnping. The series inverter of a UPFC controls the power flow in a transmission line. The interaction between the series injected voltage and the transmission line current causes the series inverter to exchange real and reactive power with the transmission line. The real power exchange by the series inverter with the transmission line is supplied/ absorbed by the DC link capacitor. This causes a decrease/'increase in the DC capacitor voltage. For proper operation of the UPFC, the DC capacitor voltage should be regulated. The decrease increase in the DC link capacitor voltage is sensed by the shunt inverter control system. The shunt inverter control system operates to meet the demand In decrease increase in DC capacitor voltage by absorbing/supplying real power to the power system through the shunt inverter to maintain the DC capacitor voltage at a specified level. If the control system of the shunt and the series inverters is such that the shunt inverter is not able to meet the real power demand of the series inverter, then the DC capacitor voltage might collapse resulting in the removal of the UPFC from the power system. This is one problem that will be considered in this work during the design of the UPFC control system. This c d s for coordination between the shunt and the series control system operation

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with respect to the real power flow through the DC link of the UPFC.

2.4. Complexity in the operation of a UPFC in an integrated power system:

One of the problems that exist in an integrated power system environment is the presence of inter-area oscillations. These oscillations involve groups of generators in a control area swinging against another group of generators in a different control area. UPFC when placed on tie lines connecting two areas should be able to damp out these inter-area oscillations. Since UPFC is a multi-variable controller, it should be able to enhance power system stability under dynamic conditions. Thus it is seen that though the concept of UPFC is elegant, the control system design for a UPFC is a very complicated one as it involves simultaneous control of multi variables. Inappropriate design of the control system with respect to the four variables will definitely lead to instability. Thus extreme care has to be exercised during the design process of the control system for UPFC to provide fast control of power flow and effective power oscillation damping.

2.5. Facts Devices:

Due to recent advances in power electronics, FACTS devices have gained good popularity during the last few years. FACTS devices have been mainly used for solving various power system control problems such as voltage regulation, power flow control, and transfer capability enhancement, damping the inter-area modes and enhancing power system stability.The vision of the FACTS has been formulated by the Electric Power Research Institute (EPRI) in the late 1980s. The various power-electronics based controllers regulate power flow and transmission voltage and mitigate dynamic disturbances. The main objectives of FACTS are to increase the useable transmission capacity of lines and control power flow over designated transmission routes. Hingorani (1988, 1991) and Hingorani and Gyugyi (2000) have proposed the concept of FACTS.

There are two generations for the realization of power electronics-based FACTS controllers: the first generation uses conventional thyristor-switched capacitors and reactors, and quadrature tap-changing transformers and the second generation uses Gate Turn-Off (GTO) thyristor-switched converters as Voltage Source Converters (VSCs). The first generation has resulted in the Static Var Compensator (SVC), the Thyristor-Controlled Series Capacitor (TCSC), and the Thyristor-Controlled Phase Shifter (TCPS). The second generation has produced the Static Synchronous Compensator (STATCOM), the Static Synchronous Series Compensator (SSSC), the Unified Power Flow Controller (UPFC), and the Interline Power Flow Controller (IPFC). The two groups of FACTS controllers have distinctly different operating and performance characteristics. The thyristor-controlled set-up has capacitor and reactor banks with fast solid-state switches in shunt or series circuit arrangements. The voltage source converter (VSC) type FACTS controller set-up has self-commutated DC to AC converters, using GTO thyristors, which can internally generate capacitive and inductive reactive power for transmission line compensation, without the use of capacitor or reactor banks. The converter with energy storage device can also exchange real power with the system, in addition to the independently controllable reactive power. Yong Hua Song and Allan T. Johns (1999) have proposed that the VSC can be used uniformly to control transmission line voltage, impedance, and angle by providing reactive shunt compensation, series compensation, and phase shifting, or to control directly the real and reactive power flow in the line.

