Optimal location of Flexible AC Transmission Systems (FACTS) Controllers in Electrical Power System Applications

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Abstract*: The load imposed on the electrical power system is always subjected to change and is being dynamic in nature. Due to the dynamic load of the power system the various parameters which are associated with the system is also dynamic in nature. But the various system parameters such as voltage, current, power, power flows etc are should be maintained within the permissible limit. So, monitoring the system continuously and taking steps to maintain the system parameters in the power system is the essential job of the power engineers. In the process of analysis and assessment of the static and dynamic performance of the power system the flexible AC Transmission Systems (FACTS) controllers play very important role. FACTS devices are power electronics devices which are used to improve the voltage regulation, transmission loss, optimum operation of power system; optimal power flow control etc. There are many FACTS device combinations are being used in the power system as a controller for the purpose of improving the system static and dynamic performance. This paper provide an overview of the different types of FACTS controllers that are being used/applied/located in the different places of the power system to improve the static and dynamic performance of the power system. In addition to the FACTS controllers there are several devices in the FACTS family which are also discussed in brief.

Keywords— Power System, Static & dynamic performance, FACTS controllers, FACTS devices

I. INTRODUCTION

Power system which is includes the power generation by power plant, power transmission through the power transmission lines, and distribution to the power utility. The parameters which are associated with power system is voltage, current, frequency, power factor, transmission line parameters such as resistance inductance, and capacitance etc. The load imposed on the system is always subjected to change which also may changes the system voltages, current, frequency, power etc. The power flow in the transmission lines are need to be properly maintained and managed to reduce the power transmission losses and better power transmission from the power generation to distribution end. Early days the purely electrical devices such as inductors, capacitors, synchronous motor etc, are solely used to improve the static and dynamic performance of the power system [1]. But after the invention of

power electronics devices such as SCR, Traic, DAIAC, the power electronics device based power system control become more effective and efficient approach and the same has been replaced the conventional electrical approach in many part of the power system control.

The main objective of the power system is to transfer power with minimum power loss and optimum power utilization and also to provide quality power supply to the consumer with affordable cost. The quality supply means that the voltage and frequency of the supply reaching the consumer should be within permissible limit with uninterrupted power supply even though the load imposed on the system is continuously subjected to change. To reduce the transmission losses, the powers at sending end is increased to very high level and send through the transmission line then at the receiving end the same has been reduced to the low values. . This is called as high voltage AC transmission. In some case the DC transmission is takes place in which AC power is converted in to DC at sending end, and then transmitted through the high voltage transmission line. At the receiving end the HVDC is converted back in to AC through the DC to AC converter and send to distribution purpose. The FACTS controllers play very importance role in both AC and DC power high voltage transmission. Site specific transmission system challenges are being resolved with the help of prober design, proper identification of the location of the FACTS controller devices, and proper commissioning by the FACTS controllers.

II. FACTS CONTROLLERS

The FACTS [2] controllers is defined as "Combination of power Electronics devices and some of the conventional electrical voltage and current injecting devices which are used to provide AC transmission parameters in order to control the power flow in the transmission lines and maintain the power flow within the permissible limits. Transmission system power transfer capability can be increased and/or improved by using the FACTS controllers. The FACTS controllers are used to control the parameters which are very useful in the operations and maintenances of the transmission system. The FACTS controller can effectively change/alter the transmission system parameters such as series, shunt impedance, voltage, Current, phase angle etc. FACTS devices will ensure power transmission through the transmission line very closed to the thermal rating of the transmission line. The power system parameters can be effectively controlled / managed for better power transmission by using the FACTS devices individually/group. The representation of FACTS controllers is shown in below fig (1).

Fig.1 FACTS Controllers Representation

The FACTS controllers can be classified in to four types. They have been explained briefly in this sub- section

A. Shunt Controllers

The shunt controllers [3] are connected in parallel to the transmission line/ bus bar in the power transmission system. The main purpose of the shunt controllers is to inject the current in to the transmission line system at which point or place the controller is being inserted. The shunt controllers can change the transmission system parameters. The fig (2) shows the connection of shunt controller in the transmission line. The change in the impedance parameter will change the current flow.

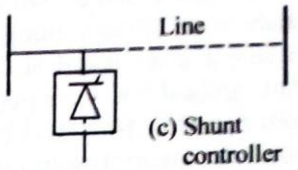

Fig.2 Shunt Controller Representation

The current which is injected by the shunt controllers will be in phase quadrature to the transmission line voltage. This relation of current (injected current) with the voltage will ensure the supply or consumption of the variable reactive power by the shunt controller. If the injected current is not in phase quadrature to the line voltage, then the real power control may also will takes place.

