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# Transmission System Using Unified Power Flow Controller

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***Abstract:*** **Flexible alternating current transmission systems (FACTS) technology opens up new opportunities for controlling power and enhancing the usable capacity of present, as well as new and upgraded lines. FACTS technology reveals up new opportunities for controlling power and enhancing the usable capacity of present, as well as new and upgraded lines. This project describes the real and reactive power flow control through a transmission line by placing the UPFC at the sending end of an electrical power transmission system. The Unified Power Flow Controller (UPFC) is a second generation FACTS device which enables independent control of active and reactive power besides improving reliability and quality of the supply. The power flow control performance of the UPFC is compared with that of the other FACTS device called Static Synchronous Series Compensator (SSSC), TCSC, STATCOM Simulations are carried out in Matlab/Simulink environment to validate the performance of the UPFC**

***Keywords* - —power flow controller, FACTS, Statcomm, UPFC.**

## I. INTRODUCTION

FACTS is defined as Flexible alternating current transmission systems incorporating power electronics based devices to enhance controllability and increase power transfer capability. The controllers that are designed based on the concept of FACTS technology to improve the power flow control; stability and reliability are known as FACTS controllers. These controllers were introduced depending on the type of power system problems. Some of these controllers were capable of addressing multiple problems in a power system but some are limited to solve for a particular problem. The maintenance and reliability of power system is the major issue in today's competitive environment. With increase demand and supply in power system, maintaining stability and security in this emerging electricity market. The solution is the use of FACTS devices especially the use of UPFC [1]. UPFC belong to last generation of FACTS devices they are capable of controlling simultaneously all three parameters of lines power flow (line impedance, voltage and phase angle). The Unified Power Flow Controller (UPFC) concept was proposed by L. Gyugyi [2] in 1991. It is used to control the active and reactive powers flow through transmission lines. Such FACTS device is a combination of two old FACTS devices i.e. The Static Synchronous Compensator (STATCOM) and the Static Synchronous series Compensator (SSSC). The above said two devices work as Voltage Source Inverters (VSI's) connected respectively in shunt with the transmission line through shunt transformer and in series with series transformer, these two devices are connected to each other by a common dc link including a storage capacitor. The first Unified Power Flow Controller (UPFC) in the world, with a total rating of ±320MVA, was commissioned in mid-1998 at the Inez station of the American Electric Power (AEP) in Kentucky for voltage support and power flow control. [3]-[6] Power systems today are highly complex and the requirements to provide a stable, secure, controlled and economic quality of power are becoming vitally important with the rapid growth in industrial area. To meet the demand of power in a power system it is essential to increase the transmitted power either by installing new transmission lines or by improving the existing transmission lines by adding new devices. [7] Installation of new transmission lines in a power system leads to the technological complication such as economic and environmental disorders. Considering these factors power system engineers concentrated the research process to modify the existing transmission system instead of constructing new transmission lines. The main objective to introduce FACTS Technology is to increase the power transfer capability of a transmission network in a power system, provide the direct control of power flow over designated transmission routes, provide secure loading of a transmission lines near the thermal limits, improve the damping of oscillations as this can threaten security or limit usage line capacity.

**FACTS Technology**

The concept of FACTS (Flexible Alternating Current Transmission System) refers to a family of power electronics-based devices able to enhance AC system controllability and stability and to increase power transfer capability.

The design of the different schemes and configurations of FACTS devices is based on the combination of traditional power system components (such as transformers, reactors, switches, and capacitors) with power electronics elements (such as various types of transistors and thyristors). Over the last years, the current rating of thyristors has evolved into higher nominal values making power electronics capable of high power applications of tens, hundreds and thousands of MW.

FACTS devices, thanks to their speed and flexibility, are able to provide the transmission system with several advantages such as: transmission capacity enhancement, power flow control, transient stability improvement, power oscillation damping, voltage stability and control. Depending on the type and rating of the selected device and on the specific voltage level and local network conditions, a transmission capacity enhancement of up to 40-50% may be achieved by installing a FACTS element. In comparison to traditional mechanically-driven devices, FACTS controllers are also not subject to wear and require a lower maintenance.

Costs, complexity and reliability issues represent nowadays the main barriers to the integration of these promising technologies from the TSOs' perspective. Further FACTS penetration will depend on the technology providers' ability to overcome these barriers, thanks to more standardization, interoperability and economies of scale.

