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A New approach for controlling the power flow in a transmission system using Unified Power Flow Controller

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ABSTRACT: *Electrical power systems is a large interconnected network that requires a careful design to maintain the system with continuous power flow operation without any limitation. Flexible Alternating Current Transmission System (FACTS) is an application of a power electronics device to control the power flow and to improve the system stability of a power system. Unified Power Flow Controller (UPFC) is a new concept for the compensation and effective power flow control in a transmission system.Through common DC link, any inverters within the UPFC is able to transfer real power to any other and there by facilitate real power transfer among the line. In this paper a test system is simulated in MATLAB/SIMULINK and the results of the network with and without UPFC are compared and when the voltage sag is compensated, reactive power is controlled and transmission line efficiency is improved.*

Keywords: *FACTS, UPFC, Power flow, Real and reactive power, Matlab/simulink.*

I. Introduction

The technology of power system utilities around the world has rapidly evolved with considerable changes in the technology along with improvements in power system structures and operation. The ongoing expansions and growth in the technology, demand a more optimal and profitable operation of a power system with respect to generation, transmission and distribution systems [1]. In the present scenario, most of the power systems in the developing countries with large interconnected networks share the generation reserves to increase the reliability of the power system. However, the increasing complexities of large interconnected networks had fluctuations in reliability of power supply, which resulted in system instability, difficult to control the power flow and security problems that resulted large number blackouts in different parts of the world. The reasons behind the above fault sequences may be due to the systematical errors in planning and operation, weak interconnection of the power system, lack of maintenance or due to overload of the network. The main objective of the power system operation is to match supply/demand, provide compensation for transmission loss, voltage and frequency regulation, reliability provision etc. The need for more efficient and fast responding electrical systems has given rise to innovative technologies in transmission using solid-state devices. These are called FACTS devices which enhance stability and increase line loadings closer to thermal limits [2]. FACTS have gained a great interest during the last few years, due to recent advances in power electronics. FACTS devices have been mainly used for solving various power system steady state control problems such as voltage regulation, power flow control, and transfer capability enhancement. The development of power semiconductor devices with turn-off capability (GTO, MCT) opens up new perspectives in the development of FACTS devices. FACTS devices are the key to produce electrical energy economically and environmental friendly in future. The latter approach has two inherent advantages over the more conventional switched capacitor- and reactor- based compensators. Firstly, the power electronics-based voltage sources can internally generate and absorb reactive power without the use of ac capacitors or reactors. Secondly, they can facilitate both reactive and real power compensation and thereby can provide independent control for real and reactive power flow [3]. Since then different kind of FACTS controllers have been recommended. FACTS controllers are based on voltage source converters and includes devices such as Static Var Compensators (SVC), static Synchronous Compensators (STATCOM), Thyristor Controlled Series Compensators (TCSC), Static Synchronous Series Compensators (SSSC) and Unified Power Flow Controllers (UPFC) [4].Among them UPFC is the most versatile and efficient device which was introduced in 1991. In UPFC, the transmitted power can be controlled by changing three parameters namely transmission magnitude voltage, impedance and phase angle.

II. Control of Power Systems

2.1 Power System Constraints

The limitations of the transmission system can take many forms and may involve power transfer between areas or within a single area or region and may include one or more of the following characteristics:

- Steady-State Power Transfer Limit
- Voltage Stability Limit
- Dynamic Voltage Limit
- Transient Stability Limit
- Power System Oscillation Damping Limit
- Inadvertent Loop Flow Limit
- Thermal Limit
- Short-Circuit Current Limit
- Others

Each transmission bottleneck or regional constraint may have one or more of these system-level problems. The key to solving these problems in the most cost-effective and coordinated manner is by thorough systems engineering analysis [5].