3. IMPLEMENTATION

In this Paper the proposed controller is found to be suitable for operating in both voltage regulation and PQ mode. To mitigate the power oscillations in the system, the required amount of series voltage injected by UPFC controller has also been computed. It is also found that the proposed controller works effectively under low as well as high range of power rating of generator. The objective of this paper is to answer to the following question: How the unified power flow controller (UPFC) parameters should be controlled in order to achieve the maximal desired effect in solving first swing stability problem. This problem appears for bulky power systems with long transmission lines. Various methods of reference

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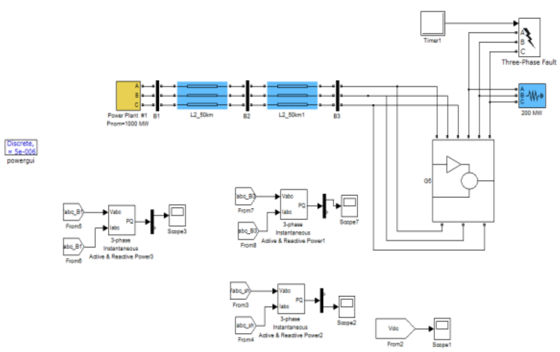
identification of the series part, in order to improve the transient stability of the system based on: optimal parameters, state variables and also injection models were studied. Finally, a new identification method based on state variables and using the local measurement was proposed. The controller have been designed and tested for controlling the real and reactive power flow of UPFC. Computer simulation by MATLAB/SIMULINK has been used to verify proposed control strategies.

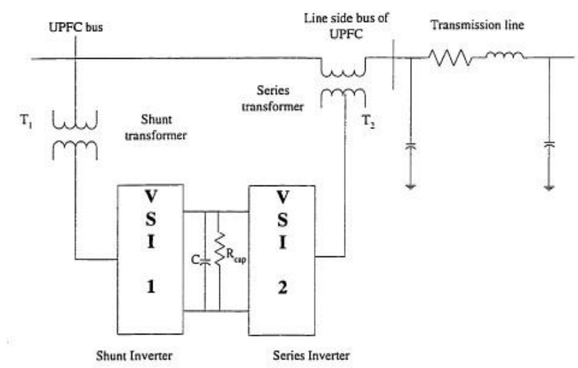


Simulink Model Circuit For Present Study

4. UPFC Mode1 for Load Flow

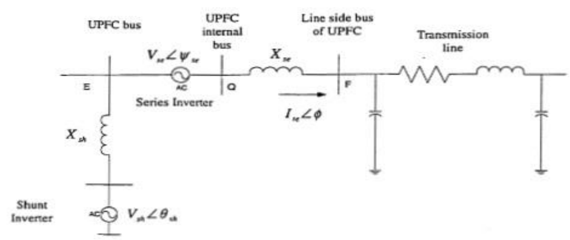
Load flow studies are very important as it provides the necessary initial conditions for conducting small-signal and large-signal performance studies with UPFC. This paper discusses a load flow model for UPFC. The corresponding equations relating to integration of the UPFC model into load flow studies has been described.

The construction and operation of a unified power controller have been proposed. In brief, a unified power flow controller consists of two voltage source inverters (VSI) connected back to back with a common DC coupling capacitor as shown in below figure. Such an arrangement allows for dl the three functions namely series, shunt and phase angle compensation to be unified into one unit. Inverter-1 is connected to the power system through a transformer Ti in shunt and the inverter-2 is connected to the power system through another transformer TT such that the secondary of the transformer T2 is in series with the transmission line. The transformers Ti and T2 would be referred to as shunt and series transformers respectively for the purpose of clarity.



Unified power flow controller configuration.

The model provides for detailed interaction between the series and the shunt inverter. Fig.4.2 shows the UPFC model. Xrh and X,, represent the reactance of transformers Ti and T2 respectively. Vshand V, represent the voltage generated by the shunt and the sense inverter respectively. Bus-E and bus-F represent the UPFC bus and the transmission line side bus of UPFC respectively.



UPFC model.

