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Congestion Management with Optimal Location of FACTS Devices

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ABSTRACT

Line outage, congestion, cascading line tripping and system stability loss are the major problems faced by a power system. Solution to this problem is the use of FACTS devices especially Unified Power Flow Controller (UPFC). UPFC can uphold the voltage magnitude, phase angle and line impedance of a power system transmission line. In this paper, performance of unified power flow controller is investigated using MATLAB based commercial power system simulation software Power System Toolbox (PST) in various modes of operation. With the help of model of power system in MATLAB, and by installing UPFC in transmission system, its use as power flow controller and voltage injector, is used to relieve power congestion in transmission system.
Keywords: FACTS, UPFC, Power Flow Controller

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, and improve the damping of oscillations as this can threaten security or limit usage line capacity.

II. FACTS SYSTEM

A. Advantages of FACTS Devices

FACTS controllers can be used for various applications to enhance power system performance.

Environmental benefit: The construction of new transmission line has negative impact on the environment. FACTS devices help to distribute the electrical energy more economically through better utilization of existing installation there by reducing the need for additional transmission lines.

Increased stability: Instabilities in power system are created due to long length of transmission lines, interconnected grid, changing system loads and line faults in the system. These instabilities results in reduced line flows or even line trip. FACTS devices stabilize transmission systems with increased transfer capability and reduced risk of line trips.

Increased quality of supply: Modern industries require high quality of electricity supply including constant voltage and frequency, and no supply interruptions. Voltage dips, frequency variations or the loss of supply can lead to interruptions in manufacturing processes with high economic losses. FACTS devices can help to provide the required quality of supply.

Flexibility and uptime: Unlike new overhead transmission lines that take several years to construct, FACTS installation requires only 12 to 18 months. FACTS installation has the flexibility as it requires small land area.

Reduced maintenance cost: The FACTS maintenance cost is very minimum as the number of transmission line increases, the probability of fault occurring in a line is also high. So, by utilizing the transmission systems optimally with the use of FACTS, the total number of line fault is minimized, thus reducing the maintenance costs.

B. FACTS Devices Used in Power System

1) Static VAR Compensator SVC)

It is a variable impedance device where the current through the reactor is controlled using back to back connected thyristor valves. The application of thyristor valve technology to SVC is an offshoot of the developments in HVDC technology. The major difference is that thyristor valves used in SVC are rated for lower voltages as the SVC is connected to an EHV line through a step down transformer or connected to an EHV line through a step down transformer or connected to the tertiary winding of a power transformer. The application of SVC was initially for load compensation of fast changing loads such as steel mills and arc furnaces.

2) Static Synchronous Compensator (STATCOM)

A STATCOM is a device for reactive power control and is connected in parallel to the electric network with a transformer. STATCOM has a VSC (Voltage Source Converter) interface, and the DC-voltage support is provided with capacitors of relatively small energy storage, so the active power exchange is zero in steady-state. In practice there will be a little active power interchange due to losses. The basic principle of operation for the STATCOM is to compare the voltage in the system and the terminal voltage on the VSC, and control the phase angle and amplitude on the voltage drop over the transformer inductance. When the voltage in the electric system is lower than the terminal voltage on the VSC, the STATCOM will generate reactive power, the STATCOM works in capacitive mode. If the voltage on the VSC is lower than the voltage in the electric network, the STATCOM will absorb reactive power, the STATCOM works in inductive mode. If the voltage of the electric network and the terminal voltage on the VSC are equal, there will not be any reactive flow in the STATCOM. This device can serve the best solution for meeting the grid code demands. The continuous increase of installed wind power seen during recent years has forced the Transmission System Operators (TSO) to tighten their grid connection rules - also known as Grid Code - in order to limit the effects of power parks on network quality and stability. These new rules demand that power plants of any kind support the electricity network throughout their operation. Key issues are steady state and dynamic reactive power capability, continuously acting voltage control and fault ride through behavior. Some commonly used turbine designs have some limits in terms of achieving Grid Code compliance in several countries.

3) Thyristor Controlled Series Capacitor (TCSC)

A TCSC is a capacitive reactance compensator, which consists of a series capacitor bank shunted by a thyristor controlled reactor in order to provide a smoothly variable series capacitive reactance. Even through a TCSC in the normal operating range in mainly capacitive, but it can also be used in an inductive mode. TCSC controls the line impedance by changing the firing angle of the thyristors. A TCSC segment consists of a series stable capacitor that is coupled in parallel to a Thyristor Controlled Reactor (TCR).

