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An Efficient Power Flow Improvement in Transmission Line using UPFC

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Abstract:*A new reactive powercoordination controller has been designed to limitexcessive voltage excursions during reactive powertransfers. The shunt converter of the UPFC controls theUPFC bus voltage/shunt reactive power and the dc linkcapacitor voltage. The series converter of the UPFCprovides simultaneous control of real and reactive powerflow in the transmission line the shunt converter has beenmodeled as a 4-module converter. The series converterconsists of two sets of converters. One set of converter isused for the real power flow control and the other set ofconverter is used for the reactive power flow control.Recent advances in high voltage IGCT technology allowfor higher switching frequencies with lower losses. Thisallows for practical implementation of PWM control. Theswitching frequency for the converters has been chosen tobe nine times the fundamental. Here we use matlab/simulink for the simulation purpose and outputs areverified in the scope.*

Keywords-Flexible AC Transmission System (FACTS),Unified Power Flow Controller (UPFC), PWM, IGCT

I. INTRODUCTION

The power transmitted over an ac transmission line is a function of the line impedance, the magnitudeof sending-end and receiving-end voltages, and the phase angle between these voltages. Traditional techniquesof reactive line compensation and step-like voltage adjustment are generally used to alter these parameters toachieve power transmission control. Fixed and mechanically shunt and series reactive compensation areemployed to modify the natural impedance characteristics of transmission lines in order to establish the desiredeffective impedance between the sending and receiving-ends to meet power transmission requirements. Voltageregulating and phase shifting transformers with mechanical tap-changing gears are used to minimize voltagevariation and control power flow. These conventional method provide adequate control under steady-state andslowly changing system conditions, but are largely ineffective in handling dynamic disturbances.The traditional approach to contain dynamic problems is to establish generous stability marginsenabling the system to recover from faults, line and generator outages, and equipment failures. This approach,although reliable, generally results in a significant under utilization of the transmission system. As a result ofrecent environmental legislation, rights-of-way issues, construction cost increases, and deregulation policies,there is an increasing recognition of the necessity to utilize existing transmission system assets to themaximum extent possible. To this end, electronically controlled, extremely fast reactive compensators andpower flow controllers have been developed within the overall framework of the FACTS initiative. Thesecompensators and controllers either use conventional reactive components and tap-changing transformerarrangements with thyristor valves and control electronics or employ switching power converters, assynchronous voltage sources, which can internally generate reactive power for, and also exchange real powerwith, the ac system.

The Unified Power Flow Controller (UPFC) is a member of this latter family of compensators andpower flow controllers which utilize the synchronous voltage source(SVS) concept for providing a uniquelycomprehensive capability for transmission system control. Within the framework of traditional powertransmission system concepts, the UPFC is able to control, simultaneously or selectively, all the parametersaffecting power flow in the transmission line. Alternatively, it can provide the unique functional capability ofindependently controlling both the real and reactive power flow in the line. These basic capabilities make theUnified Power Flow Controller the most powerful device presently available for transmission system control.Unified power flow controller (UPFC) is a member of FACTS family. It is a combination of Staticsynchronous compensator (STATCOM) and Static synchronous series compensator (SSSC) coupled via acommon dc-link, to allow bi-directional flow of real power between the series output terminals of the SSSCand the shunt output terminals of the STATCOM. The UPFC, by means of angularly unconstrained seriesvoltage injection, is able to control the transmission line voltage, impedance and angle or the real and reactivepower flow in the line.

Also the problem of low-frequency power swings is a matter of concern for power systems engineers.As it is becoming increasingly important to fully utilize the existing transmission system assets, properattention should be given to the enhancement of utilizing the transmission capacity by damping of the powerswings. Flexible AC transmission system (FACTS) devices are found to be very effective for this purpose. AFACTS device should have an adequate margin of variable compensation for effective damping of powerswings. Therefore, while planning for FACTS controllers, the damping effect per MVar and the control costshould be taken into consideration.

