Improvement In Power System Transient Stability with an Off-Centre Location Using Shunt FACTS Devices

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Abstract — *This paper presents various facts related to the landmark development: practical installations, benefits and application of Shunt Flexible AC Transmission System (FACTS) controllers in the electric utilities. FACTS devices, when placed at the mid-point of a long transmission line, play an important role in controlling the reactive power flow to power network and hence both the system voltage fluctuations and transient stability. This paper also deals with the location of a shunt FACTS device to improve transient stability in a long transmission line with predefined direction of real power flow. The validity of the mid-point location of shunt FACTS devices is verified, with different shunt FACTS devices, namely static VAR compensator (SVC) and static synchronous compensator (STATCOM) in a long transmission line using the actual line model. It has been observed that the FACTS devices, when placed slightly off-centre towards sending-end, give better performance in improving transient stability and the location depends on the amount of local/through load.*

Key words: - FACTS, SVC, STATCOM

I. INTRODUCTION

The AC transmission system has various limits classified as static limits and dynamic limits [1-3]. These inherent power system limits restrict the power transaction, which lead to the under utilization of the existing transmission resources. Traditionally, fixed or mechanically switched shunt and series capacitors, reactors and synchronous generators were being used to solve much of the problem. However, there are restrictions as to the use of these conventional devices. Desired performance was not being able to achieve effectively. Wear and tear in the mechanical components and slow response were the heart of the problems. There was greater need for the alternative technology made of solid state devices with fast response characteristics. The need was further fuelled by worldwide restructuring of electric utilities, increasing environmental and efficiency regulations and difficulty in getting permit and right of way for the construction of overhead transmission lines [4]. This, together with the invention of Thyristor switch (semiconductor device), opened the door for the development of power electronics devices known as Flexible AC Transmission Systems (FACTS) controllers. The path from historical Thyristor based FACTS controllers to modern state-of-the-art voltage source converters based FACTS controllers, was made possible due to rapid advances in high power semiconductors devices [1-3]. SVC and STATCOM are members of FACTS family that are connected in shunt with the system. Even though the primary purpose of shunt FACTS devices is to support bus voltage by injecting (or absorbing) reactive power, they are also capable of improving the transient stability by increasing (decreasing) the power transfer capability when the machine angle increases (decreases), which is achieved by operating the shunt FACTS devices in capacitive (inductive) mode.

There are consists of the comparison of various results found for the different locations of shunt FACTS device in a long transmission line considering the actual models of the line for a transient stability study. Computer simulation results under a severe disturbance condition (three phase fault) for different fault clearing times and different locations of FACTS devices are analyzed. It is shown that for the actual long transmission line model with a predefined direction of real power flow, shunt FACTS device needs to be located slightly off-centre.

II. BASIC TYPES OF FACTS CONTROLLERS

1) *Series Controllers:*

The series controller could be variable impedance, such as capacitor, reactor etc., or a power electronic based variable source of main frequency, sub-synchronous and harmonic frequencies to serve the desired need. In principle, all series controllers inject voltage in series with the line. (fig.1)

Fig. 1 Series Controllers

2) *Shunt Controllers:*

As in case of series controllers, the shunt controllers may be variable impedance, variable source, or a combination of these. In principle, all shunt controllers inject current into the system at the point of connection. The shunt controllers may be variable impedance connected to the line voltage causes a variable current flow hence represents injection of current into the line. (fig.2)

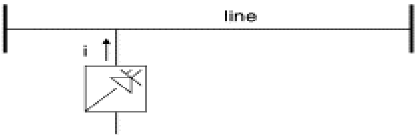

Fig. 2 Shunt Controllers

3) Combined Series-Series Controllers:

This could be combination of separate series controllers or unified series-series controller refers to Interline Power Flow Controller. (fig.3)

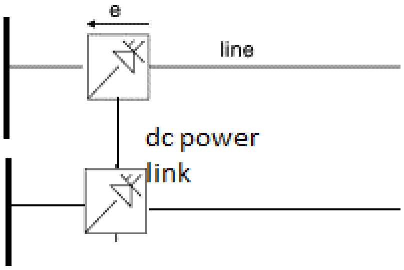

Fig. 3 Combined Series-Series Controllers

4) Combined Series-Shunt Controllers:

This could be a combination of separated series and shunt controllers or a unified power flow controller with series and shunt elements. In principle, combined shunt and series controllers inject current into the system with the shunt part of the controllers and voltage in series, in the line with the series part of the controller. (fig.4)

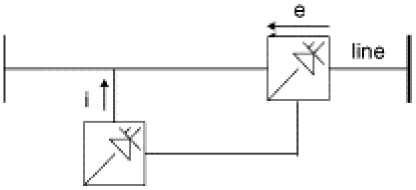

Fig. 4 Combined Series-Shunt Controllers

III. SHUNT FACTS DEVICES

They are classified into two categories namely variable impedance type (SVC) and switching converter type (STATCOM).