## II. WORKING OF UPFC SYSTEM

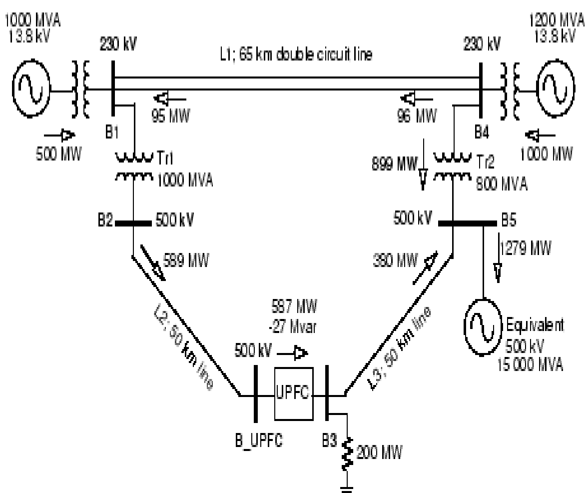


**Figure 1**

A Unified Power Flow Controller (UPFC) is used to control the power flow in a 500 kV transmission system. The UPFC located at the left end of the 75-km line L2, between the 500 kV buses B1 and B2, is used to control the active and reactive powers flowing through bus B2 while controlling voltage at bus B1. It consists of two 100-MVA, three-level, 48-pulse GTO-based converters, one connected in shunt at bus B1 and one connected in series between buses B1 and B2. The shunt and series converters can exchange power through a DC bus. The series converter can inject a maximum of 10% of nominal line-to-ground voltage (28.87 kV) in series with line L2.

This pair of converters can be operated in three modes:

- **Unified Power Flow Controller (UPFC)** mode, when the shunt and series converters are interconnected through the DC bus. When the disconnect switches between the DC buses of the shunt and series converter are opened, two additional modes are available:
- Shunt converter operating as a **Static Synchronous Compensator (STATCOM)** controlling voltage at bus B1
- Series converter operating as a **Static Synchronous Series Capacitor (SSSC)** controlling injected voltage, while keeping injected voltage in quadrature with current.

The mode of operation as well as the reference voltage and reference power values can be changed by means of the "UPFC GUI" block.

