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Transfer Capability Enhancement of Transmission Line using Static Synchronous Compensator (STATCOM)

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Abstract

Growth of complex electrical power networks introduces lack of controllability of active and reactive power flow in energies networks Power flow control in an existing long transmission line, plays an important role in power system area. This paper employs the shunt connected compensation STATCOM based FACTS devices for the control of voltage and the power flow in long distance transmission line. The proposed device is used in different locations of transmission line and also deals with determination of the optimal location of shunt flexible A.C. transmission line (FACTS) devices for a long transmission line for voltage and power transfer improvement. The results also show the line loading and system initial operating conditions. In this paper the two machine 4-bus test system is simulated using MATLAB Simulink environment.

Keywords

Stability, Simulation, Power Transfer, STATCOM.

1. Introduction

The flexible AC transmission system (FACTS) has received much attention in the last two decades. It uses high-current power electronic devices to control the voltage, power flow, stability etc. of a transmission system. Some forms of FACTS devices are already available for prototype installation and others are still under development .FACTS devices can be connected to a transmission line in various ways, such as in series, shunt or a combination of series and shunt. For example, the static VAr compensator (SVC) and static synchronous compensator (STATCOM) are connected in shunt; static synchronous series compensator (SSSC) and thyristor controlled series capacitor (TCSC) are connected in series; thyristor controlled phase shifting transformer (TCPST) and unified power flow controller (UPFC) are connected in a series and shunt combination. The terms and definitions of various FACTS devices are described in a recent IEEE article [1]. FACTS devices are very effective and capable of increasing the power transfer capability of a line,if the thermal limit permit while maintaining the same degree of stability Flexible a.c transmission system (FCTS) technology opens up new opportunities for controlling power flow and enhancing the usable capacity of present transmission lines. FACTS devices control the interrelated parameters that govern the operation of a transmission system, thus enabling the line to carry power close to its thermal rating [2].

The introduction of Flexible AC Transmission System (FACTS) controllers are increasingly used to provide voltage and power flow controls. Insertion of FACTS devices is found to be highly effective in preventing voltage instability [3]. However, the benefits and performance of FACTS controllers are determined by their location and size [1]. The SVC and STATCOM are members of the FACTS family that are connected in shunt with the system with the system and are highly effective in improving the voltage stability and power transmission of system. The analytical method is used here to find out the optimal location of FACTS device, in which first system model simulated ,and after simulation observe the voltage magnitude and reactive power consumption at all buses. Now select the lowest voltage magnitude and highest reactive power consumption bus, for considerable voltage and power transfer capability this lowest voltage magnitude and highest reactive power consumption bus is the optimal location to install FACTS devices.

It has been observed that shunt FACTS devices give maximum benefit from their stabilized voltage support when placed at the optimal location of the transmission line. The proof of maximum increase in power transfer capability is based on a simplified model of the line that neglects the resistance and capacitance, which is a reasonable assumption for short transmission lines . However , for long transmission lines, when the accurate model of the line is considered , the results may deviate significantly from those found for the simplified model especially with respect to stability improvement .

2. Power System Stability

2.1 Definition of Stability of a System

The stability of a system is defined as the tendency and ability of the power system to develop restoring forces equal to or greater than the disturbing forces to maintain the state of equilibrium [4]. Let a system be in some equilibrium state. If upon an occurrence of a disturbance and the system is still able to achieve the equilibrium position, it is considered to be stable. The system is also considered to be stable if it converges to another equilibrium position in the proximity of initial equilibrium point. If the physical state of the system differs such that certain physical variable increases with respect to time, the system considered to be unstable .Therefore, the system is said to remain stable when the forces tending to hold the machines in synchronism with one another are enough to over -come the disturbances .The system stability that is of most concern is the characteristic and the behavior of the power system after a disturbance[4] .

2.2 Need for Power System Stability

The power system industry is a field where there are constant changes. Power industries are restructured to cater to more users at lower prices and better power efficiency. Power systems are becoming more complex as they become inter-connected. Load demand also increases linearly with the increase in users. Since stability phenomena limits the transfer capability of the system, there is a need to ensure stability and reliability of the power system due to economic reasons .Different types of power system stability have been classified into rotor angle stability, frequency stability and voltage stability [4].