2.2 Controllability of Power Systems

To illustrate that the power system only has certain variables that can be impacted by control, we have considered here the power-angle curve, shown in Figure 2. Although this is a steady-state curve and the implementation of FACTS is primarily for dynamic issues, this illustration demonstrates the point that there are primarily three main variables that can be directly controlled in the power system to impact its performance [5]. These are:

(1) Voltage
(2) Angle
(3) Impedance

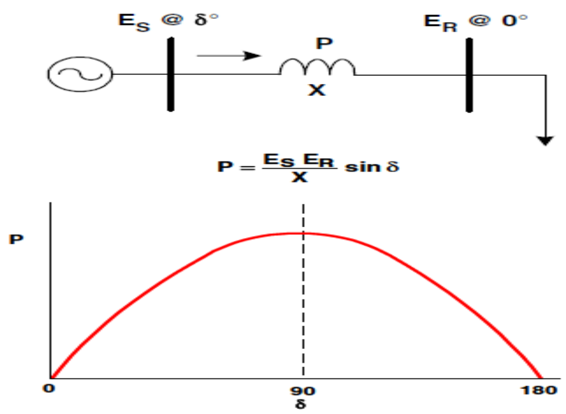

Fig.1 Illustration of controllability of power systems

2.3 Conventional Devices for Enhancing Power System Control

(1) Series Capacitor -Controls impedance
(2) Switched Shunt-Capacitor and Reactor -Controls voltage
(3) Transformer LTC -Controls voltage
(4) Phase Shifting Transformer -Controls angle
(5) Synchronous Condenser -Controls voltage
(6) Special Stability Controls-Focuses on voltage control but often include direct control of power.

2.4 FACTS Controllers for Enhancing Power System Control

(1) Static Synchronous Compensator (STATCOM) -Controls voltage
(2) Static VAR Compensator (SVC) -Controls voltage
(3) Unified Power Flow Controller (UPFC)

(4) Convertible Series Compensator (CSC)
(5) Inter-phase Power Flow Controller (IPFC)
(6) Static Synchronous Series Controller (SSSC)

2.5 Benefits of utilizing FACTS devices

The benefits of utilizing FACTS devices in electrical transmission systems can be summarized as follows [6]:

(1) Better utilization of existing transmission system assets
(2) Increased transmission system reliability and availability
(3) Increased dynamic and transient grid stability and reduction of loop flows
(4) Increased quality of supply for sensitive industries
(5) Environmental benefits Better utilization of existing transmission system assets

III. Incorporation of UPFC in Power System

In real time applications the UPFC would have to manage the power flow control of a complex, transmission system in which the length, voltage, and capacity of the individual lines could widely offer. One of the attractive features of the UPFC is that it is inherently flexible to accommodate complex systems and several operating requirements. The UPFC is particularly advantageous when controlled series compensation or other shunt power flow control is already contemplated. Moreover, the single inverter of the UPFC can be operated as independent series reactive compensator. The operating areas of the individual inverter of the UPFC can differ significantly, depending on the voltage and power ratings of the individual ones and on the amount of compensation desired. The UPFC is an ideal solution to balance both real and reactive power flow in a transmission [7].

The basic operation of the unified power flow controller was described and the UPFC consists of two switching converters operated from a common dc link, as shown in Fig.1.Converter 2 (series converter) performs the main function of the UPFC by injecting an AC voltage with controllable magnitude and phase angle is series with the transmission line. The basic function of converter 1 (shunt converter) is to supply or absorb the active power demanded by converter 2 at the common dc link. This is represented by the current I_q. Converter 1 can also generate or absorb controllable reactive power and provide independent shunt reactive compensation for the line. This is represented by the current I_q. The open and closed loop modified system for UPFC shunt injected current is as shown in the Fig.1

3.1 Operation of UPFC System

This arrangement of UPFC ideally works as a ideal ac to dc power converter in which real power can freely flow in either direction between ac terminals of the two converters and each converter can independently generate or absorb reactive power at its own AC output terminal. The main functionality of UPFC provided by shunt converter by injecting an ac voltage considered as a synchronous ac voltage source with controllable phase angle and magnitude in series with the line. The transmission line current flowing through this voltage source results in real and reactive power exchange between it and the AC transmission system. The inverter converts the real power exchanged at ac terminals into dc power which appears at the dc link as positive or negative real power demand [8].