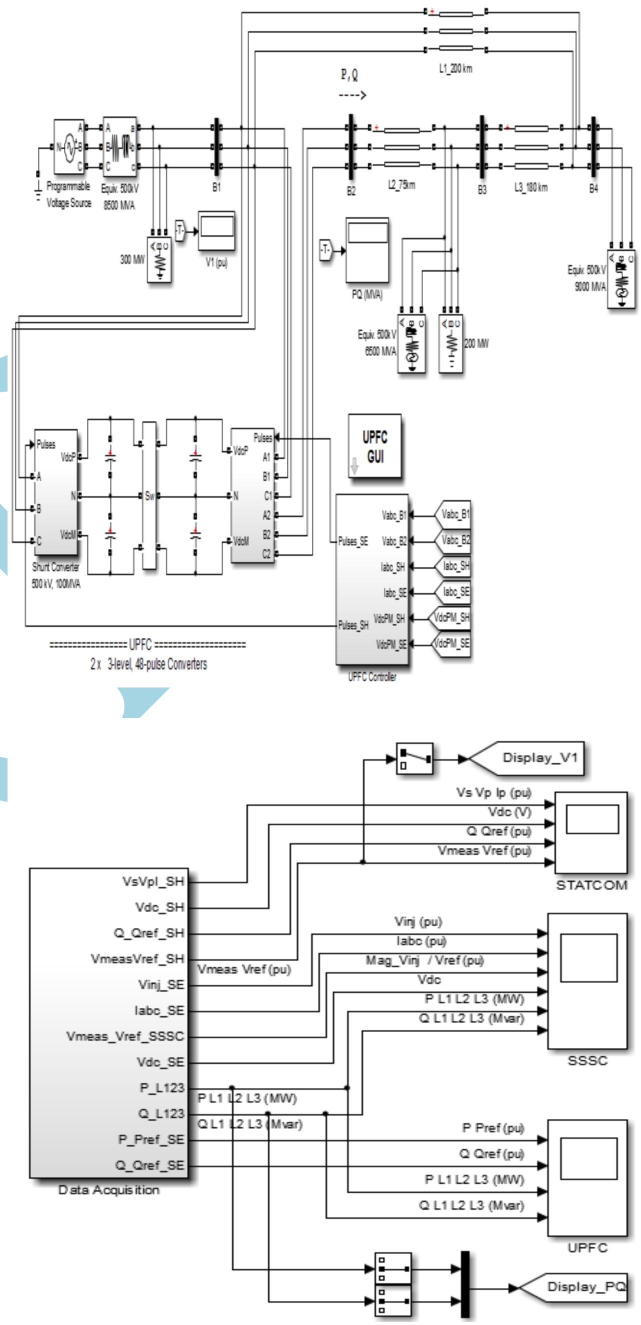


**Figure 2**

The principle of operation of the harmonic neutralized converters is explained here. When the two converters are operated in UPFC mode, the shunt converter operates as a STATCOM. It controls the bus B1 voltage by controlling the absorbed or generated reactive power while also allowing active power transfer to the series converter through the dc buses. The reactive power variation is obtained by varying the dc bus voltage. The four three-level shunt converters operate at a constant conduction angle (Sigma= 180-7.5 = 172.5 degrees), thus generating a quasi-sinusoidal 48-step voltage waveform. The first significant harmonics are the 47th and the 49th.

When operating in UPFC mode, the magnitude of the series injected voltage is varied by varying the Sigma conduction angle, therefore generating higher harmonic contents than the shunt converter. As illustrated in this example, when the series converter operates in SSSC mode it generates a "true" 48-pulse waveform.

The natural power flow through bus B2 when zero voltage is generated by the series converter (zero voltage on converter side of the four converter transformers) is P=+870 MW and Q=-70 Mvar. In UPFC mode, both the magnitude and phase angle and the series injected voltage can be varied, thus allowing control of P and Q. The UPFC controllable region is obtained by keeping the injected voltage to its maximum value (0.1 pu) and varying its phase angle from zero to 360 degrees. To see the resulting P-Q trajectory, double click the "Show UPFC Controllable Region". Any point located inside the PQ elliptic region can be obtained in UPFC mode.

## III. SIMULATION

### 1. Power control in UPFC mode

In the operation mode (UPFC, STATCOM or SSSC) as well as the Pref/Qref reference powers and/or Vref reference voltage settings . Also, in order to observe the dynamic response of the control system, the GUI allows you to specify a step change of any reference value at a specific time.

Make sure that the operation mode is set to "UPFC (Power Flow Control)". The reference active and reactive powers are specified in the last two lines of the GUI menu. Initially, Pref= +8.7 pu/100MVA (+870 MW) and Qref=-0.6 pu/100MVA (-60 Mvar). At t=0.25 sec Pref is changed to +10 pu (+1000MW). Then, at t=0.5 sec, Qref is changed to +0.7 pu (+70 Mvar). The reference voltage of the shunt converter (specified in the 2nd line of the GUI) will be kept constant at Vref=1 pu during the whole simulation (Step Time=0.3*100> Simulation stop time (0.8 sec). When the UPFC is in power control mode, the changes in STATCOM reference reactive power and in SSSC injected voltage (specified respectively in 1st and 3rd line of the GUI) as are not used.

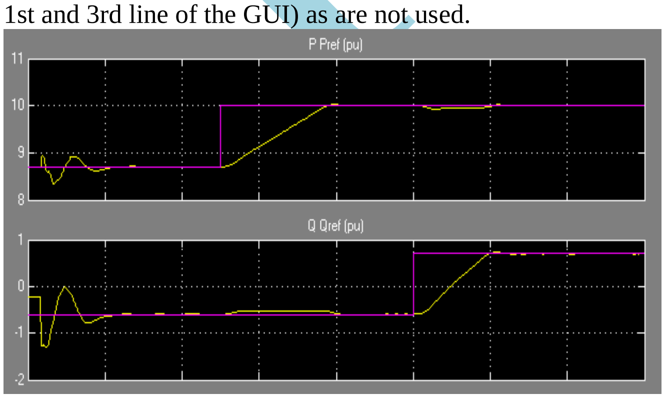


**Figure 3**

Now run the simulation for 0.8 sec. Then we observe on traces 1 and 2 of the UPFC scope the variations of P and Q. After a transient period lasting approximately 0.15 sec, the steady state is reached (P=+8.7 pu; Q=-0.6 pu). Then P and Q are ramped to the new settings (P=+10 pu Q=+0.7 pu). Observe on traces 3 and 4 the resulting changes in P Q on the three transmission lines. The performance of the shunt and series converters can be observed respectively on the STATCOM and SSSC scopes. If you zoom on the first trace of the STATCOM scope, you can observe the 48-step voltage waveform Vs generated on the secondary side of the shunt converter transformers (yellow trace) superimposed with the primary voltage Vp (magenta) and the primary current Ip (cyan).