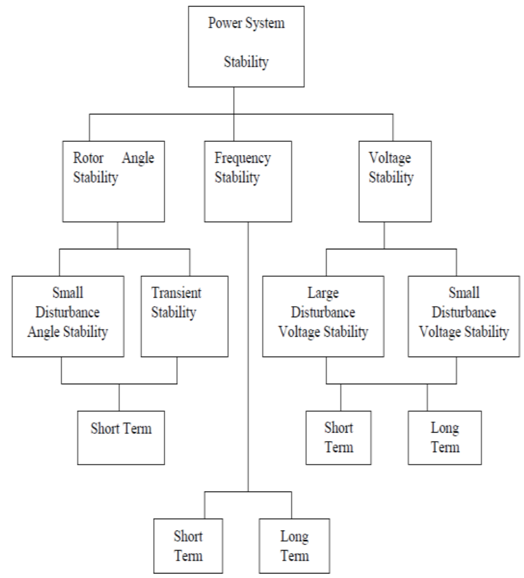


Figure 1: Classification of Power System Stability.

3. Problem Formulation

The problem formulation for total power transfer capability with FACTS devices including transmission power loss is used to determine the maximum power that can be transferred from a specific set of generators in source area to loads in sink area within real and reactive power generation limits, line flow limits, voltage limits, stability limits, and FACTS devices operation limits. Two types of FACTS devices are included: SVC and STATCOM is used to enhance the loadability of the transmission line. SVC and STATCOM is used to control bus voltage, reactive power injection, stability control, oscillations damping and unbalanced compensation.
The equations for system flow and stability are given as:

$$P_{Gi} - P_{Di} + P_L + P_{FDi}(V_{FDi}) + \sum_{j=1}^{N} V_i V_j Y_{ij} \cos(\theta_{ij} - \delta_i + \delta_j) = 0$$

$$Q_{Gi} - Q_{Di} + Q_L + Q_{FDi}(V_{FDi}) + \sum_{j=1}^{N} V_i V_j Y_{ij} \sin(\theta_{ij} - \delta_i + \delta_j) = 0$$

$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max}$$
$$Q_{Gi}^{min} \leq Q_{Gi} \leq P_{Gi}^{max}$$
$$V_i^{min} \leq V_i \leq V_i^{max}$$
$$|S_{Li}| \leq S_{Gi}^{max}$$
$$0 \leq V_{FDi} \leq V_{FDi}^{max}$$
$$Q_{FDi}^{min} \leq Q_{FDi} \leq P_{FDi}^{max}$$

Where,

P_{Gi}, Q_{Gi} : Real and reactive power generations at bus *i*
P_{Di}, Q_{Di} : Real and reactive demand loads at bus *i* ,V_i , V_j : Voltage magnitudes at bus *i* and *j* ,
$P_{FDi}(V_{FDi}, \alpha_{FDi})$: Injected real power of FACTS device at bus *i* ,
$Q_{FDi}(V_{FDi}, \alpha_{FDi})$: Injected reactive power of FACTS device at bus *i* ,
S_{Li} : *i*th line or transformer loading,
N: Total number of buses,
δ_i, δ_j : Voltage angles of bus *i* and *j* ,
Y_{ij} : Magnitude of the *ij*th element in bus admittance matrix,
θ_{ij} : Angle of the *ij*th element in bus admittance matrix

And the equations for power transmission are given as:

$$P = \frac{V_S V_r}{X_L} \sin(\delta_S - \delta_r) = \frac{V^2}{X_L} \sin\delta \quad \text{.. (1.9)}$$

$$Q = \frac{V_S V_r}{X_L} [1 - \sin(\delta_S - \delta_r)] = \frac{V^2}{X_L} [1 - \cos\delta] \quad \text{...(1.10)}$$

$$\delta = \delta_S - \delta_r \quad \text{..(1.11)}$$

$$|V_S| = |V_r| = |V| \quad \text{...(1.12)}$$

Where, P: Active power in p.u.
Q: Reactive power in p.u.
Vs: Sending end voltage in p.u.
Vr : Receiving end voltage in p.u.
X_L: Line reactance in p.u.
δs: Voltage angle at sending end.
δr : Voltage angle at receiving end.

