Improvement In Power Transmission Capability By Using FACTS Devices

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Abstract — *In this paper contains the study of Flexible AC Transmission System (FACTS) equipment operation in transmission systems. In the present scenario the demand for electrical energy has increased manifold. This has led to the facing of power transmission limitation crisis by energy transmission systems. The limitations occur due to maintaining a balance between supplying the allowed level of voltage and maintaining stability of the system. Due to the power crisis the FACTS devices play a crucial role in the present scenario. In energy transmission systems FACTS are effective equipments on power control. They help facilitating the improvement in power transmission capability while minimising the transmission losses and impact on the environment. They also aid in the improvement of power quality while maintaining the stability of the system*.

Key words

Power quality, Compensation, Transmission systems, SVC, STATCOM, TCSC, SSSC, UPFC

I. INTRODUCTION

Modern bulk power systems cover large geographic areas, and have a large number of load buses and generators. Additionally, available generating plants are often not situated near load centers and power must consequently be transmitted over long distances. To meet the load and electric market demands, new lines should be added to the system, but due to environmental reasons, the installation of electric power transmission lines must often be restricted. Hence, the utilities are forced to rely on already existing infra-structure instead of building new transmission lines. In order to maximize the efficiency of generation, transmission and distribution of electric power, the transmission networks are very often pushed to their physical limits, where outage of lines or other equipment could result in the rapid failure of the entire system. With such increasing stress on the existing transmission lines the use of Flexible AC Transmission Systems (FACTS) devices becomes an important and effective option. Facts technology opens up new opportunities for controlling power and enhancing the usable capacities of present, as well as new and upgraded lines, the possibility that current through a line can be controlled at a reasonable cost enables large potential of increasing the capacity of existing lines with large conductors.

In an interconnected transmission network, power flow control is a key problem in designing and operating. Requirement of interconnected networks, unforeseen increase of load demands, limitations on installation of power plant in appropriate places and limitations on building new transmission lines are the factors that lead to such problems. The employment of FACTS devices in transmission lines becomes necessary owing to reasons like over loaded transmission lines in special paths, power flow in unwanted paths, and non-optimal operation of line capacity.

Flexible AC transmission system (FACTS) devices can be able to provide rapid active and reactive power compensations to power systems, and therefore can be used to provide voltage support and power flow control, increase transient stability and improve power oscillation damping. Suitably located FACTS devices allow more efficient utilization of existing transmission networks.

II. CLASSIFICATION OF FACTS

FACTS technology consists of high power electronics based equipment with its real-time operating control. There are two groups of FACTS controllers based on different technical approaches, both resulting in controllers able to solve transmission problems.

The first group employs reactive impedances or tap-changing transformers with thyristor switches as controlled elements; the second group employs self-commutated voltage-sourced switching converters. The sophisticate control and fast response are common for both groups. The Static VAr Compensator (SVC), Thyristor Controlled Series Capacitor

(TCSC) and Phase Shifter, belong to the first group of controllers while Static Synchronous Compensators (STATCOM), Static Synchronous Series Compensators (SSSC), Unified Power Flow Controllers (UPFC) and Interline Power Flow Controllers (IPFC) belong to the other group.
Basically the FACTS controllers are four types:-

1) *Series Controller*
2) *Shunt controller*
3) *Combined Series - Series Controller*
4) *Combined Series - Shunt Controller*

Among the FACTS family, the shunt FACTS devices such as the static synchronous compensator (STATCOM) has been widely used to provide smooth and rapid steady state and transient voltage control at points in the network. The application of a STATCOM on a wind farm equipped with doubly fed induction generators (DFIGs) to ride through grid disturbances in a single machine infinite bus (SMIB) system have been investigated in.
Series FACTS devices, such as the static synchronous series compensator (SSSC), on the other hand, can regulate the flow of active and reactive power by injecting a controllable capacitive or inductive impedance compensation into a line at the point of connection. In addition, with a suitably designed damping controller, the SSSC has an excellent performance in damping low frequency power oscillations in a power network.

III. TRANSMISSION LINE ABCD MODEL

In this paper, the transmission line is modeled by a two-port, four terminal networks as shown.

Figure 1. Two port four terminal model of a transmission line.