For performing load flow studies with UPFC, the series and the shunt invertersare assumed to produce balanced 60 Hz voltages of variable magnitude and phase angle.The shunt and the series voltage sources phasorscan be mathernatically represented as

$$\bar{V}_{sh} = V_{sh}(\cos\theta_{sh} + j\sin\theta_{sh})$$
$$\bar{V}_{se} = V_{sem}(\cos\psi_{se} + j\sin\psi_{se})$$

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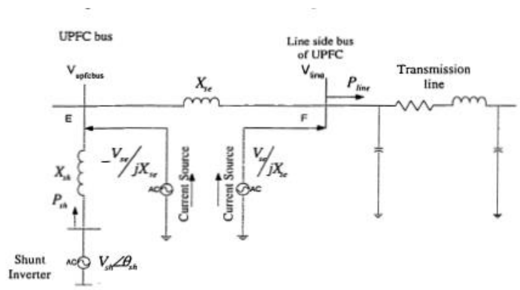
Where Vshand V, are the root mean squared magnitudes of the shunt and the sense voltage sources.Brhand 'Y, are the shunt and the series voltage source angles with respect to a reference frame.

4.1. Norton's equivalent circuit for UPFC

The series voltage source dong with its associated series transformer reactanceXsccm be converted into equivalent current injections at bus-E and bus-F. Fig.4.3 shows the Norton's equivalent of the circuit shown in Fig.4.2.



4.2. Load flow procedure

It is well known that load flow analysis is an iterative type of solution. UPFC has the capability of controlling the real power and transmission line side bus voltage/reactive power flow in a transmission line. it provides a very simplistic method to solve load flow that is only applicable to small power systems. The method requires information regarding the short circuit impedance at the bus where the UPFC is to be installed. The algorithm provided to perform load flow study is applicable only to assess the impact of UPFC on power systems in a localized way. Niakiet.al [Il] has provided a simpler method of performing load flow with UPFC. Here the bus to which the shunt inverter is connected is modelled as a PQ bus and the transmission line side bus is modelled as a PV bus. This method works only when the variables namely, the UPFC bus voltage, real power flow in the transmission line, transmission line side bus voltage are controlled simultaneously. This method will fail if one wishes to control a subset of them. Further, the solution obtained is multi-valued, meaning that one could obtain a load flow solution that could not be feasible or the UPFC parameters could be out of acceptable limits. This requires that the variables be confined within acceptable limits to obtain feasible solutions. Arabierd have modelled the shunt inverter and series inverter as a set of PQ injections at the appropriate buses. This model however neglects the interaction between the series and the shunt inverter. Esquivel et.al [12] have improved upon the limitations on the model by Niakiet-al and provides a solution to the problem of UPFC parameters limitation by fixing the parameter that has violated the limits and freeing the regulated variable. In this case, the need for good initial conditions are emphasized. To obtain a load flow solution with a specified real power flow in the transmission line and transmission line side voltage with UPFC, the series voltage source Vseis decomposed into two phasors. Fig shows the phasor diagram with the two components of the series voltage source. The UPFC bus voltage phasor is denoted by VE. One phasor denoted by V,, is in quadrature with the UPFC bus voltage phasor(VE) and the other phasor denoted by Vsepi s in-phase wirh the UPFC bus phasor(VE).The function of the quadrature component of the series voltage source V,, is to Vary the phase angle of bus VE to achieve a specified real power flow in the transmission line. The function of the in-phase component of the series voltage source Vseips to achieve a specified transmission line side voltage. The net voltage phasorV, (the phasor sum of VSepan d V') is denoted by phasorAD .The D and the Q axes refer to the network ais. Since the series voltage phasorV, is added to the UPFC bus voltage phasorV', the quadrature component of the series voltage that controls the real power has little effect on the reactive power.