1) STATCOM

A static synchronous compensator (STATCOM), also known as a "static synchronous condenser" ("STATCON"), is a regulating device used on alternating current electricity transmission networks.

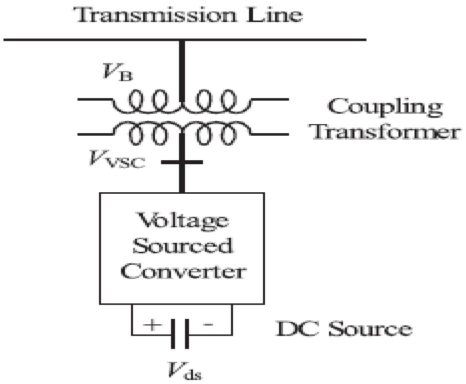

Fig. 5 STATCOM

It is based on a power electronics voltage source converter and can act as either a source or sink of reactive AC power to an electricity network. If connected to a source of power it can also provide active AC power. It is a member of the FACTS family of devices.

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 configuration of a STATCOM is shown in Fig. 5 Basically it consists of a voltage source converter (VSC), a coupling transformer and a dc capacitor. Control of reactive current and hence the susceptance presented to power system is possible by variation of the magnitude of output voltage (VVSC) with respect to bus voltage (VB) and thus operating the STATCOM in inductive region or capacitive region.

Usually a STATCOM is installed to support electricity networks that have a poor power factor and often poor voltage regulation. There are however, other uses, the most common use is for voltage stability. A STATCOM is a voltage source converter (VSC)-based device, with the voltage source behind a reactor. The voltage source is created from a DC capacitor and therefore a STATCOM has very little active power capability. However, its active power capability can be increased if a suitable energy storage device is connected across the DC capacitor. The reactive power at the terminals of the STATCOM depends on the amplitude of the voltage source. For example, if the terminal voltage of the VSC is higher than the AC voltage at the point of connection, the STATCOM generates reactive current; on the other hand, when the amplitude of the voltage source is lower than the AC voltage, it absorbs reactive power.

2) SVC

A Static Var Compensator (or SVC) is an electrical device for providing fast acting reactive power on high-voltage electricity transmission networks. SVCs are part of the Flexible AC transmission system device family, regulating voltage and 236tabilizing the system. The term “static” refers to the fact that the SVC has no moving parts (other than circuit breakers and disconnects, which do not move under normal SVC operation), unlike the Synchronous condenser, which is a rotating electrical machine. Prior to the invention of the SVC, power factor compensation was the preserve of large rotating machines such as synchronous condensers

The SVC is an automated impedance matching device, designed to bring the system closer to unity power factor. SVCs are used in two main situations:

i) Connected to the power system, to regulate the transmission voltage ("Transmission SVC")

ii) Connected near large industrial loads, to improve power quality ("Industrial SVC")

In transmission applications, the SVC is used to regulate the grid voltage. If the power system's reactive load is capacitive (leading), the SVC will use reactors (usually in the form of Thyristor-Controlled Reactors) to consume vars from the system, lowering the system voltage. Under inductive (lagging) conditions, the capacitor banks are automatically switched in, thus providing a higher system voltage.

The SVC uses conventional thyristors to achieve fast control of shunt connected capacitors and reactors. The configuration of the SVC is shown in Fig.7 which basically consists of a fixed capacitor © and a thyristor controlled reactor (L). The firing angle control of the thyristor banks determines the equivalent shunt admittance presented to the power system.