Transmission lines are operated with a balanced three phase load; the analysis can therefore proceed on a per phase basis. A transmission line on a per phase basis can be regarded as a two port network, wherein the sending end voltage V_s and current I_s are related to the receiving end voltage V_r and current I_r through ABCD constants as

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

$$I_S = CV_R + BI_R \quad (2)$$

The ABCD constants of a line of length l, having a series impedance of z Ω/km and shunt admittance of y S/km are given by

$$A=D=\cosh(\gamma\ l) \qquad B=Z_c \sinh(\gamma\ l)$$

$$C=\sinh(\gamma\ l)$$

$$Z_C = \sqrt{\frac{z}{y}} \qquad \gamma = \sqrt{zy}$$

Where,

Z_C = Characteristic impedance of the line
γ=propagation constant of the line
z=series impedance/unit length/phase
y=shunt admittance/unit length/phase to neutral
l =transmission line length
α =attenuation constant
β =phase constant

A. Power flow through a tranamission line for a actual line model

The principle of power flow through a transmission line is illustrated through a single transmission line (2-node/2-bus system).
Let us consider receiving-end voltage as a reference phasor (│Vs│∠0) and let the sending end voltage lead it by an angle δ is known as the torque angle.

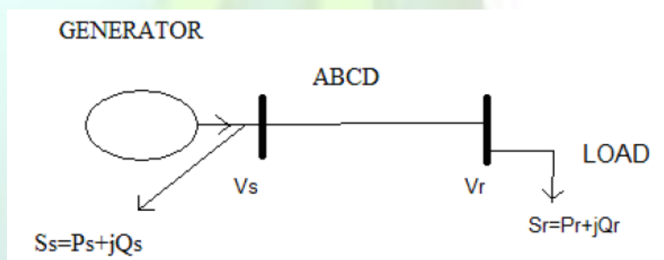

Figure 2 A Two bus system

The complex power leaving the receiving end and entering the sending-end of the transmission line can be expressed as

$$S_r = P_r + jQ_r = V_r I^*_r \quad (3)$$

$$S_S = P_S + jQ_S = V_S I_S \quad (4)$$

Receiving and sending end currents can be expressed in terms of receiving and sending end voltages.

$$I_r = \left|\frac{1}{B}\right| |V_s| \angle(\delta - \beta) - \left|\frac{A}{B}\right| |V_r| \angle(\alpha - \beta) \quad (5)$$

$$I_s = \left|\frac{D}{B}\right| |V_s| \angle(\alpha + \delta - \beta) - \left|\frac{1}{B}\right| |V_r| \angle - \beta \quad (6)$$

We can write the real and reactive powers at the receiving-end and the sending end as

$$P_S = C_1 \cos(\beta - \alpha) - C_2 \cos(\beta + \delta) \qquad (7)$$

$$P_R = C_2 \cos(\beta - \delta) - C_3 \cos(\beta - \alpha) \qquad (8)$$

$$Q_S = C_1 \sin(\beta - \alpha) - C_2 \sin(\beta + \delta) \qquad (9)$$

$$Q = C_2 \sin(\beta - \delta) - C_3 \sin(\beta + \delta) \qquad (10)$$

IV. POWER FLOW IN A TRANSMISSION LINE AFTER USING FACTS DEVICE

A. *Shunt FACTS devices in a power system*

Consider that the line is transferring power from a large generating station to an infinite bus and equipped with a shunt FACTS device at point m. a parameter k is used to show the fraction of line length at which the FACTS device is placed.

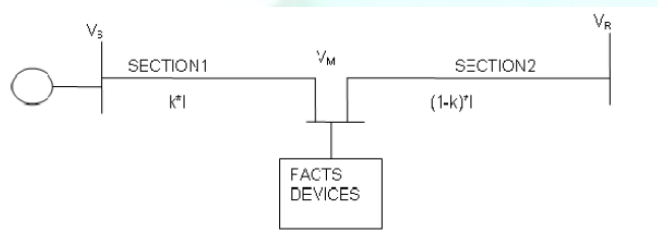

Figure 3 Transmission Line with the FACTS device.

