Implementation of Shunt and Series FACTS Devices for Overhead Transmission Lines

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Abstract — In this paper proposes optimal location and parameters of Unified Power Flow Controllers (UPFCs) to unify the power flow in electrical power systems. Shunt and Series FACTS devices are used for controlling the transmission voltage, power flow and reducing reactive losses and damping of power system oscillations for high power transfer levels. FACTS devices are very efficient and increasing the power transfer capability of a line. With the improvements in current and voltage handling capabilities of the power electronic devices that have allowed for the development of Flexible AC Transmission System (FACTS), the possibility has arisen in using different types of controllers for efficient shunt and series compensation. In series compensation, the FACTS devices are connected in series with the power system. It works as a controllable voltage source. Shunt compensation power system is connected in shunt with FACTS. It works as a controllable current source. The shunt FACTS device is operated at that rating that is able to control the bus voltage of shunt FACTS device equal to sending end voltage so as to get the maximum possible benefit of maximum power transfer and stability under steady state conditions. The performance of optimal location of shunt and series FACTS devices are verified by simulation using MATLAB/SIMULINK and Power World Simulator.

Key Words — Shunt Compensation, Series Compensation, STATCOM, Optimal Location, Power Converter, UPFC.

I. INTRODUCTION

FACTS devices can be connected to a transmission line in various ways, such as series and shunt devices towards maintaining voltage stability in transmission lines. Thyristor controlled phase shifting transformer (TCPST) and unified power flow controller (UPFC) connections are series and shunt combination [1], [5]. In series compensation, the FACTS are connected in series with the power system, it works as a controllable voltage source. Series inductance occurs in long transmission lines and when a large current flow causes a large voltage drop [2] - [3]. To compensate, series capacitors are connected. In shunt compensation, power system is connected in shunt with the FACTS. It works as a controllable current source. The pressure associated with economical and environmental constraints has forced the power utilities to meet the future demand by fully utilizing the existing resources of transmission facilities without building new lines. FACTS devices are very effective and capable of increasing the power transfer capability of a line, as thermal limits permit, while maintaining the same degree of stability [4]. Numerous recent applications of FACTS have proven to be cost-effective, long-term solutions. With the improvements in current and voltage handling capabilities of the power electronic devices that have allowed for the development of Flexible AC Transmission System (FACTS), the possibility has arisen in using different types of controllers for efficient shunt and series compensation [6].

Applying FACTS on a broad-scale basis for both series and Shunt FACTS devices are used for calculating transmission voltage, power flow, reducing reactive losses and damping of power system oscillations for high power transfer levels [7]. The extensive active considerations of the equipment of FACTS controllers for improved controllability. Shunt capacitive compensation is used to develop the power factor. When an inductive load is coupled to the transmission line, power factor lags for the reason that of lagging load current. To compensate a shunt capacitor is connected which draws current foremost the source voltage [8] – [9].

Shunt inductive compensation is used moreover when charging the transmission line, when there is extremely low load at the receiving end. Due to no load, very low current flows from beginning to end the transmission line. Shunt capacitance in the transmission line effects voltage amplification. To balance a no-loss line, voltage magnitude at receiving end is the same as voltage magnitude at sending end (VS = VR=V). Transmission results in a phase lag ‘δ’ that depends on line reactance ‘X’. Shunt inductors are linked across the transmission lines [10].

The FACTS is a standard term instead of the application of power electronics based solutions to AC power system. These systems can offer compensation in series or shunt or a grouping of both series and shunt [11]-[12]. The FACTS can effort the compensation by modifying impedance, voltage or phase angle [13].
The ability of FACTS in providing that series or shunt compensation is explained with the help of transmission line [14]. In the case of a no-loss transmission line, voltage magnitude at receiving end is the identical as voltage magnitude at sending end (\(V_1 = V_2 = V\)). Fig. 1 shows equivalent circuit and Phasor diagram of no loss transmission line.

II. SERIES COMPENSATION

The series Compensator could be variable impedance such as capacitor and reactor are Power Electronics based variable source of main frequency to serve the desired need. Various Series connected FACTS devices are,

- Static Synchronous Series Compensator
- Thyristor Controlled Series Capacitor
- Thyristor Switched Series Capacitor
- Thyristor Controlled Series Reactor
- Thyristor Switched Series Reactor

A. STATIC SYNCHRONOUS SERIES COMPENSATOR (SSSC)

Static series compensator (SSSC) is generally implemented using GTO based voltage source inverter that can provide controllable compensating voltage over an identical capacitive or inductive range independent of the line current as shown in Fig. 2. The basic operation of SSSC is very much analogous to the conventional series compensation, except that it uses switching power converter as a synchronous voltage. SSSC is able to provide bi-directional compensation to the line by injecting compensating voltage into the series line.