4. FACTS Devices in Power System

Shunt compensation is used to influence the natural electrical characteristics of the transmission lines by generating the reactive power. There are two distinctly different approaches to controllable VAr generation. The first group employs reactive impedances with thyristor switches as controlled-elements (e.g. SVC); while the second group uses self – commutated static converters as controlled voltage sources (e.g. STATCOM). Extensive elaborations on FACTS devices can be found in the literature [6].

4.1 Static Synchronous Compensator (STATCOM)

The STATCOM is based on a solid state synchronous voltage source, which generates a balanced set of three sinusoidal voltages at the fundamental frequency , with rapidly controllable amplitude and phase angle. The STATCOM block used in the present study models an IGBT based STATCOM. However, as details of the inverter and harmonics are not represented in transient stability studies, a GTO-based model can also be used. Figure 2 shows a single-line diagram of the STATCOM and a simplified block diagram of its control system. The STATCOM control system consists of:

* A phase-locked loop (PLL) to synchronize on the positive -sequence component of the three – phase primary voltage V_1. The direct-axis and quadrature-axis components of the a.c. three-phase voltages and currents (labeled as Vd, Vq or Id, Iq on the diagram) are computed using the output of the PLL.
* The measurement system for measuring the d-axis and q-axis components of a.c. positive - sequence voltages and currents to be controlled and the d.c. voltage Vdc.
* The regulation loops, namely the a.c. voltage regulator and a d.c. voltage regulator. The outputs of the a.c. voltage regulator and d.c. voltage regulator (namely Iq ref and Id ref) act as reference currents for the current regulator.
* An inner current regulation loop consisting of a current regulator, which controls the magnitude and phase of the voltage generated by the PWM converter.

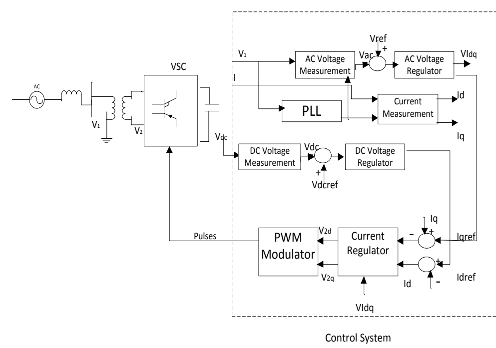


Figure 2: Single-line diagram of a STATCOM and its control system block diagram

5. Four-bus test system

5.1 Introduction

The system described in this section illustrates modeling of a simple transmission system containing two hydraulic power plants. The FACT device (STATCOM) and power system stabilizers (PSS) are used to improve voltages stability and power oscillation damping of the system. The power system illustrated in this paper is quite simple. However

,the phasor simulation method allows simulating more complex grids.

5.2 Description of the transmission system

The single line diagram shown below represents (four bus systems) a simple 400 kV transmission system. This system which has been made in ring mode consisting of buses (B1 to B4) connected to each other through three phase transmission lines L1, L2-1, L2-2 and L3 with the length of 280, 150,150 and 150 km respectively. And the four loads are connected of 250 MW, 100MW, 50MW and dynamic load as shown in Fig.3 System has been supplied by two power plants with the phase to phase voltage equal to 11 kv. Active and reactive powers injected by power plants 1 and 2 to the power system are presented in per unit by using base parameters Sb =2100 MVA and Vb=400KV, the power plants 1 (M1) and plants 2 (M2) generated 2100 MVA and 1400 MVA in per unit, respectively.

To maintain system stability with respect to loading, the transmission line is shunt compensated at its center by shunt FACTS device STATCOM. The two machines are equipped with a hydraulic turbine and governor (HTG), excitation system, and power system stabilizer (PSS) .The dynamic load is connected at bus B3 .We can use it to program different types of faults on the 400 kV systems and observe the impact of the FACTS on system stability and power transfer capability.

To start the simulation in steady-state, the machines and the regulators have been previously initialized by means of the Load Flow and Machine Initialization utility of the powergui block. Load flow has been performed with machine M1 defined as a PV generation bus (V=11000 V, P =1600 MW) and machine M2 defined as a swing bus (V=11000 V, 0 degrees).