This is because the quadrature component of the series voltage changes the phase anglewith little change in the magnitude of the bus voltage on the transmission line side (Vh,).The in-phase component controls the voltage of the bus on the transmission line side(Vk) has greater effect on the reactive power than on the real power in the transmissionline. This is because the in-phase component has little effect on the phase angle. Thus theinteraction between the control of real and reactive power flow in a transmission line is toa great extent reduced. This allows the load flow solution process of achieving aspecified real power flow in the transmission line and a line side voltage to be separated.

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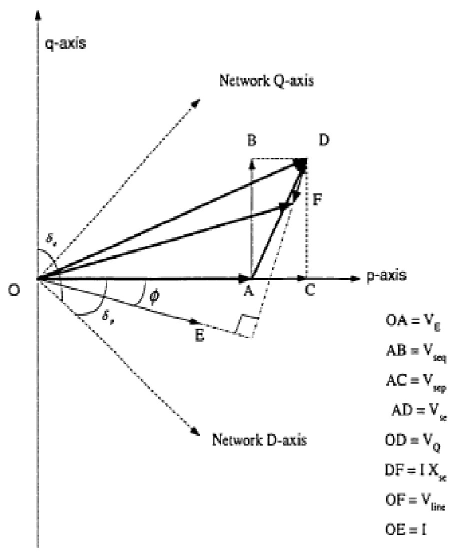
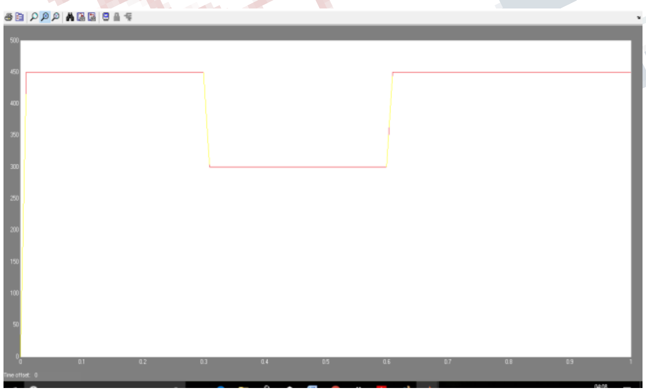


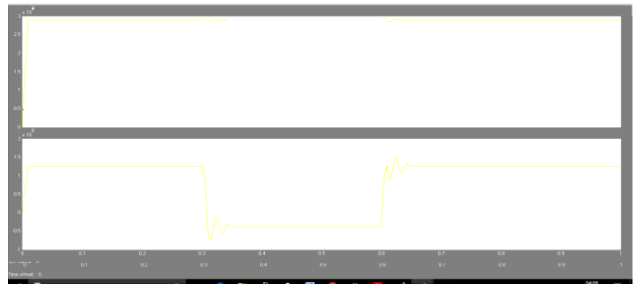
5. RESULTS AND DISCUSSION

Simulation Results:

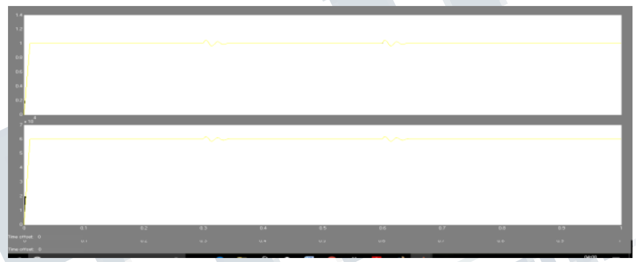
The Response of power system to step changes in transmission line real power reference with time



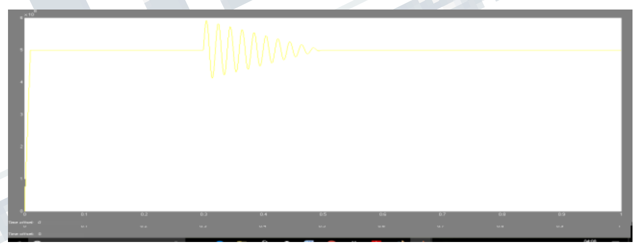
Active and reactive Power Plot during real and reactive power coordination controller



