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Power Flow Control in Power System Using Unified Power Flow Controller (Upfc): A Review

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Abstract:

The world's electric power supply systems are widely interconnected. Today's power system demand have been increase with loads, it is more difficult to provide stability and control. Power electronic controllers for a flexible ac transmission system (FACTS) can offer a greater control of power flow, secure loading and damping of power system oscillations. FACTS technology new opportunities for controlling power and enhancing the usable capacity of present, as well as new and upgraded lines. A unified power flow controller (UPFC) is a one of FACTS elements that can provide VAR compensation, line impedance control and phase angle shifting. The UPFC consist of two fully controlled converter, series converter is connected in series with the transmission line by series transformer, whereas parallel converter is connected in parallel with the transmission line by parallel transformer. The real and reactive power flow in the transmission line can be controlled by changing the magnitude and phase angle of the injected voltage produced by the series converter. The basic function of the parallel converter is to supply the real power demanded by series inverter through the common dc link. The parallel converter can also generate or absorb controllable reactive power. In this paper discusses that used a UPFC to improving the real and reactive power flow of the power systems.

Keywords **— Flexible AC Transmission System (FACTS), Power Flow Control, UPFC..**

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I. INTRODUCTION

Last year, the high quality of electric power has become more significant for electric utilities and customers. Electricity is an everyday as it was an essential part of our life and need to get electricity to the consumer in reliable and specified quality. Transmission of electricity in the interconnected cooperating electricity system is steadily increasing due to increasing growth in consumption and electricity generation. Utility and customer-side disturbances result in terminal voltage fluctuations, transients, and waveform distortions on the electric grid that finally gives a problem in power quality. Power Quality (PQ) refers to "maintaining the waveforms of voltages and currents as sinusoidal at rated frequency and magnitude" Recently power systems maintaining power quality became most important issue due to the introduction of equipment's with power electronic devices which are more sensitive to power quality problems. World-wide transmission systems are undergoing continuous changes and restructuring. They are becoming more heavily loaded. The transmission systems must be flexible to react to more diversified generation and load patterns. The three control parameters such as voltage magnitudes, phase angle and line reactance Governs flow of power in the transmission system. Considering a symmetrical lossless transmission line of Fig. 1 between two areas, the power flow P in the transmission line can be expressed as:

Whereas |Vs| & |Vr| are the sending end and receiving end voltage magnitudes and (δs – δr) are phase angle between the two ends. Considering resistance and susceptance as negligible, XTL is defined as reactance of the transmission line.

Either by controlling voltage magnitudes, phase angle or line reactance, power flow in the transmission line can be governed effectively and system can be operated reliably and securely. By improving the sending end or receiving end voltage profile (|Vs| & |Vr|), both real and reactive power flow of the transmission line can be enhanced. The absolute magnitude of ‗sending-end' and ‗receiving-end' voltages governs the reactive power flow in the transmission line. If

|Vs| > |Vr|, then reactive power flows from sending end to receiving end side i.e., from area-1 to area-2 as shown in Fig. 1 and vice versa. The Real Power flow, on the other hand is governed by the phase angles difference (δs – δr) between sending end and receiving end voltages in the transmission Line. If the difference between the phase angles (δs – δr) are large and positive, then real power flow in the transmission line is large and power flows in the direction from area-1 to area-2 as shown in Fig. 1 The power flow is vice versa for negative value of phase angle difference. the real power flow in transmission line is also inversely proportional to transmission line reactance XTL and thus can be improved by compensating inherent line reactance partially. These three parameters to improve power flow in the transmission line. The power (P and Q) at the receiving end bus as shown in equation 1.1 and 1.2

$$\text{Active Power} \quad P = \frac{Vs\,Vr\,Sin\,(\delta s-\delta r)}{XTL} = \frac{V^2\,\text{Sin}\delta}{XTL} \quad \cdots (1.1)$$