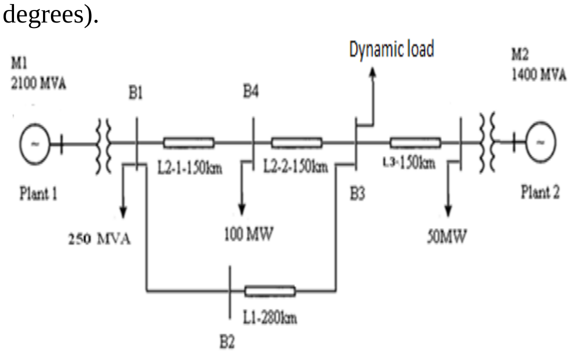
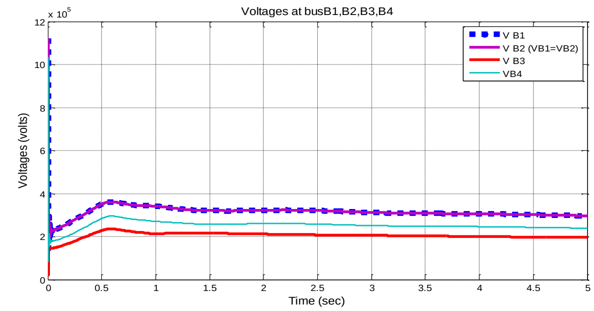


Fig 3: The single line diagram of 4-bus transmission test system.

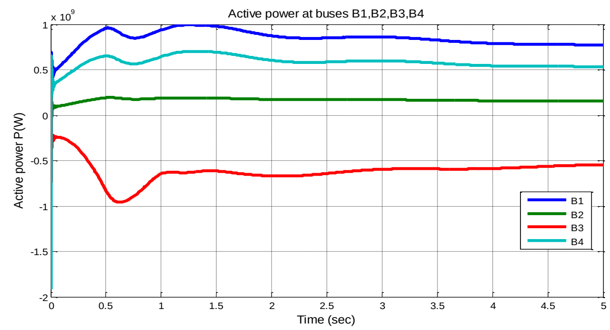
6. Simulation and Results

6.1 System analysis with-out FACTS

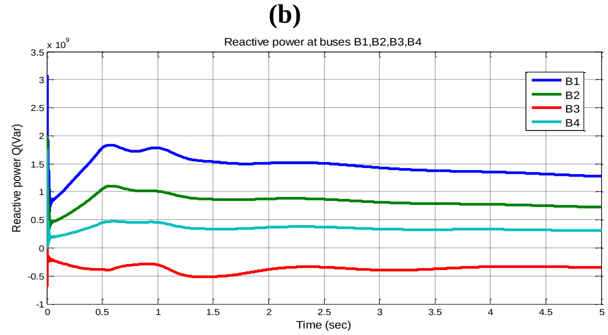
The simulation results for test system with-out FACT are given below. The data for different parameters are given in table 1.



(a)



(b)



(c)

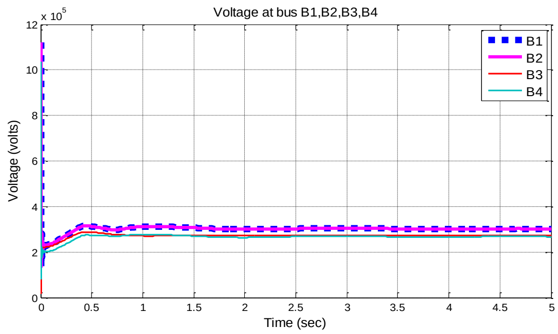
Fig 4: Profiles at buses B1, B2, B3, B4 with- out FACT Device, (a) Voltage, (b) Active Power, (c) Reactive Power.

Table 1: Active, Reactive power & voltages with-out FACTS

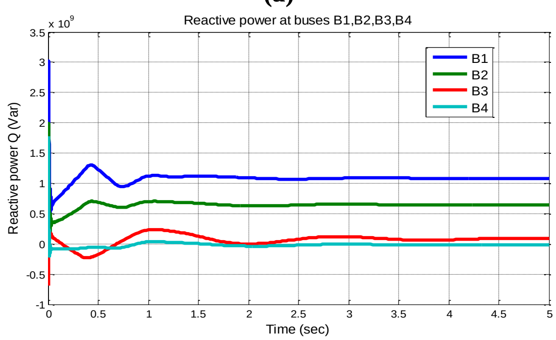
Bus	P (MW)	Q (Mvar)	S (MVA)	V (k volts)
B1	768.4	1274	1487.79	296.8
B2	154.6	725.2	741.496	296.8
B3	-545.4	-342.6	664.08	195.4
B4	530.8	304.4	611.89	239.1