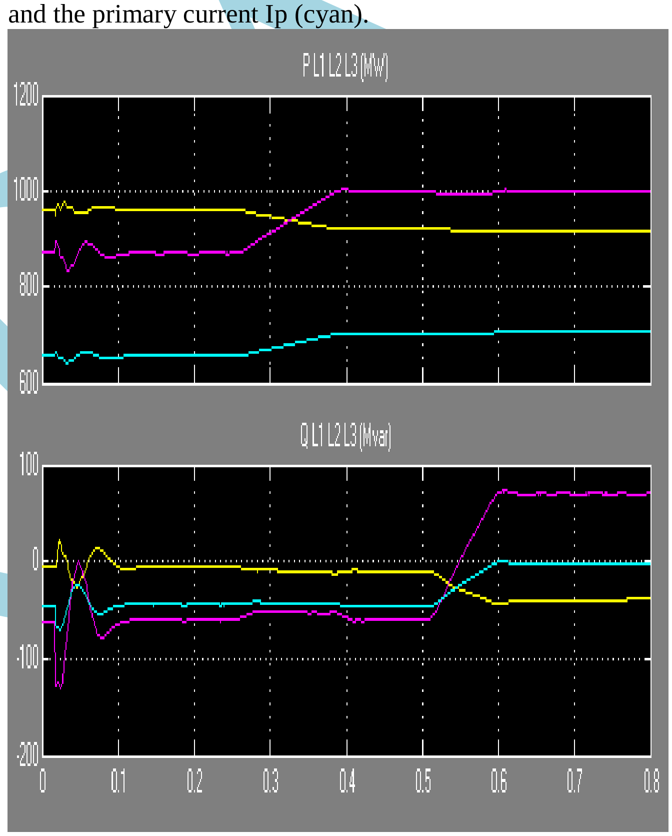


**Figure 4**

The dc bus voltage (trace 2) varies in the 19kV-21kV range. If you zoom on the first trace of the SSSC scope, you can observe the injected voltage waveforms Vinj measured between buses B1 and B2.

### 2. Var control in STATCOM mode

Now change the operation mode to "STATCOM (Var Control)". Make sure that the STATCOM references values (1st line of parameters, [T1 T2 Q1 Q2]) are set to [0.3 0.5 +0.8 -0.8 ]. In this mode, the STATCOM is operated as a variable source of reactive power. Initially, Q is set to zero, then at T1=0.3 sec Q is increased to +0.8 pu (STATCOM absorbing reactive power) and at T2=0.5 sec, Q is reversed to -0.8 pu (STATCOM generating reactive power).

 

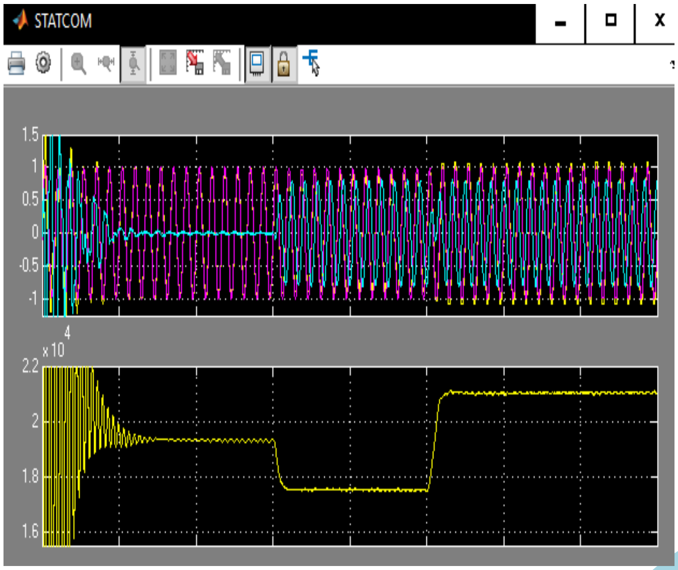


**Figure 5**

Run the simulation and observe on the STATCOM scope the dynamic response of the STATCOM. Zoom on the first trace around t=0.5 sec when Q is changed from +0.8 pu to -0.8 pu. When Q=+0.8 pu, the current flowing into the STATCOM (cyan trace) is lagging voltage (magenta trace), indicating that STATCOM is absorbing reactive power. When Qref is changed from +0.8 to -0.8, the current phase shift with respect to voltage changes from 90 degrees lagging to 90 degrees leading within one cycle. This control of reactive power is obtained by varying the magnitude of the secondary voltage Vs generated by the shunt converter while keeping it in phase with the bus B1 voltage Vp. This change of Vs magnitude is performed by controlling the dc bus voltage. When Q is changing from +0.8 pu to -0.8 pu, Vdc (trace 3) increases from 17.5 kV to 21 kV.