$$\text{Reactive Power} \quad Q = \frac{VsVr\,[1-Cos(\delta s-\delta r)]}{XTL} = \frac{V^2(1-\cos\delta)}{\text{XTL}} \quad \cdots (1.2)$$

$$\delta = \delta s - \delta r \quad \cdots (1.3)$$

II. INTRODUCTION OF FLEXIBLE AC TRANSMISSION SYSTEM (FACTS)

Flexible AC Transmission system technology opens up new opportunities for controlling power and enhancing the usable capacity of present, as well as new and upgraded lines. FACTS has number of benefits, such as greater power flow control, increased secure loading of existing transmission lines, damping of power oscillations, less environmental impact and potentially less cost than most alternative techniques of transmission system reinforcement. The FACTS devices are certainly an improvement over the conventional methods as they are fast and control these parameters efficiently to manage power flow effectively in transmission system. These opportunities arise through the ability of FACTS Controllers to control the interrelated parameters that govern the operation of transmission systems including series impedance, shunt impedance, current, voltage, phase angle, and the damping of oscillations at various frequencies below the rated frequency. In general, FACTs controller may divided into four categories as shown in figure. 2

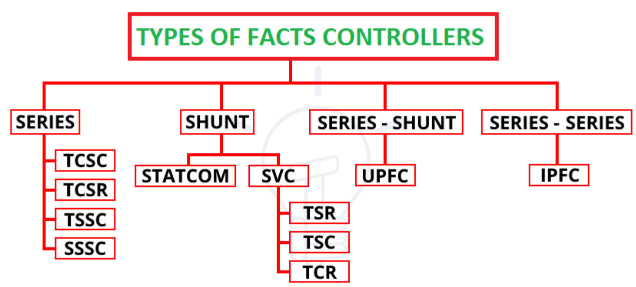
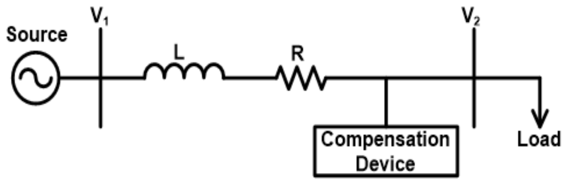


Fig.2. Classification of FACTS controllers.

➢ Series Compensation

In series compensation, the FACTS devices are connected in series with the power system network. This device can be a variable impedance like a capacitor or an inductor. Generally, the capacitor is connected in series with the transmission line. It is mostly used to improve the power transfer capability of EHV/UHV transmission lines.



The power transfer capacity of a transmission line without using compensation device-

$$P = \frac{V1V1}{XL} \sin \delta$$

Where,

V1 = Sending end voltage
V2 = Receiving end voltage
XL = Inductive reactance of transmission line
δ = Phase angle between V1 and V2
P = Power transferred per phase

Now, we connect a capacitor in series with the transmission line. The capacitive reactance of this capacitor is XC.

So, the total reactance is XL-XC.

So, with a compensation device, the power transfer capacity is given by;

$$P' = \frac{V1V1}{XL - XC} \sin \delta$$

$$\frac{P}{P'} = \frac{1}{1 - \frac{XC}{XL}}$$

$$\frac{P}{P'} = \frac{1}{1 - k}$$

$$k = \frac{XC}{XL}$$

The factor k is known as the compensation factor or degree of compensation. Generally, the value of k is lies between 0.4 to 0.7. Let's assume the value of k is 0.5.

$$\frac{P}{P'} = \frac{1}{1 - 0.5} = \frac{1}{0.5} = 2$$

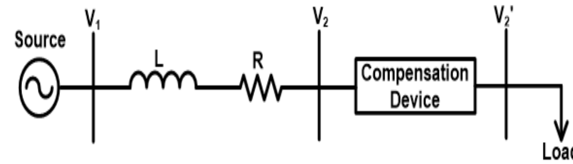
$$P' = 2P$$

Hence, it is clear that, if we use the series compensation devices, approximately 50% more power can be transfer.