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B. Series Controller

The main objective of series controller is to inject voltage in series to the power transmission line. The series controller may be of a series reactor, a series capacitor and /or power electronics devices. In the series controller the voltage should be in phase quadrature to the line current. The relationship of injected voltage in phase quadrature to the line current will ensure the supply or consumption of the variable reactive power by the series controller. Other relation between voltage and current will leads to real power control. The controller is shown in fig. (3)

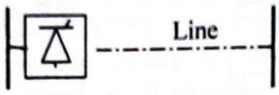

Fig. 3 Series Controller Representation

C. Series –shunt controller

There are two types of series-shunt controllers namely series-shunt controller (coordinated) and series –shunt controller (Unified). The diagrammatic representation of both series-shunt controllers (coordinated) and series –shunt controller (Unified) have been shown in fig (4) and fig (5) respectively. The series-shunt combinations will inject both voltage (by series controller) and current (by shunt controller) in to the power system transmission line.

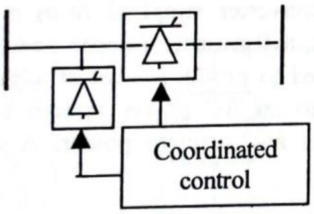

Fig. 4 Series- Shunt Controller (Coordinated)

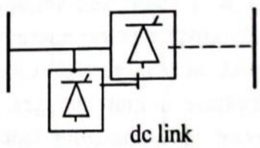

Fig. 5 Series- Shunt Controller (Unified)

D. Series-series controller

The series-series controller can be of two configurations as shown in fig. (6 and 7). They are series-series controller (Unified) and series-series controller (coordinated). The series-series controller (coordinated) will be used in the multi-line power transmission system whereas the series-series controller (unified) will provide series reactive compensation to individual lines and also transfer real power in the lines through DC power link. The series-series controller (unified) is referred to as IPFC ie. Interline power flow controller during the real power transfer. Unified power flow means that the connection of all DC terminals of the converters together joined for the purpose of real power transfer.

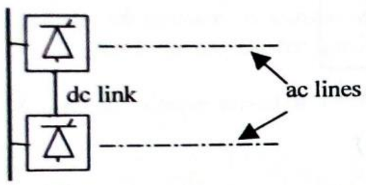

Fig.6 Series –Series controller (unified)

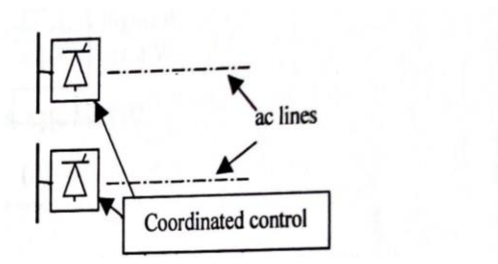

Fig.7 Series –Series controller (Coordinated)

III. POWER SYSTEM FACTS DEVICES

There are many FACTS devices are used in the power system for the purpose of real and reactive power flow in the power transmission system.

A. Static compensator (STATCOM):

The synchronous motor can be operated at different power factor such as leading and lagging power factor by adjusting the excitation of the field winding of the motor. Over excited synchronous motor will provide leading current or capacitive current whereas under excited synchronous motor will provide lagging current or inductive current. The static compensator means that the operation of synchronous motor as leading/lagging power factor device and connected in parallel to the system in which the compensation of real and reactive power is needed. So the synchronous motor can act as a voltage source /current source converter and the representation of the same have been shown in the below figure 8a &b. The STATCOM [9] not only control the reactive power flow but also can be designed to control/maintain the system harmonics.

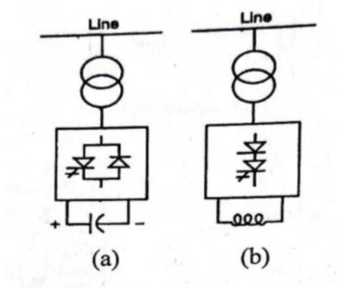

Fig. (8a) STATCOM Voltage Source Converters
Fig. (8b) STATCOM Current Source Converters

B. Static Synchronous Generator (SSG)

It is the power converter supplied from a battery/ a large DC storage capacitor.[5] It will provide multi phase output voltage on need basis. This is used for real and reactive power flow control in the power transmission and power system optimal power flow control. A simple model of the static synchronous generator is shown in figure 9.