Therefore, SSSC is often used to enhance the dynamic behavior of power system by providing temporarily increment and decrement of real power into the line as compensation.

B. THYRISTOR CONTROLLED SERIES COMPENSATOR (TCSC)

Thyristor controlled series compensator consists of a series capacitor bank shunted by a thyristor-controlled reactor in order to provide a smoothly variable series capacitive reactance as shown in Fig. 3. The bi-directional thyristor valve that is fired with an angle ‘\(\alpha\)’ ranging between 90° and 180° with respect to the capacitor voltage.

The TCSC can be operated in bypass thyristor mode, blocked thyristor mode and vernier mode. In bypass thyristor mode, the thyristors are made to fully conduct with a conduction angle of 180°. Gate pulses are applied as soon as the voltage across the thyristors reaches zero and becomes positive, resulting in a continuous flow of current through the thyristor valves. The TCSC module behaves like a parallel capacitor inductor combination.
In blocked thyristor mode, the firing pulses to the thyristor valves are blocked. If the thyristors are conducting and a blocking command is given. The thyristors turn off as soon as the current through them reaches a zero crossing. The net TCSC reactance is capacitive.

The vernier mode allows the TCSC to behave either as a continuously controllable capacitive reactance or as a continuously controllable inductive reactance. It is achieved by varying the thyristor pair firing angle in an appropriate range.

C. THYRISTOR SWITCHED SERIES CAPACITOR (TSSC)

A capacitive reactance compensator which consists of a series capacitor bank shunted by a thyristor switched reactor to provide a stepwise control of series capacitive reactance. It consists of a capacitor shunted by a pair of reversely parallel connected thyristor. The basic component that makes up a thyristor switched series capacitor is shown in Fig. 4. The operation of TSSC is to make use of a thyristor to act as a valve or switch for the capacitor connected parallel to it such that when thyristor is triggered the capacitor will be activated to start compensation.

When the firing angle of the thyristor controlled reactor is 180°, it stops conducting and the uncontrolled reactor acts as a fault current limiter. As the angle decreases below 180°, the net inductance decreases until firing angle of 90°, when the net inductance is the parallel combination of the two reactors. The TCSR may be a single large unit or several smaller series units.

E. THYRISTOR SWITCHED SERIES REACTOR (TSSR)

An inductive reactance compensator which consists of a series reactor shunted by a thyristor-switched reactor in order to provide a stepwise control of series inductive reactance. TSSR is an inductive reactance compensator which consists of a series reactor shunted by a thyristor controlled switched reactor in order to provide a stepwise control of series inductive reactance. This is complement of TCSR, but with thyristor switches fully ON or fully OFF to achieve a combination of stepped series inductance.

III. SHUNT COMPENSATION

Shunt Controllers may be variable impedance, variable source or a combination of these two. In principle, all shunt Controllers inject current into the system at the point of connection. Various shunt connected controllers are, Static Compensator, Static VAR Compensator, Thyristor Controlled Reactor, Thyristor Switched Capacitor.

A. STATIC COMENSATOR (STATCOM)
STATCOM is a self commutated switching power converter supplied from an appropriate electric energy source and operated to produce a set adjustable multiphase voltage, which may be coupled to an AC power system for the purpose of exchanging independently controllable real and reactive power. The STATCOM is a solid-state based power converter version of the SVC. Operating as a shunt connected SVC, its capacitive or inductive output currents can be controlled independently from its terminal AC bus voltage.

Basically, STATCOM is comprised of three main parts as shown in Fig. 6. A Voltage source converter (VSC) is a step-up coupling transformer and a controller. The advantages of STATCOM compared to other shunt compensators are equality of lagging and leading output, continuous reactive power control with fast response and possible active harmonic filter capability.

**B. STATIC VAR COMPENSATOR (SVC)**

SVC is “A shunt-connected static VAR generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of the electrical power system”.

**C. THYRISTOR CONTROLLED REACTOR (TCR)**

A shunt connected, thyristor controlled inductor whose effective reactance is varied in a continuous manner by partial conduction control of the thyristor valve. TCR is a shunt connected, thyristor controlled inductor whose effective reactance is varied in a continuous manner by partial conduction control of the thyristor valve. TCR is a subset of SVC, in which conduction time and hence, current in a shunt reactor is controlled by a thyristor based AC switch with firing angle control. The TCR consists of a fixed reactor of inductor L and a bi-directional Thyristor valve.