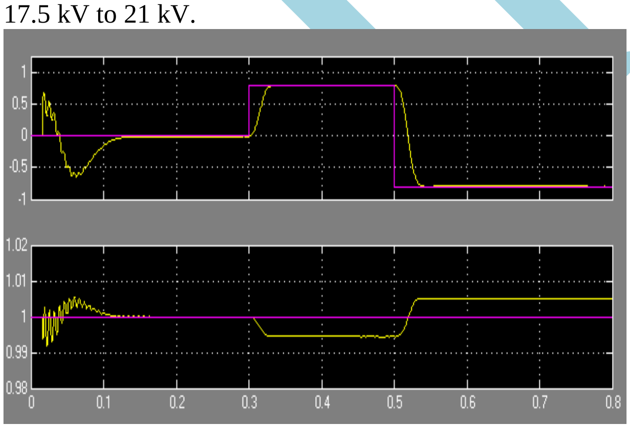

**Figure 6**

**3. Series voltage injection in SSSC mode**

In the operation mode to "SSSC (Voltage injection)". Make sure that the SSSC references values (3rd line of parameters) [Vinj_Initial Vinj_Final StepTime] ) are set to [0.0 0.08 0.3 ]. The initial voltage is set to 0 pu, then at t=0.3 sec it will be ramped to 0.8 pu.

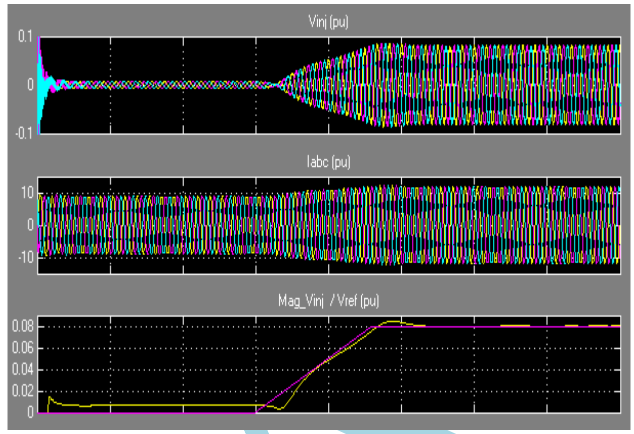


**Figure 7**

Then run the simulation and observe on the SSSC scope the impact of injected voltage on P and Q flowing in the 3 transmission lines. Contrary to the UPFC mode, in SSCC mode the series inverter operates with a constant conduction angle (Sigma= 172.5 degrees). The magnitude of the injected voltage is controlled by varying the dc voltage which is proportional to Vinj (3rd trace).

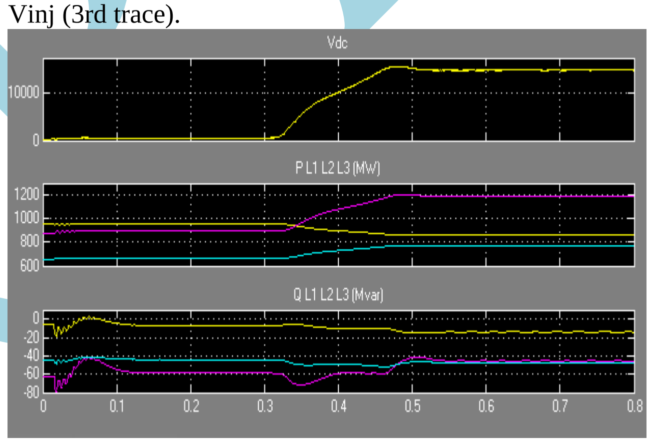


**Figure 8**

Also, observe the waveforms of injected voltages (1st trace) and currents flowing through the SSSC (2nd trace). Voltages and currents stay in quadrature so that the SSSC operates as a variable inductance or capacitance.

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