A TCR comprises of a pair of anti-parallel thyristors that are joined in series with an inductor. In a TCSC, a Metal Oxide Varistor (MOV) besides a bypass breaker is connected in parallel to the stationary capacitor for overvoltage fortification. A complete compensation system may be made up of numerous of these units.

4) Unified Power Flow Controller (UPFC)

A Unified Power Flow Controller is an electrical device for providing fast- active reactive power compensation high voltage electricity transmission networks. It uses a pair of three phase controllable bridges to produce current that is injected into a transmission line using a series transformer. The controller can control active and reactive power flows in a transmission line. The UPFC uses solid state devices, which provide functional flexibility, generally not attainable by conventional thyristor controlled systems. The UPFC is a combination of a static synchronous compensator (STATCOM) and a Static Synchronous Compensator (SSSC) coupled via a common DC voltage link. The UPFC is a multipurpose and most robust FACTS device. UPFC is also known as the most wide-ranging multivariable Flexible AC Transmission System (FACTS) controller. The Unified Power Flow Controller (UPFC) controls the power flow in the transmission systems by controlling the impedance, phase angle and voltage magnitude. This controller exhibits large benefits both in terms of static and dynamic operation of the power system. [8] It also conveys Innovative challenges in the power system sector mainly in power system design. The elementary UPFC consists of two inverter; wherein one is connected in series to the transmission line while the other is in parallel with the transmission line. The UPFC consists of two voltage source converters; series and shunt converter, which are connected to each other with a common dc link. Series converter or Static Synchronous Series Compensator (SSSC) is used to add controlled voltage magnitude and phase angle in series with the line, while shunt converter is used to provide reactive power to the ac system. Each of the branches consists of a transformer and power electronic converter. These two voltage source converters share a common dc capacitor. The energy storing capacity of this dc capacitor is generally small. Therefore, active power drawn by the shunt converter should be equal to the active power generated by the series converter. The reactive power in the shunt or series converter can be chosen independently, giving greater flexibility to the power flow control.

UNIIFIED POWER FLOW CONTROLLER

1. UPFC Description and Operation

The unified power flow controller consist of two switching converters, which in the implementations considered are voltage source inverters using the Gate Turn Off (GTO) or insulated gate bipolar thyristor valves, as shown in Fig. 1. These inverters labelled “Inverter 1” and “Inverter 2” are operated from a common dc link provided by a dc storage capacitor. This arrangement functions as an ideal ac to ac power converters in which real power can freely flow in either direction between the ac terminals of the two inverters and each inverter can independently generate or absorb reactive power at its own ac output terminals

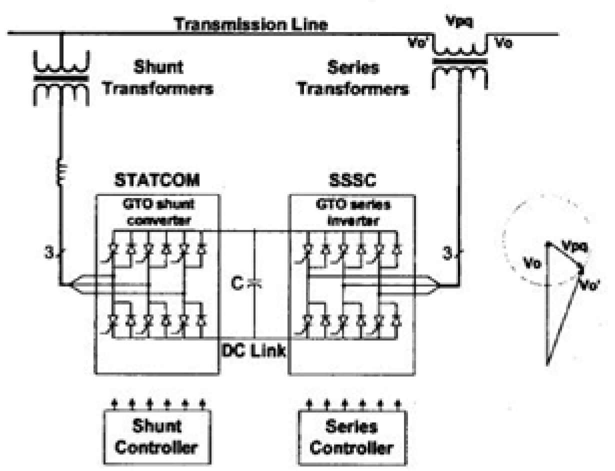

Figure 1. UPFC system

Inverter 2 provides the main function of the UPFC by injecting an ac voltage V_{pq} with controllable magnitude V_{pq} ($0 \leq V_{pq} \leq V_{pqmax}$) and phase angle ρ ($0 \leq \rho \leq 360°$), at the power frequency, in series with the line via an insertion transformer. This injected voltage can be considered essentially as a synchronous ac voltage sources.