**D. THYRISTOR SWITCHED CAPACITOR (TSC)**

TSC is a shunt connected, thyristor switched capacitor whose effective reactance is varied in a stepwise manner by full or zero conduction operation of the thyristor valve. The TSC is different from TSR and TCR as its branch can be switched out at zero crossing of the current, as shown in Fig. 8.

**IV. OPTIMAL PLACEMENT OF STATIC VAR COMPENSATOR (SVC)**

The electric power industry in the present is very complex and undergoes unforeseen rapid changes in terms of demand/generation patterns and trading activities that hinder the system security. Load curtailment is the collection of control strategies employed to reduce the electric power loading in the system and main aim is to push the disturbed system towards a new equilibrium state. Load curtailment may be required even when voltages at some buses deviate from their acceptable voltage limits. In such cases, reactive power is supplied locally to keep the voltages within limits. The main disadvantage of the reactive power over the active power is that it cannot be transmitted over long distances and hence must be provided locally by some means.

Flexible AC Transmission Systems (FACTS) controllers can be a suitable alternative to provide such reactive power locally. Generators have the capability of controlling reactive power but the location of the reactive power demand can hinder their effects considerably. Due to high costs of FACTS devices, their proper location in the system must be ascertained. In the impacts of TCSC and SVC on system load curtailments based on optimal power flow (OPF) are studied by placing the devices in the system on a hit and trial basis.
V. SYSTEM MODELING

The modeling of a transmission line and the static representation of Static VAR Compensator (SVC) has been described in this part.

A. REPRESENTATION OF TRANSMISSION LINE

A simple transmission line connected between bus-i and bus-j can be represented by its lumped π equivalent parameters as shown in Fig. 9. The complex voltages at bus-i and bus-j have been represented by \( V_i \angle \delta_i \) and \( V_j \angle \delta_j \) respectively. The real (\( P_{ij} \)) and reactive (\( Q_{ij} \)) powers from bus-i to bus-j can be written as,

\[
P_{ij} = V_i^2g_{ij} - V_iV_j(g_{ij}\cos\delta_{ij} + b_{ij}\sin\delta_{ij}) \quad (1)
\]

\[
Q_{ij} = -V_i^2(b_{ij} + B_{sh}/2) - V_iV_j(g_{ij}\sin\delta_{ij} - b_{ij}\cos\delta_{ij}) \quad (2)
\]

Similarly, the real (\( P_{ji} \)) and reactive (\( Q_{ji} \)) from bus-j to bus-i can be written as,

\[
P_{ji} = V_j^2g_{ij} - V_jV_i(g_{ij}\cos\delta_{ij} - b_{ij}\sin\delta_{ij}) \quad (3)
\]

\[
Q_{ji} = -V_j^2(b_{ij} + B_{sh}/2) + V_jV_i(g_{ij}\sin\delta_{ij} + b_{ij}\cos\delta_{ij}) \quad (4)
\]

VI. EXPERIMENTAL RESULTS

A. SIMULATION RESULT

The proposed method has been tested and simulation results are shown in Fig. 11. This model has been implemented using MATLAB/SIMULINK environment with SIMPOWER system toolbox.

Is are related to the receiving end voltage \( V_r \) and current \( I_r \) through ABCD constants as,

\[
V_s = AV_r + BI_r \quad (5)
\]

\[
I_s = CV_r + DI_r \quad (6)
\]
B. OPTIMAL LOCATION OF SHUNT AND SERIES FACTS DEVICES
C. POWER WORLD SIMULATOR

Power World Simulator is an interactive power system simulation package designed to simulate high voltage power system operation on a time frame ranging from several minutes to several days. Power world Simulator is used to carry out the simulations and represent the results graphically.
VII. CONCLUSION

Modern Power Systems are designed to operate efficiently to supply power on demand to various load centres with high Reliability. The effects of shunt and series compensation on the best location of a shunt and series FACTS device to obtain the utmost possible advantage of maximum power transfer as well as system stability. Generally power systems networks are large and complex. Now-a-days, increase the loads connected to the system and more demands transfer of huge power to the transmission lines. The variation in the optimal location of the shunt FACTS device from the centre point of line depends upon the extent of series compensation and it increases approximately linear from the centre point of the transmission line towards the generator side as the extent of series compensation is increased. Mutually the power transfer capacity and strength of the system can be enhanced much more if the shunt and series FACTS devices are located at the new optimal location in its place of the mid-point of the line. The result of series and shunt compensations controllers in attractive power system stability has been examined.

REFERENCES