Series converter Operation: In the series converter, the voltage injected can be determined in different modes of operation: direct voltage injection mode, phase angle shift emulation mode, Line impedance emulation mode and automatic power flow control mode. Although there are different operating modes to obtain the voltage, usually the series converter operates in automatic power flow control mode where the reference input values of P and Q maintain on the transmission line despite the system changes [7]. Shunt converter operation: The shunt converter operated in such a way to demand the dc terminal power (positive or negative) from the line keeping the voltage across the storage capacitor V_{dc} constant. Shunt converter operates in two modes: VAR Control mode and Automatic Voltage Control mode. Typically, Shunt converter in UPFC operates in Automatic voltage control mode [7].

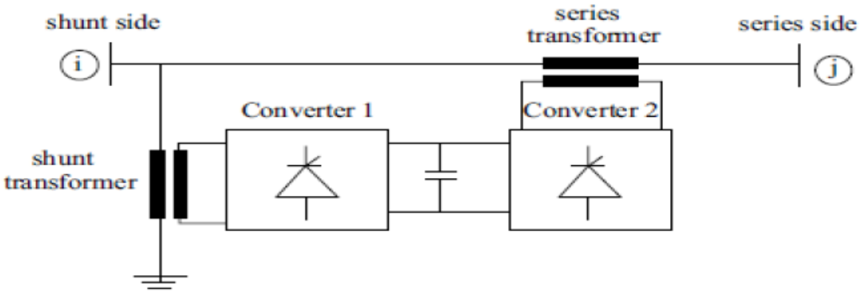

Fig.2 Block diagram arrangement of the UPFC system

3.2 The Controlling Parameters of UPFC System

Without UPFC shunt compensation, the line current, which is consisted of active and reactive components, made up of the following terms: (neglecting the dc and harmonic components).

$$i(t)=ip(t)+iq(t)$$
$$=Ip \sin(wt)+Iq \cos(wt) \qquad (1)$$

Where,

$i_p(t)$- in phase line active current of the transmission line

$i_q(t)$- reactive current of the transmission line

To regulate the voltage at bus connected to the shunt converter of the UPFC, the only component that this bus should supply is the active current component. Using eqn(1), it can be noted that if the shunt converter of the UPFC supplies the reactive component, then the sending bus needs only to supply the active component as shown in figure.1. This can easily accomplished by subtracting the active current component from the measured line current [9].

$$I_q(t)= i(t)-I_p\sin(wt) \qquad (2)$$

In eqn. (2), I_p is the magnitude of the in-phase current to be estimated and sin (wt) is a sinusoidal in phase with the line voltage. Consider the product of the line current of eqn. (2) and a sinusoid in phase with the line voltage.

IV. Simulation & Performance Analysis

4.1 Open Loop Model Based UPFC System

The overall simulation model of open loop UPFC incorporated to the test system is shown below in Fig. 3.