II. UNIFIED POWER FLOW CONTROLLER (UPFC)

Gyugyi proposed the Unified Power Flow Controller (UPFC) concept in 1991. The UPFC was devised for thereal time control and dynamic compensation of ac transmission systems, providing multifunctional flexibilityrequired to solve many of the problems facing the deliveryindustry. Within the framework of traditional powertransmission concepts, the UPFC is able to control,simultaneously or selectively, all the parameters affectingpower flow in the transmission line (i.e., voltage,impedance and phase angle), and this unique capability issigned by the adjective “unified” in its name. Alternatively,it can independently control both the real and reactivepower flows in the line.

A. Circuit Arrangement

In the presently used practical implementation, TheUPFC consists of two switching converters, which in theimplementations considered are voltage source invertersusing gate turn-off (GTO) thyristor valves, as illustrated inthe Fig.1.

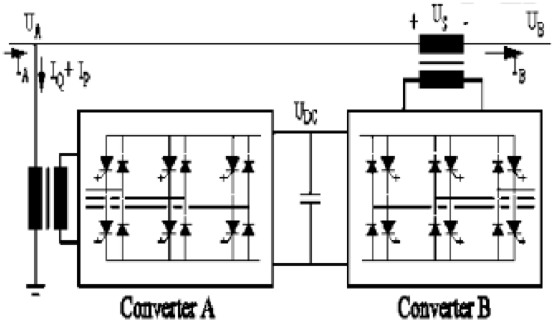


Fig.1. Basic circuit arrangement of unified power flowcontroller

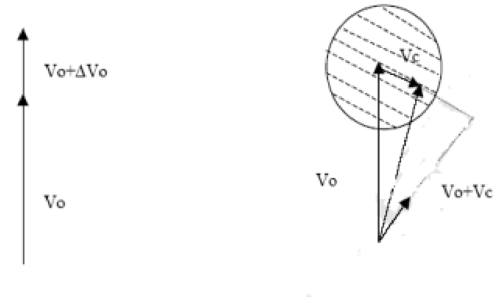
These back to back converters labeled “Inverter1 and “Inverter 2” in the figure, are operated from acommon dc link provided by a dc storage capacitor. Thisarrangement functions as an ac to ac power converter inwhich the real power can freely flow in either directionbetween the ac terminals of the two inverters and eachinverter can independently generate (or absorb) reactivepower at its own ac output terminal.

B. Operation of UPFC

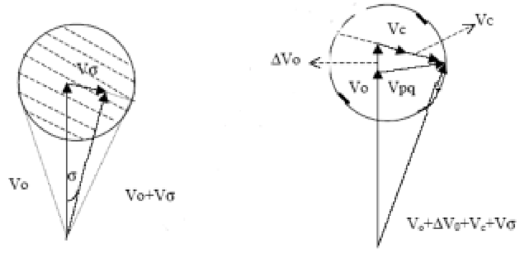
Inverter 2 provides the main function of the UPFC by injecting an ac voltage Vpq with controllable magnitude Vpq(0≤Vpq≤Vpqmax) and phase angle (0≤*p*≤360), at the powerfrequency, in series with the line via an insertion transformer.The injected voltage is considered essentially as asynchronous voltage source. The transmission line currentflows through this voltage source resulting in real and reactivepower exchange between it and the ac system. The real powerexchanged at the ac terminal (i.e., at the terminal of insertiontransformer) is converted by the inverter into dc power thatappears at the dc link as positive or negative real powerdemanded. The reactive power exchanged at the ac terminal isgenerated internally by the inverter. The basic function ofinverter 1 is to supply or absorb the real power demanded byInverter 2 at the common dc link. This dc link power isconverted back to ac and coupled to the transmission line via ashunt-connected transformer. Inverter 1 can also generate orabsorb controllable reactive power, if it is desired, and thereby it can provide independent shunt reactive compensation forthe line. It is important to note that where as there is a closed“direct” path for the real power negotiated by the action ofseries voltage injection through Inverters 1 and 2 back to theline, the corresponding reactive power exchanged is suppliedor absorbed locally by inverter 2 and therefore it does not flowthrough the line. Thus, Inverter 1 can be operated at a unitypower factor or be controlled to have a reactive powerexchange with the line independently of the reactive powerexchanged by the Inverter 2. This means there is nocontinuous reactive power flow through UPFC.