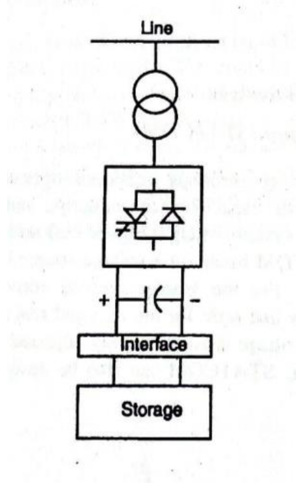

Fig.9 Static Synchronous generator (SSG)

C. Static VAR Compensation (SVC)

The SVC system can exchange the inductive and capacitive current in the power transmission system for the purpose of control/maintain the real and reactive power flows in the power system. [8]The SVC is power electronics based thyrister (SCR) with no ON/OFF of the gate signal. The system arrangement will have separate devices for leading and lagging VAR. The cost of SVC is comparatively very less than that of STATCOM. The below shown figure number 10 is the representation of the simple model of the SVC.

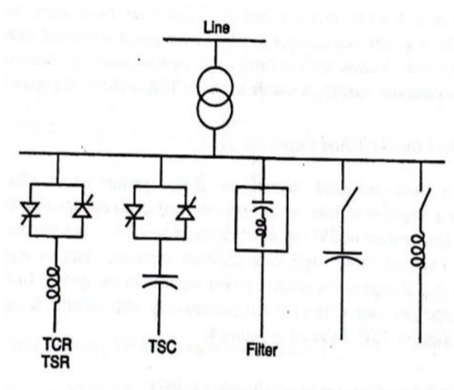

Fig.10 Representation of the simple model of the SVC

D. TCR, TSR, and TSC:

The TCR (Thyristor Controlled Reactor), [8] TSR (Thyristor Switched Reactor), and TSC (Thyristor Switched Capacitor) are part of SVC and are connected in parallel to the line in which the power flow control is needed. In TCR and TSR the reactor of the inductor will be adjusted by thyristor firing angle adjustment whereas in TSC the reactance of the capacitor is adjusted. The TCR is based on the firing angle control of the thyristors gate pulses whereas the TSR and TSC will ON/OFF the many number of thyristors connected in the system for the purpose of the power flow control. The representation of the TCR, TSR, and TSC are having been shown in the fig.10.

E. TCSR and TSSR:

The TCSR (Thyritor Controlled Series Reactor is a series inductor bank with which a parallel TCR (Thyritor controlled reactor) will be connected to provide variable reactive inductance in order to improve the VAR. The TSSR (Thyritor Switch Series Inductor will also have a series inductor bank with a parallel connected thyritors to provide stepwise control by simply ON/OFF of the thyritors and the firing angle of the thyritors will not be adjusted. The representation of TCSR and TSSR will be remaining same as shown in the fig. 11. The only difference between them is that in TCSR the firing angle will be varied whereas in the TSSR the ON/OFF of the thyritors will takes place.

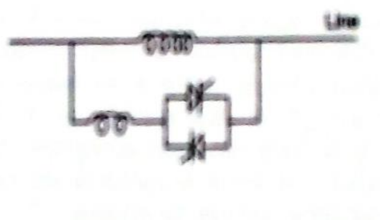

Fig.11 TCSR and TSSR

F. TCSC and TSSC:

The TCSC (Thyritor Controlled Series Capacitor is a series capacitor bank with which a parallel TCR (Thyritor controlled reactor) will be connected to provide variable reactive capacitance in order to improve the VAR. The TSSC [9] (Thyritor Switch Series Capacitor will also have a series capacitor bank with a parallel connected thyritors to provide stepwise control by simply ON/OFF of the thyritors and the firing angle of the thyritors will not be adjusted. The representation of TCSC and TSSC will be remaining same as shown in the fig. 12. The only difference between them is that in TCSC the firing angle will be varied whereas in the TSSC the ON/OFF of the thyritors will takes place.

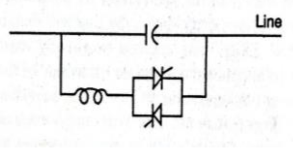

Fig.12 TCSC and TSSC

G. Thyrister Controlled phase Shift Transformer (TCPST):

The transformer not only used for stepping up and down of the voltage level but also to provide proper phase shift in the power system. So, the Thyristor Controlled Phase Shift Transformer (TCPST) [6] is one of the phase shift transformer and will be adjusted by the thyristor switches in order to provide variable phase angle for the power flow control in the power transmission line. The TCPST can also be referred to as TCPAR (Thyristor Controlled Phase Angle Regulator. The switching of thyristor will provide voltage which will be added in series to the power transmission line to provide a phase shift of φ. The fig.13 shows the representation of TCPST.