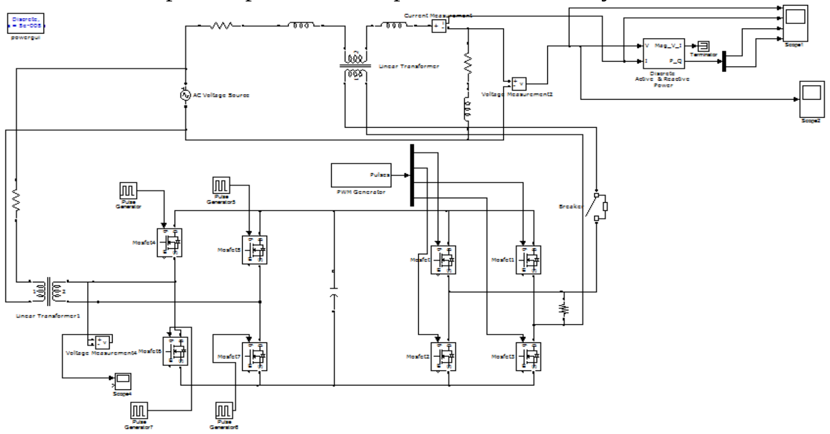

Fig.3 Open loop based UPFC model to the test system

The test system represented in Fig.3 consists of single phase 230V/50Hz AC source, delivering active and reactive power to non-linear load through a transmission system along with UPFC which is used to provide necessary compensation. Voltage measurement block is used to measure the source and load voltage and current measurement block is used to measure the instantaneous current flowing across the load. The active & reactive power measurement block in Matlab/simulink is used to measure the real power and reactive power across the non-linear load.

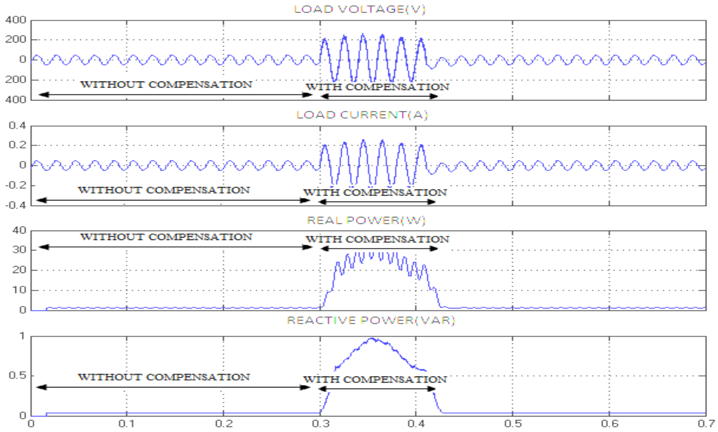

Fig.4 Output waveforms across the non-linear load

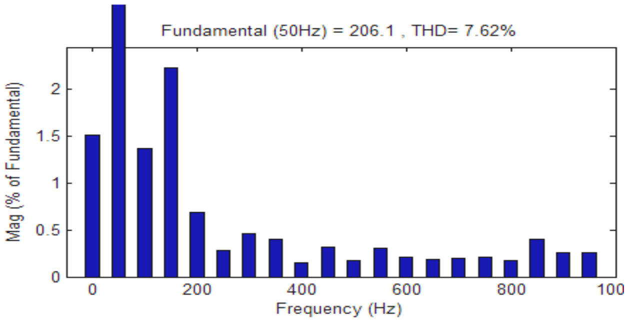

Fig.5 FFT Analysis for open loop UPFC

In Fig.4, the load voltage & current and real & reactive power of the system measured by the scope is shown. Here real and reactive power flow is obtained without any compensation. Here the active power (P) is 1kw and reactive power is 0.1kvar for uncompensated system model. So, it has to provide reactive power compensation in order to keep the system stable. Now for compensated system model, the real power observed is 20kw and reactive power is 0.4kvar.

Here for all three system models, generated waveforms are taken and calculations are done for the common parameter C=1000µF, sampling time 50e-6 sec. The THD (Total Harmonic Distortion) block is used to measure the THD level of the system and the THD is around 7.62%.

4.2 Closed Loop Model Based UPFC System

The overall simulation model of closed loop UPFC incorporated to the test system is shown below in Fig. 6.