C. Basic Control Functions

Operation of the UPFC from the standpoint of conventionalpower transmission based on reactive shunt compensation,series compensation, and phase shifting, the UPFC can fulfillthese functions and thereby meet multiple control objectivesby adding the injected voltage Vpq,with appropriate amplitude.
Terminal Voltage Regulation, similar to that obtainable witha transformer tap-changer having infinitely small steps, asshown at (a) where Vpq=V (boldface letters representphasors) is injected in-phase (or anti-phase) with V_o



(a) voltage regulation (b) series compensation



(c) Phase angle Regulation (d) Multi-function Power flow control

Fig.2.Basic UPFC Control Functions: a) Voltage Regulate, b) Series Compensation, c) Angle Regulation and d) Multifunction Power.

Series capacitor compensation is shown at (b) where Vpq=Vc is in quadrature with the line current I.
Transmission angle Regulation (phase shifting) is shownat (c) where Vpq=Vo is injected with angular relationshipwith respect to Vo that achieves the desired s phase shift(advance or retard) without any change in magnitude.

Multifunctional Power Flow Control, executed bysimultaneous terminal voltage regulation, series capacitivecompensation, and phase shifting, is shown at (d) whereVpq=□ V+Vc+Vo.

D. Basic Principles of P and Q Control

Consider Fig.2 At (a) a simple two machine (or two busac inter-tie) system with sending end voltage Vs, receivingend voltage Vr, and line (or tie) impedence X (assumed, forsimplicity, inductive) is shown. At (b) the voltages of thesystem in the form of a phasor diagram are shown withtransmission angle and □ Vs□ =□ Vr□ =V. At (c) thetransmitted power P (P=V2/X sin□) and the reactive powerQ=Qs=Qr (Q=V2/X (1-cosθ)) supplied at the ends of theline are shown plotted against angleθ. At (d) the reactive power Q=Qs=Qr is shown plotted against the transmittedpower corresponding to “stable values of (i.e., $0<=\theta<=90^{o}$). Basic power system of fig with the well knowntransmission characteristics is introduced for the purpose ofproviding a vehicle to establish the capability of the UPFCto control the transmitted real power P and the reactivepower demands, Qs and Qr, at the sending end,respectively, the receiving end of the line. Consider Fig.2.The simple power system of Fig is expanded to include theUPFC. The UPFC is represented by a controllable voltagesource in series with the line which, as explained in theprevious section, can generate or absorb reactive powerthat it, or absorbed from it, bye the sending end generator.The UPFC in series with the line is represented by thephasor Vpq having magnitude Vpq(0 ≤ Vpq ≤ Vpqmax) andangle ρ (0 ≤ ρ ≤ 360) measured from the given phaseposition of phasor Vs, as illustrated in the figure. The linecurrent represented by the phasor I, flows through the series voltage source, Vpq and generally results in bothreactive and real power exchange. In order to representUPFC properly, the series voltage source is stipulated togenerate only the reactive power Qpq it exchanges with theline. Thus the real power Ppq it negotiates with the line isassumed to be transferred to the sending-end generatorexcited. This is in arrangement with the UPFC circuitstructure in which the dc link between the two constituentinverters establish a bi-directional coupling for real powerflow between the injected series voltage source and thesending end bus.

As Fig.3 implies, in the present discussion itis further assumed for clarity that the shunt reactivecompensation capability of the UPFC not utilized. This is theUPFC shunt inverter is assumed to be operated at unity powerfactor, its sole function being to transfer the real powerdemand of the series inverter to the sending-end generator.With these assumptions, the series voltage source, togetherwith the real power coupling to the sending end generator asshown in fig.4, is a an accurate representation of the basicUPFC.