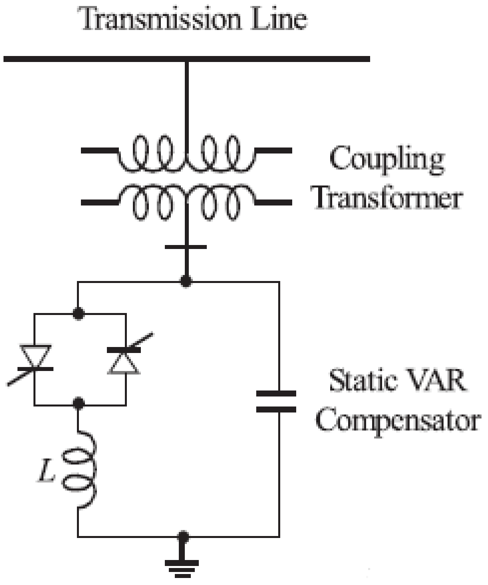

Fig. 6 SVC

IV. TWO AREA SYSTEM WITH SHUNT FACTS DEVICES

Consider a two area system (area 1 & area 2), connected by a single circuit long transmission line as shown in Fig.8 (a) The direction of real power flow is from area 1 to area 2. The transmission line is divided in two sections (section 1 and section 2) and 's' is the fraction of line length at which the FACTS device is placed.

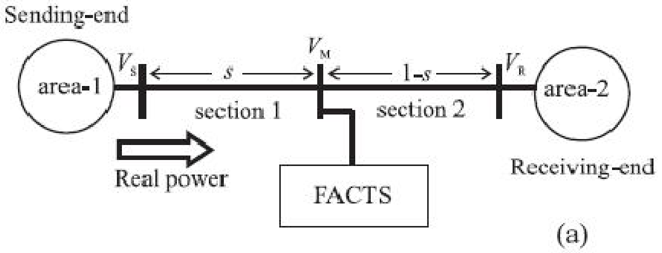

Fig.7 Two area system with shunt FACTS device

For a long transmission line of length l, having a series impedance of z ohm/km and shunt admittance of y mho/km, the relationship between the sending-end and receiving-end quantities with A, B, C, D constants of the line can be written as:

$$V_S = AV_R + BI_R \qquad (1)$$

$$I_S = CV_R + DI_R \qquad (2)$$

For the simplified model, where the line resistance and capacitance are neglected, both sending end power (P_S) and receiving end power (P_R) become maximum at power angle $\delta = 90$. When a shunt FACTS device is connected to a long line to increase the power transfer capability, the above simplifications may provide erroneous results.

The active power flows at the sending end and receiving end for a long transmission line with distributed parameters can be written as

$$P_S = K_1 \cos(\theta_B - \theta_A) - \cos(\theta_B + \delta) \qquad (3)$$

$$P_R = K_2 \cos(\theta_B - \delta) - K_3 \cos(\theta_B - \theta_A) \qquad (4)$$

Where

$K_1 = AV_S^2 / B$, $K_2 = AV_SV_R / B$, $K_3 = AV_R / B$

$A = |A|\angle\theta_A$, $B = |B|\angle\theta_B$, $V_R = |V_R|\angle 0$, $V_S = |V_S|\angle\delta$

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It is clear from Eqn. 4 that the receiving end power PR reaches the maximum value when the angle δ becomes θ_B. However, the sending end power PS of Eqn. 3 becomes maximum at $\delta = (180 - \theta_B)$.

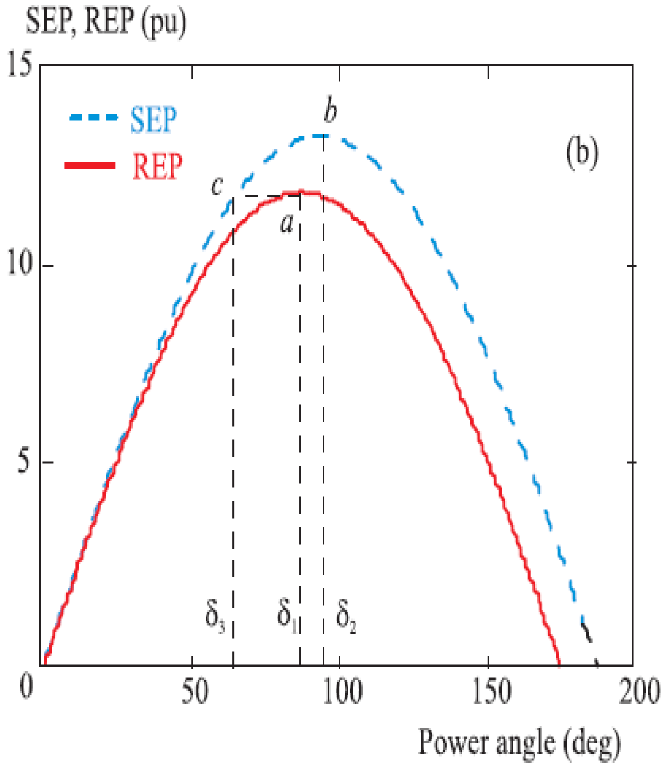

Fig.8 Sending-end and receiving-end power angle characteristics using actual line model