By using the series capacitor, the angle between voltage and current (δ) is less compared to the uncompensated line. The lower value of δ will give better system stability. Hence, for the same amount of power transfer and the same value of sending end and receiving end, the compensated line will give better stability compared to the uncompensated line.

➢ Shunt Compensation

In a high voltage transmission line, the magnitude of receiving end voltage depends on the loading condition. The capacitance performs an important role in the high voltage transmission line.



When the line is loaded, the load needs reactive power. This reactive power demand fulfills by the line capacitance. When the load is more than SIL (surge impedance loading), then high demand for reactive power will result in a large voltage drop at receiving end of a transmission line. Therefore, the capacitor bank is connected in parallel with a transmission line at the receiving end to feed the demand for reactive power. So, it reduces receiving end voltage drop.

$$Q = \frac{[V2]^2}{XC} = [V2]^2 \omega c$$

If the capacitance of the line increases, the receiving end voltage will increase.

When the line is lightly loaded (less than SIL), the reactive power demand is less compared to the line capacitance. In this condition, the magnitude of receiving end increases than the magnitude of sending end voltage. This effect is known as the Ferranti effect. To avoid this condition, the shunt reactor is used to connect in series with the transmission line at the receiving end. The shunt reactor will absorb extra reactive power from line and maintain receiving end voltage at rated value.

$$Q = \frac{[V2]^2}{XL} = \frac{[V2]^2}{\omega L}$$

Each FACTS device can individually or collectively control. The Static VAR Compensator (SVC) and Static Synchronous Compensator (STATCOM) improve the power flow of the transmission line by increasing the voltage profile at the point of connection. The Thyristor Controlled Series Compensator (TCSC) and Static Series Synchronous Compensator (SSSC) is series compensator switch Compensator. The transmission line reactance to improve the real power flow. In addition, SSSC regulates the phase angle of the transmission system. The Unified Power Flow Controller (UPFC) is the only device which can be employed to govern all three parameters of given transmission line, however cost and complexity is an important issue.

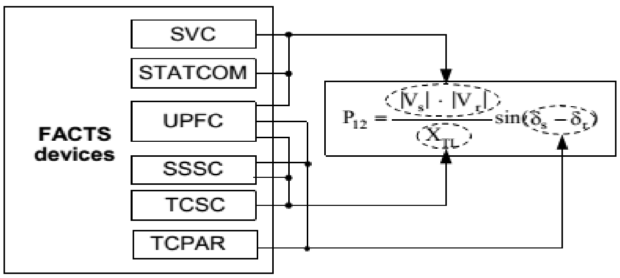


Fig. 3:Representation of different type's controllers controlled different parameters of transmission line.

The basic applications and advantages of FACTS devices are:

1. Reactive power compensation
2. Power flow control
3. Reduce system losses
4. Enhance power system stability
5. Voltage control
6. Power quality improvement.
7. Flicker mitigation Power conditioning
8. Increased system security and reliability
9. Rapid, continuous control of the transmission line reactance
10. Optimizing load sharing between parallel circuits

III. UPFC AND POWER FLOW CONTROL

FACTS controllers are incorporated in power systems. Significant device from the group FACTS is a UPFC, UPFC is a combination of STATCOM and SSSC Coupled via a common DC voltage link. to produce current, it uses a pair of three-phase controllable bridges. And this current is injected into the transmission line using a transformer. It is used to improve the voltage stability, power angle stability, and damping of the system.

This device can control the Active and reactive power flow in the transmission line. In abnormal conditions, the UPFC will not work. It only works under a balanced sine wave source. It is also used to suppress the oscillation power system and improve the transient stability of the power system. The basic diagram of the Unified Power Flow Controller (UPFC) is as shown in the below figure.