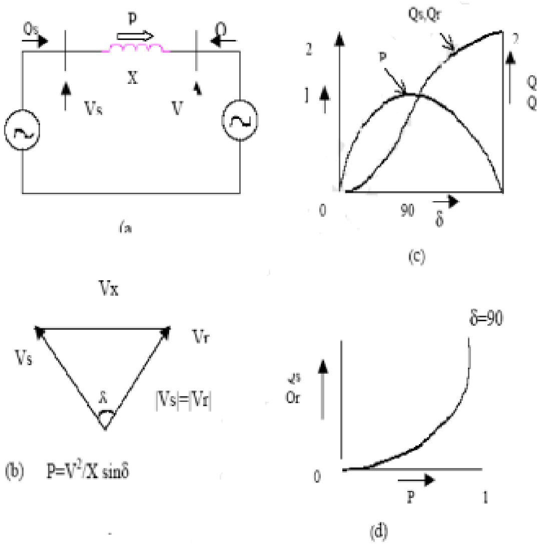


Fig.3. Simple two machine system (a) Related voltagephasor (b) Real and Reactive power verses transmissionangle (c) sending end /receiving end reactive power v/stransmitted real power.

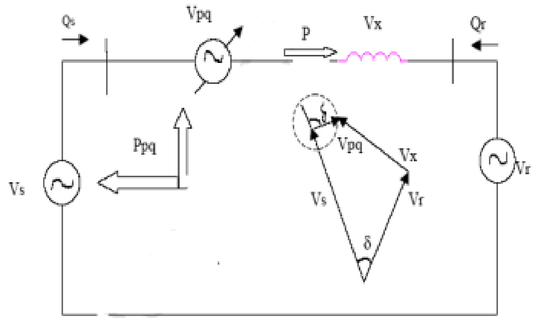


Fig.4. Two machine system with the unified power flowcontroller.

It can be observed in Fig that the transmission line“sees” Vs+Vpq as the effective sending end voltage. Thus itis clear that the UPFC effects the voltage (both itsmagnitude and angle) across the transmission line andtherefore it is reasonable to expect that it is able to control,by varying the magnitude and angle of Vpq, thetransmittable real power as well as the reactive powerdemand of the line at any given transmission anglebetween the sending-end and receiving-end voltages.

III. MODELLING OF CASE STUDY

A. Control Strategy for UPFC

Shunt Converter Control Strategy: The shunt converterof the UPFC controls the UPFC bus voltage/shunt reactivepower and the dc link capacitor voltage. In this case, theshunt converter voltage is decomposed into twocomponents. One component is in-phase and the other inquadrature with the UPFC bus voltage. De-coupled controlsystem has been employed to achieve simultaneous controlof the UPFC bus voltage and the dc link capacitor voltage.Series Converter Control Strategy: The series converterof the UPFC provides simultaneous control of real andreactive power flow in the transmission line. To do so, theseries converter injected voltage is decomposed into twocomponents. One component of the series injected voltageis in quadrature and the other in-phase with the UPFC bus

voltage. The quadrature injected component controls thetransmission line real power flow. This strategy is similarto that of a phase shifter. The in-phase component controlsthe transmission line reactive power flow. This strategy issimilar to that of a tap changer.

B. Basic Control System

Shunt Converter Control System: Fig.5 shows the decoupled control system for the shunt converter. The D-axiscontrol system controls the dc link capacitor voltage andthe Q-axis control system controls the UPFC bus voltage/shunt reactive power. The details of the de-coupled controlsystem design can be found .The de-coupled controlsystem has been designed based on linear control systemtechniques and it consists of an outer loop control systemthat sets the reference for the inner control system loop.The inner control system loop tracks the reference.