The power-angle characteristic of the line using the actual line model without FACTS device is shown in Fig.8. It also represents the power angle characteristics of both line sections, if a large rating shunt FACTS device capable of maintaining the voltage constant is placed at the centre. Assuming that the FACTS device does not absorb or deliver any active power, the receiving end power of section 1 must be equal to the sending end power of section 2. If section 1 delivers the maximum power at its receiving end (point a), the corresponding sending end power of section 2 can be represented by the same power level (point c) and the total transmission angle at the maximum power point is $\delta = \delta_1 + \delta_3$ Thus, the maximum power transfer capability of the system is limited by the maximum receiving end power of section 1.

The shape of the power angle curve depends on the line length or fraction‘s’. For lower values of s, the maximum receiving end power of section 1 increases, while the maximum sending end power of section 2 decreases. Thus point a in Fig. 8 moves upwards and point b goes downwards. Both of the powers will be equal at a value s < 0.5 because of the losses in the line.

In this result, the effectiveness of shunt FACTS devices has been studied in improving the transient stability of a sample two-area power system with different locations of these devices in the transmission line. It also shows that when there is a pre-defined direction of real power flow, the shunt FACTS devices need to be placed slightly off-centre towards the sending end for maximum benefit from the stability point of view. The optimal location of these devices also depends on the amount of local load and through load and it is seen that as the amount of local load increases the optimal location, from the transient stability point of view, moves towards the sending-end.

V. CONCLUSION

Previous works on the topic prove that shunt FACTS devices give maximum benefit from their stabilized voltage support when sited at the mid-point of the transmission line. The proof of maximum increase in power transfer capability is based on the simplified model of the line neglecting line resistance and capacitance. However, for long transmission lines, when the actual model of the line is considered, the results may deviate significantly from those found for the simplified model. In this work, the effectiveness of shunt FACTS devices has been studied in improving the transient stability of a sample two-area power system with different locations of these devices in the transmission line. It also shows that when there is a pre-defined direction of real power flow, the shunt FACTS devices need to be placed slightly off-centre towards the sending end for maximum benefit from the stability point of view. The optimal location of these devices also depends on the amount of local load and through load and it is seen that as the amount of local load increases the optimal location, from the transient stability point of view, moves towards the sending-end.

REFERENCES

[1] N. G. Hingorani and L. Gyugyi, “Understanding FACTS”, IEEE Press, 1999.
[2] Y. H. Song and A. T. Johns, “Flexible AC Transmission System (FACTS)”, IEE Power and Energy Series 30, 1999.
[3] “FACTS Application”, IEEE Power Engineering Society, FACTS Application Task
[4] John J. Paserba, “How FACTS Controllers Benefit AC Transmission Systems”, IEEE Power Engineering Society General Meting, Denver, Colorado, 6-10 June 2004.
[5] Sidhartha Panda, Ramnarayan N.Patel “Improving Power System Transient Stability With An Off– Centre Location Of Shunt Facts Devices” Journal of Electrical Engineering, VOL. 57, NO. 6, 2006, 365–368
[6] Wenjuan Zhang, Student Member IEEE, Fangxing Li, Senior Member, IEEE, Leon M. Tolbert, Senior Member, IEEE “Optimal Allocation Of Shunt Dynamic Var Source Svc And Statcom”
[7] GYUGYI, L.: Power Electronics in Electric Utilities: Static Var Compensators, Proceedings of IEEE 76 No. 4 (April 1988), 483–494.
[8] KAZERANI, M.MARCEAU, R.WOLANSKI, Z.GALIANA, F. D.MCGILLS, D.JOOS, G.: Mid-Point Siting of FACTS Devices in Transmission Lines, IEEE Trans. on Power Delv. 12 No. 4 (Oct. 1997), 17171722.
[9] HINGORANI, N. G.—GYUGYI, L.: Understanding FACTS:Concepts and Technology of Flexible AC Transmission System,IEEE PRESS, 2000.Pg. 1-20
[10] H. SAADAT, H.: Power System Analysis, Tata McGraw-Hill, 2002.