Transmission line current flows through this voltage source resulting in real and reactive power exchange between it and the ac system. The real power exchanged at the ac terminal (i.e., at the terminal of the insertion transformer) is converted by the into dc power which appears at the dc link as positive or negative real power demand. The reactive power exchanged at the ac terminal is generated internally by the inverter. [9], [10]

The basic function of inverter 1 is to supply or absorb the real power demanded by inverter 2 at the common dc link. This dc link power is converted back to ac and coupled to the transmission line via a shunt- connected transformer. Inverter 1 can also generate or absorb controllable reactive power, if it is desired, and thereby it can provide independent shunt reactive compensation for the line. Thus, inverter 1 can be operated at a unity power factor or be controlled to have a reactive power exchange with the line independently of the reactive power exchanged by inverter 2. This means that there is no continuous reactive power flow through the UPFC.

B. Details of Power System

A UPFC is used to control the power flow in a 500KV/230KV transmission system. The system consist of five buses (B1-B5) interconnected through three transmission line (L1, L2, L3) and two 500KV/230KV transformer banks Tr1 and Tr2 as shown in Fig. 2. There are two power plants located on 230KV system generating a total of 1500MW which is transmitted to a 500KV 15000MVA equivalent and to a 200MW load connected at bus B3. Two power plants consist of a speed regulator, an excitation system and a power system stabilizer. Total generating capacity of power plant 2 is 1200MW and in normal operation, most of the generated capacity is transmitted to 500KV equivalent through two 400MVA transformers connected between buses B4 and B5. In this thesis a contingency case is considered where only two transformers will be considered out of the three available (Tr2=2*400=800MVA). The load flow shows that most of the power generated by plant 2 is transmitted through the 800MVA transformer bank (899MW of 1000MW) and that 96MW is circulating in the loop. Transformer Tr2 is overloaded by 99MVA. UPFC used in this power system is used to relieve power congestion.

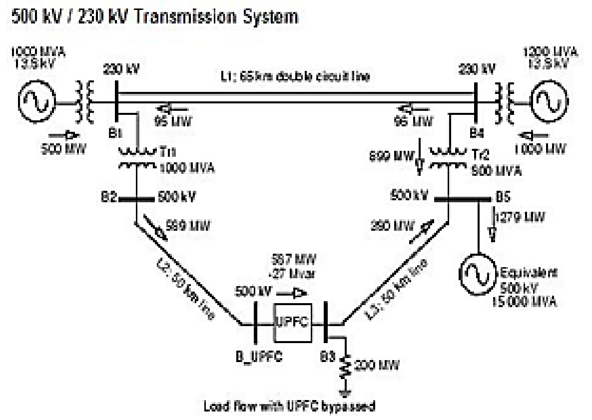

Figure 2.

C. Power Control with the UPFC

Initially the bypass breaker is closed and the resulting natural power flow at bus B3 is 587MW and -27Mvar. The P ref block is programmed with an initial active power of 5.87PU corresponding to the natural flow. Then at t=10s, P ref is increased by 1PU (100MW) from 5.87 PU to 6.87PU, while Q ref is kept constant at -0.27PU.

On running the simulation and looking on the "UPFC" scope how P and Q measured at bus B3 follow reference values. At t=5s, when bypass breaker is opened the natural power is diverted from the bypass breaker to the UPFC series branch without noticeable transient. At t=10s, the power increases at a rate of

1PU/S. It takes one second for the power to increase to 687MW. This 100MW increase of active power at bus B3 is achieved by injecting a series voltage of 0.089PU with an angle of 94 degrees. result in an approximate 100MW decrease in active power flowing through Tr2 (from 899MW to 796MW), which now carries an acceptable load as shown in Fig. 3.

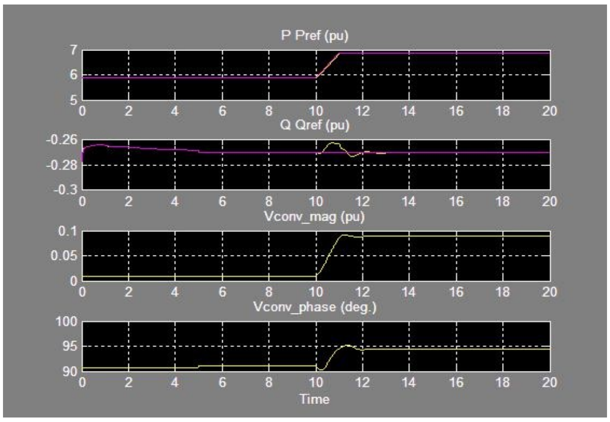

Figure 3. Simulation result of power flow control with UPFC

III. SIMULATIONS

The net reference real power output of the UPFC increased by 100MW when the breaker opened. The increase in the real power lead to decrease in congestion on bus. Referring to the reactive power, when the breaker is opened the oscillation of reactive power was finished and reactive power was then constant at -27MVAR. This can be seen by the variation at every bus as given in Fig. 4. The main concern lies at the UPFC controllable region. The region defined in the graph is such that the UPFC can only act under these conditions otherwise the UPFC behaves like open to transmission link. The result is in compliance with the UPFC characteristic.