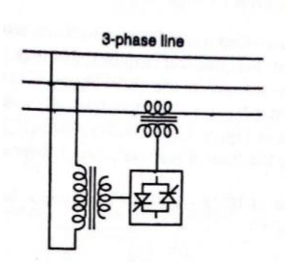

Fig.13 Representation of TCPST

H. Thyrister Controlled Voltage Regulator (TCVR):

The conventional tap changing transformer is one of the voltage regulators because by varying tapping position the voltage can be varied. The TCVR (Thyrister Controlled Voltage Regulator) is like a tap changing transformer controlled by thyristor switching. For the voltage regulation purpose the arrangement in the TCPST can also be used to provide series voltage to the line. The TCVR based on tap change and based on TCPST have been shown in fig.14

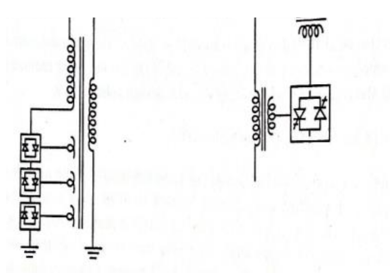

Fig.14 TCVR based on tap change & TCPST

I. Unified Power Flow Controller (UPFC):

In the UPFC arrangement there will be a two transformer namely shunt exciting transformer (connected in parallel to the line with a STATCOM), and a series boosting transformer (connected in series with the power transmission line with a

SSSC). The both STATCOM and SSSC are consists of two anti parallel GTO's and both are linked with a capacitor as a DC link. The main purpose of SSSC is to provide voltage to the line and thus SSSC provide series compensation. The STATCOM will provide real power to the SSSC through the DC link. The STATCOM can also generate/absorb reactive power from the line. This reactive power absorption/generation will not affect the real power flow transfer to the SSSC from the STATCOM. So, the UPFC provide VAR compensation through the STATCOM and voltage boost up through the SSSC. The general representation of the UPFC [4] [7] arrangement have been shown in the fig.15

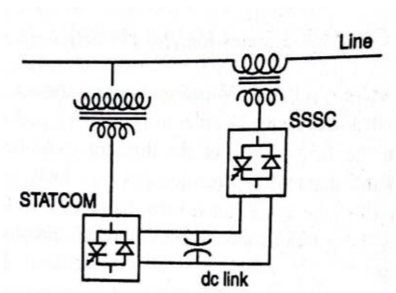

Fig.15 Unified Power Flow Controller (UPFC)

IV. COMPARISON AND CONTROL ATTRIBUTES OF FACTS CONTROLLERS AND DEVICES

A. Comparison between STATCOM and SVC:

The STATCOM is acting as a voltage source the value of which can be reactance whereas SVC is act as a variable susceptance. The SVC is very sensitive to the system harmonic resonance whereas STATCOM is insensitive. The STATCOM have very large dynamic range responses but SVC is limited with small range dynamic response. SVC has very low performance while compare with STATCOM. The STATCOM have inductive /capacitive operative region whereas the SVC only has capacitive operative region.

B. FACTS controllers control attributes:

The control attributes of STATCOM are voltage control, VAR compensation, damping oscillation & stability of the power system. Similarly the SVC, TCR, TSC and TSR have the control attributes of reactive power compensation, voltage regulation, voltage stability and transient and dynamics stability. The SSSC, TCSC, TSSC, TCSR and TSSR will have control attributes of voltage stability, current control, dynamic and transient stability and fault current limit. The TCPST and TCPAR has the control attributes of damping oscillations, watt control and voltage stability. The UPFC can used to control watt and VAR, voltage stability of the system.

V. CONCLUSION

In this paper discussion have been done about the various FACTS Controllers such as shunt controller, series controller, shunt-series controller, and series- series controller in details along with diagram. And also discussion was done in brief about the different types of FACTS devices namely Static compensator (STATCOM, Static synchronous generator (SSG), Static VAR compensator (SVC), TCR, TSR, TSC, TCSC, TSSC, TCSR, TSSR, TCPST, TCVR, and UPFC. This paper give an over view about the FACTS controllers and FACTS devices used in power system for the real and reactive power flow control.. This paper would be very beneficial to those who are doing research in the FACTS application tio the power system engineering.

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