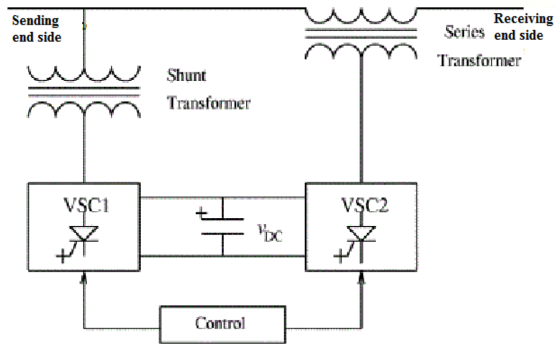


Fig. 3: Basic UPFC Configuration

➢ 2.1 Basic operating principles of UPFC

IV. OPERATING PRINCIPLE OF UPFC

The main function of UPFC is to control the flow of real and reactive power by injection of a voltage in series with transmission line. Both the magnitude and the phase angle of the voltage can be varied independently. Real and reactive power flow control can allow for power flow in prescribed routes; loading of transmission lines closer to their thermal limits and can be utilized for improving transient and small signal stability of the power system.

The UPFC consists of two voltage sourced converters, connected back-to-back and are operated from a common dc link provided by a storage capacitor as shown in the figure 1

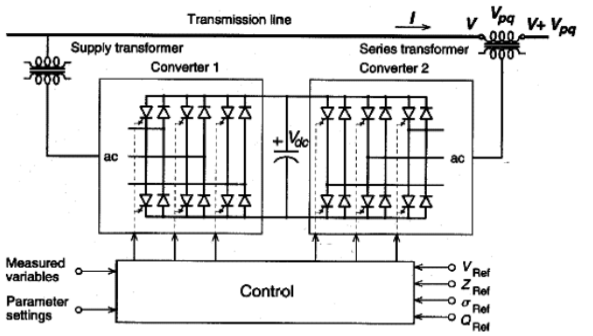


Figure 1. Implementation of the UPFC by two back-to-back voltage sourced converter

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 (or absorb) 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 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 dc power which appears at the dc 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 dc link to support the real power exchange resulting from the series voltage injection. This dc 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.

V. THE OPERATING MODES OF UPFC

The UPFC has many possible operating modes. In particular, the shunt inverter is operating in such a way to inject a controllable current, Ish into the transmission line.

The shunt inverter can be controlled in two different modes:

1) VAR CONTROL MODE:- The reference input is an inductive or capacitive VAR request. The shunt inverter control translates the VAR reference into a corresponding shunt current request and adjusts gating of the inverter to establish the desired current. For this mode of control a feedback signal representing the dc bus voltage, Vdc, is also required.

2) AUTOMATIC VOLTAGE CONTROL MODE:- The shunt inverter reactive current is automatically regulated to maintain the transmission line voltage at the point of connection to a reference value. For this mode of control, voltage feedback signals are obtained from the sending end bus feeding the shunt coupling transformer.

The series inverter controls the magnitude and angle of the voltage injected in series with the line to influence the power flow on the line. The actual value of the injected voltage can be obtained in several ways.

1) DIRECT VOLTAGE INJECTION MODE:- The reference inputs are directly the magnitude and phase angle of the series voltage.

2) PHASE ANGLE SHIFTER EMULATION MODE:- The reference input is phase displacement between the sending end voltage and the receiving end voltage.

3) LINE IMPEDANCE EMULATION MODE:- The reference input is an impedance value to insert in series with the line impedance.

4) AUTOMATIC POWER FLOW CONTROL

MODE:- The reference inputs are values of P and Q to maintain on the transmission line despite system changes.

VI. CONCLUSIONS

In this paper, the used of UPFC in power flow control between two ends of the transmission line to maintain the voltage magnitude, phase angle and line impedance. The study of Series-shunt compensation UPFC device to controlling the power flow through the transmission line by changing the effective reactance of the system. The various FACTS controller with its classification. The advantages of FACTS devices in power system and various operating modes of UPFC are specified. This paper work can be extended in future for UPFC modelling and simulation with a number of bus system for controlling the power flow.

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