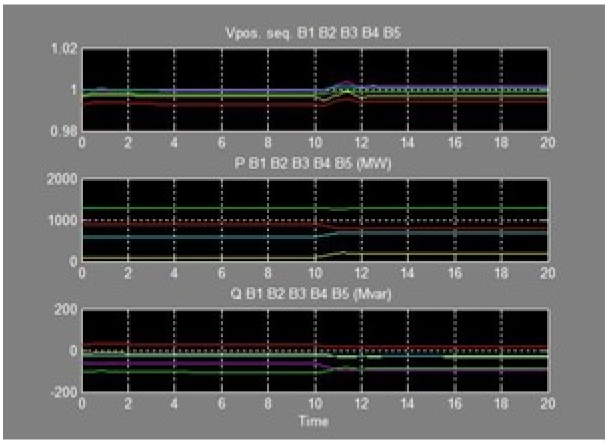

Figure 4. Power variation at five different buses.

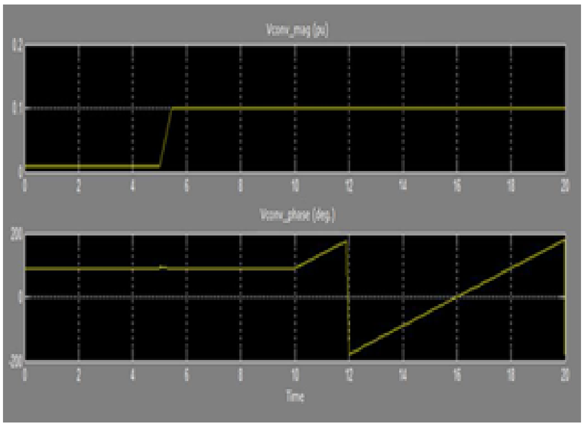

Figure 5. Simulation result of Voltage injection using UPFC.

In this control mode the voltage generated by the series inverter is controlled by two external signals V d, V q multiplexed at the Vdqref input and generated in the Vdqref block. For the first five seconds the bypass breaker stays closed, so that the PQ trajectory stays at the (-27MVAR, 587MW) point. Then when the breaker opens, the magnitude of the injected series voltage is ramped, from 0.0094 to 0.1 PU. At 10s, the angle of the injected voltage starts varying at the rate of 45deg/s as shown in Fig. 5.

IV. RESULTS

TABLE I. Reactive Power (Q) In Mvar

BUSES	Without UPFC	With UPFC
B1	-16.45	-30.06
B2	-63.81	-94.05
B3	-27	-27
B4	26.75	15.57
B5	105.7	-89.32

TABLE II. Active Power (P) In Mw

BUSES	Without UPFC	With UPFC
B1	95.35	196.6
B2	589	689.7
B3	587	687
B4	898.5	796
B5	1279	1277

TABLE III. Voltage Magnitude

BUSES	Without UPFC	With UPFC
B1	0.9966	0.9967
B2	0.9994	1.002
B3	0.9996	1.001
B4	0.9926	0.9942
B5	0.9978	0.9989

V. CONCLUSION

In this paper, a power flow analysis was carried out using MATLAB. FACTS devices improves the power transfer capability, control the power flow and reduces the losses in the power system. The effect of UPFC was demonstrated. With the presence of UPFC the total power losses will be reduced in power system transmission, it is desirable to maintain the voltage magnitude, magnitude, phase angle and line impedance. So to control the power flow in the system the concept of power flow and voltage injection is applied. Modelling the system and studying the result it shows that UPFC are very helpful FACTS controller when it comes to maintaining power system as it is clear from Table I-Table III listed in the paper that the reactive power is decreased, the active power is increased and the magnitude of voltage on all the buses is increased. So the following conclusion can be made that power flow is achieved, congestion is reduced, transient and steady stability is improved using UPFC

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