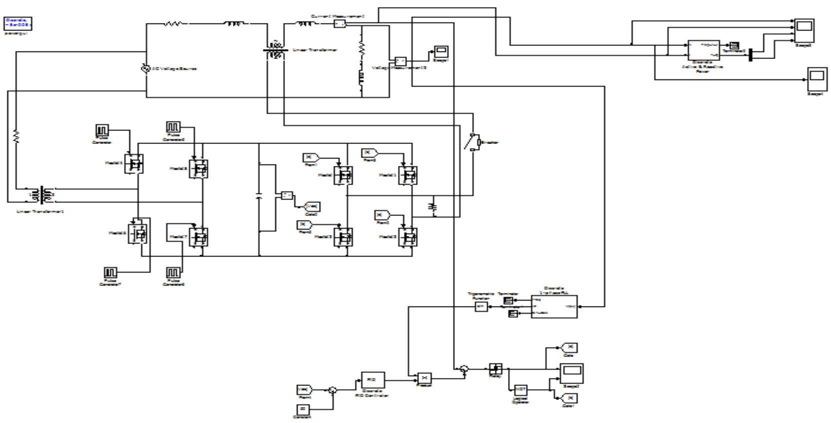

Fig.6 Closed loop based UPFC model to the test system

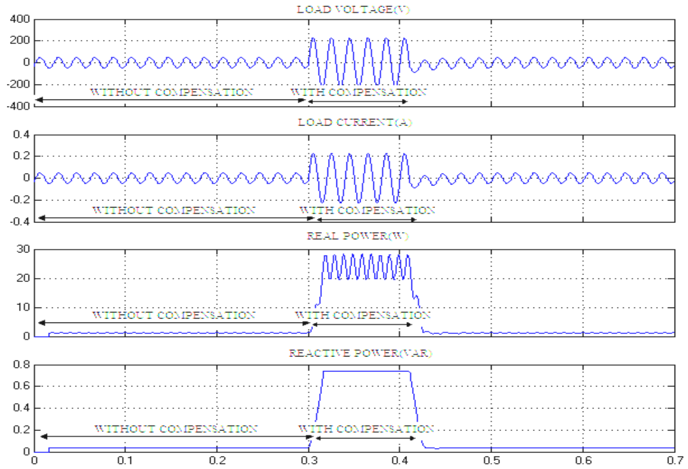

Fig.7 Output waveforms across the non-linear load

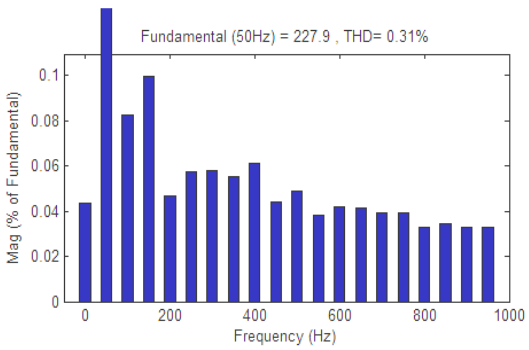

Fig.8 FFT Analysis for Closed loop UPFC

In Fig.7, the load voltage & current and real & reactive power of the system measured by the scope is shown. Here real and reactive power flow is obtained without any compensation. Here the active power (P) is 2kw and reactive power is 0.4kvar for uncompensated system model. So, it has to provide reactive power compensation in order to keep the system stable. Now for compensated system model, the real power observed is 30kw and reactive power is 0.7kvar and the THD is around 0.31%.

Here for all three system models, generated waveforms are taken and calculations are done for the common parameter C=1000µF, sampling time 50e-6 sec. The THD (Total Harmonic Distortion) block is used to measure the THD level of the system.

Table.1 Performance analysis of UPFC

FACTS DEVICE	Open loop system		Closed loop system	
	Real power(kw)	Reactive power(kvar)	Real power(kw)	Reactive power(kvar)
Without UPFC	1	0.1	2	0.4
With UPFC	20	0.4	30	0.7

Table.2 FFT analysis of UPFC

FACTS Device	Open loop system	Closed loop system
With UPFC	7.62%	0.31%

V. Conclusion

In this paper performance analysis of UPFC are presented in SMIB system and MATLAB 2009a/simulink environment is used for this comparative study to model and simulate UPFC connected to a simple transmission line. Real power (P) and reactive power (Q) of the system is compared with and without the presence of UPFC in the system for both open loop and close loop configuration. It is shown from the table.1 that power profiles are improved with the addition of the compensating devices with respect to uncompensated system model in each case.

In table.2 it is also shown with the help of FFT (Fast Fourier Transform) analysis that in open loop system the total harmonic distortion level % for UPFC are very low and it is further improving in case of close loop system.

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