6.2 Impact of STATCOM

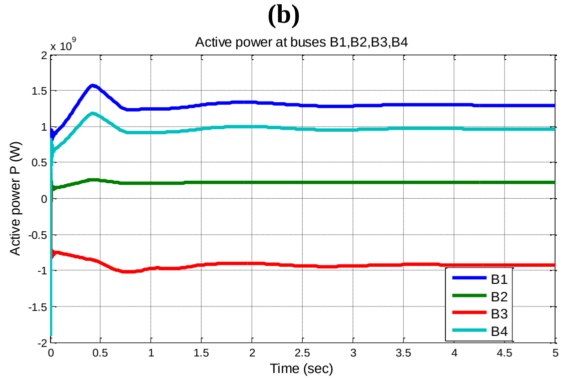
The Static Synchronous Compensator (STATCOM) is one of the key FACTS devices. STATCOM output current (inductive or capacitive) can be controlled independent of the AC system voltage. The power grid consists of two 400-kV equivalents transmission line. The STATCOM is located at bus-3 (B3) and has a rating of +/- 1000 MVA. This STATCOM is a phasor model of a typical three-level PWM STATCOM. Simulation is shown in below for STATCOM. The simulation results for test system with STATCOM are given below. The data for different parameters are given in table 2.



(a)



(b)



(c)

Fig 5: Profiles at buses B1, B2, B3, B4 with STATCOM, (a) Voltage, (b) Active Power, (c) Reactive Power.

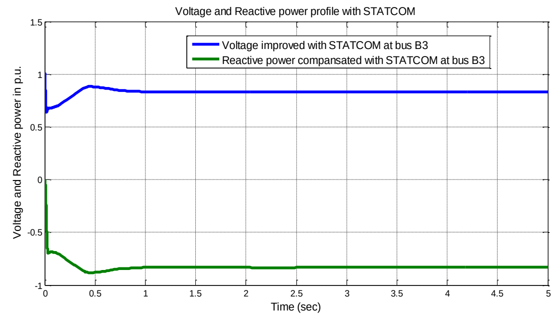


Fig 6: STATCOM voltage and Reactive power profile at BUS -3

Table 2: Active, Reactive power & voltages with STATCOM

Bus	P MW	Q (Mvar)	S (MVA)	V (k volts)	STATCOM data	
					V (pu)	Q (pu)
B1	1294	1080	1685.48	302.3	-	-
B2	219.4	643	679.4	302.3	-	-
B3	-926.7	86.99	930.78	271.2	0.8303	0.8303
B4	963.1	-15.52	963.23	267.4	-	-

Table 3: Transfer capacity

Device	**Transmitted power (MVA)**	**Transmission capacity increased (MVA)**	**Transmission capacity increased at B3 (MVA)**
No FACT	3437.99	-----	----
STATCOM	**4258.89**	**820.9**	**226.7**

7. Conclusion

This paper deals with applications of the STATCOM. The detailed model of the STATCOM implemented and tested in MATLAB/ simulink environment. The models are applicable for voltage stability analysis, and cover broader range of power transfer capability. The effects of STATCOM installed in power transmission path are analyzed in this paper, and the conclusions are as follow:

(1) The FACTS can improve voltage stability limit observably, and FACTS give better performance for power transfer capability for 4 - bus system transmission capacity increased 820.9 MVA (STATCOM),as discussed in table no 3.

(2) The power losses in system with-out FACT is more as compared when used FACTS devices. The loading capacity with FACTS is increased , the reactive power compensated form -342.6 MVAR (no FACTS) to, 86.99 MVAR (STATCOM) and voltage injected from 195.4 (no FACTS) to 271.2 Kv (STATCOM) at bus-3 for 4-bus system, as discussed in table no 2.

(3) it has been observed system performance improved by introducing the FACTS Devices, the best performance has been obtained by introducing FACTS devices such as SVC and STATCOM which compensate reactive power (MVAR), voltage injected (kv) and increased power transfer capability (MVA). It's concluded that by introducing FACTS device system performance, voltage stability and transmission capability improves considerably.

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