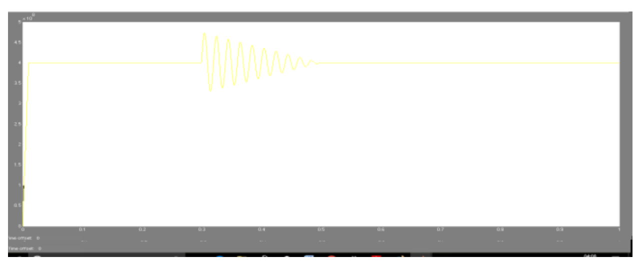
RMS voltage and Vdc plot during real and reactive power coordination controller



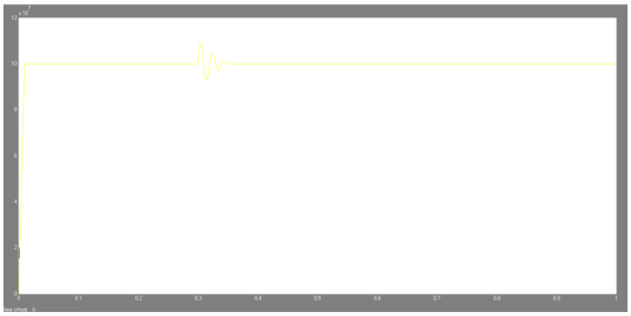
Bus1 Active power plot during fault with UPFC



Bus2 Active power plot during fault with UPFC



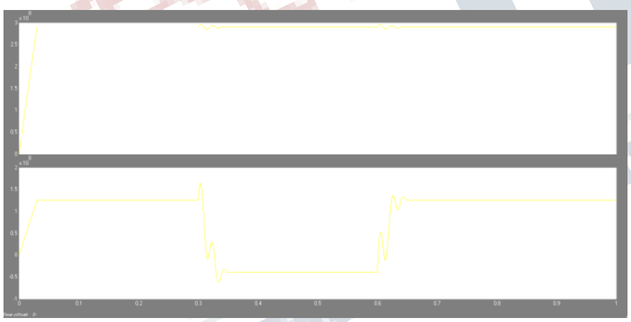
Reactive power during fault with UPFC



DC voltage during fault with UPFC

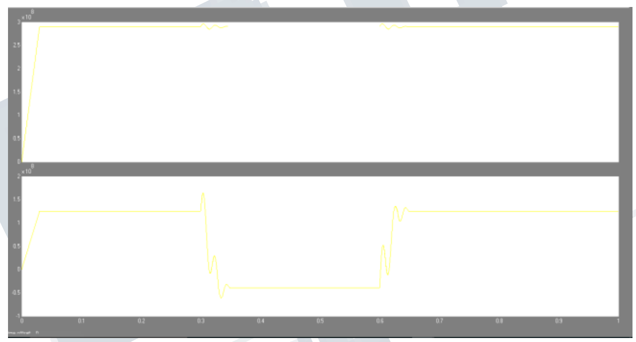
Bus2 Active power plot during fault with UPFC

Active power using UPFC without reactive power coordination



RMS and Vdc using UPFC without reactive power coordination

Active and reactive power using UPFC without real power coordination



RMS and Vdc using UPFC without real power coordination

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6. CONCLUSION

A control system control strategy for UPFC has been designed in this thesis. MATLAB computer simulations have been conducted to show the improvement in power system damping with UPFC using the designed control system/control strategy. A UPFC was constructed using the MATLAB/SIMULINK software. The three major components of the UPFC are the shunt inverter and its transformers, series inverter and its associated transformers, and the DC Link capacitor. A number of issues and problems have been encountered during the UPFC control system design process. The issues are concerning the ratings of the shunt series inverters, their transformers and the DC link capacitor. These issues are discussed in this thesis. The operational problems involve the control system design for the integrated control of the real and the reactive power flow on transmission lines. While simultaneously controlling the UPFC bus voltage and the DC link capacitor voltage.

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