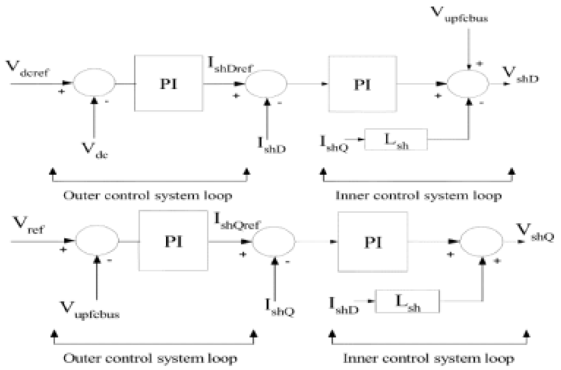


Fig.5. De-coupled D-Q axis shunt converter control system.

IV. SIMULATION RESULTS

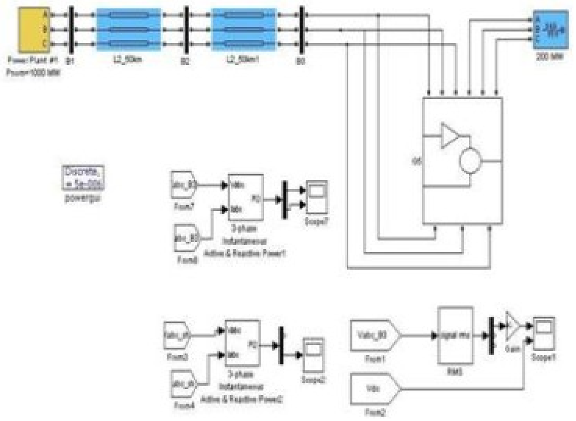


Fig.6.Model of Real and Reactive Power Coordination

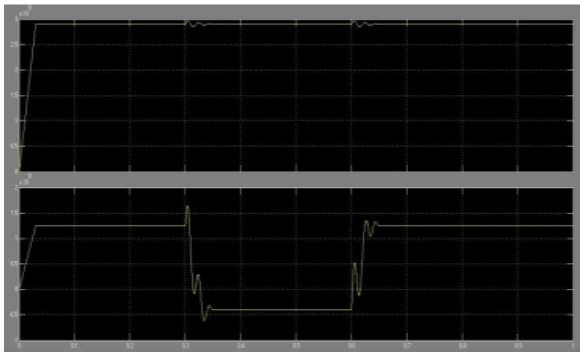


Fig.7 Simulation For Real and Reactive Power WithoutCoordination

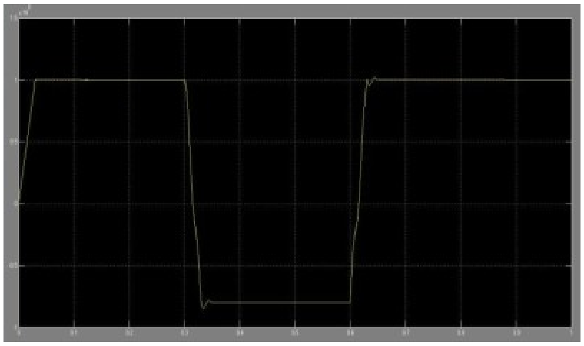


Fig.8 Simulation For Real And Reactive Power WithCoordination

CONCLUSION

This paper has presented a new real and reactive powercoordination controller for a UPFC. The basic control strategyis such that the shunt converter of the UPFC controls theUPFC bus voltage/shunt reactive power and the dc linkcapacitor voltage. The series converter controls thetransmission line real and reactive power flow. Thecontributions of this work can be summarized as follows.

Two important coordination problems have beenaddressed in this paper related to UPFC control. One, theproblem of real power coordination between the seriesand the shunt converter control system. Second, theproblem of excessive UPFC bus voltage excursionsduring reactive power transfers requiring reactive powercoordination.

Inclusion of the real power coordination controller in theUPFC control system avoids excessive dc link capacitorvoltage excursions and improves its recovery duringtransient conditions. MATLAB simulations have beenconducted to verify the improvement in dc link voltageexcursions during transient conditions.

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