1) *For a Simplified Model*

The power transfer through the line for given values of SE and RE voltage magnitude is given by eq. (15) and can be written as

$$P = P_m \sin \delta$$

Here the maximum power P is $\frac{Vs\ Vr}{X}$

When a shunt FACTS device is connected to the line both P_m and δ_m are increased and their values depend on the k factor. The power transfer through the line is then given by

$$P = \frac{V_S V_m}{kX_L} \sin \delta_S = \frac{V_R V_m}{(1-k)X_L} \sin \delta_R \qquad (11)$$

Here the SE power is equal to the RE power because the line is loss less.

$$\mathrm{P} = \frac{P_0 \sin \delta_S}{k} = \frac{P_0 \sin \delta_R}{1-k} \qquad (12)$$

2) *For Actual Lline Model*

The ABCD constants of a line of length l, having a series impedance of z ohms/km and shunt admittance of y S/km with FACTS devices the active and reactive power flows at the S_E and RE of the line can be shown in the table

Table1 SE and RE real and reactive power with the shunt FACTS Devices

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Section1	Section2
Ps=C1cos(β-α)-C2cos(β+δs)	Ps=C1cos(β-α)-C2cos(β+δR)
Qs=C1sin(β-α)-C2sin(β+δs)	Qs=C1sin(β-α)-C2sin(β+ δR)
Pr=C2cos(β-δs)-C3cos(β-α)	Pr=C2cos(β- δR)-C3cos(β-α)
Qr=C2sin(β-δs)-C3sin(β-α)	Qr=C2sin(β- δR)-C3sin(β-α)

V. RESULTS AND DISCUSSIONS

A. *CASE STUDY -1*

A 345KV, single circuit transmission line of length 450 KM is considered. The series and shunt admittance of the line is z = (.02986+j.2849) ohms/km and y=(j3.989*10^-6) S/KM respectively, at 50Hz.The results of the line is presented in p.u. on a 100MVA, 345KV base. Here $V_S = V_R = V_M = 1.0$ p.u. is used.

The various parameters of this line are calculated and are presented as follows:

Table 2 Values of various parameters of the line

VARIABLE	VALUES
A	0.8871+0.0116i
B	0.0104 + 0.1037i
C	-0.0084 + 2.0555i
D	0.8871+0.0116i
A	0.013
β	1.4705
γ	0.0001 + 0.0011i
δ	0
Ps	0.0022
Pr	-0.0022
Qs	-1.0892
Qr	1.0892

A MATLAB program is written to determine the various characteristics of the system. In all cases $V_S = V_R = V_M = 1.0$ p.u. is used. Figure 3 show the maximum power Pm and the corresponding angle δ m are determined for various values of k and a graph is plotted.

From the graph it is seen that it is observed that the maximum SE power is equal to the max RE power because the line is lossless. The maximum power

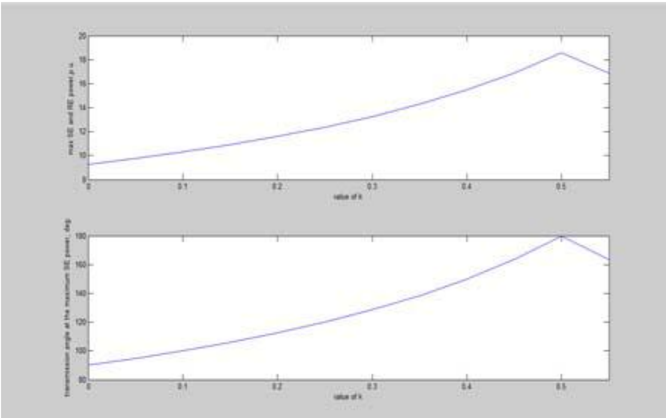

Figure 4 Variation of SE and RE power and transmission angle for the simplified Model

increases from 9.3 p.u. (for k=0) to double the value i.e. 18.6 p.u. (for k=0.5) and then decreases, Angle δ m at max. SE power increases from 90° (at k=0) to 180° (at k=0.5) and then decreases.

It is clear from eq. (4) that the RE power PR reaches the maximum value when the angle δ becomes β.

However, the SE power PS of eq. (3) becomes maximum at δ = (π - β). The maximum power flow for actual line model is given by equations

$$P_S = C_1 \cos(\beta - \alpha) + C_2 \quad (13)$$

$$P_R = C_2 - C_3 \cos(\beta - \alpha) \quad (14)$$

Using the above equations a graph is plotted for the variation of maximum sending end and receiving end power with different values of k.

If the maximum receiving end power of section 1 is greater than the maximum sending end power of section 2 then the max. SE power of section 2 is plotted and viceversa

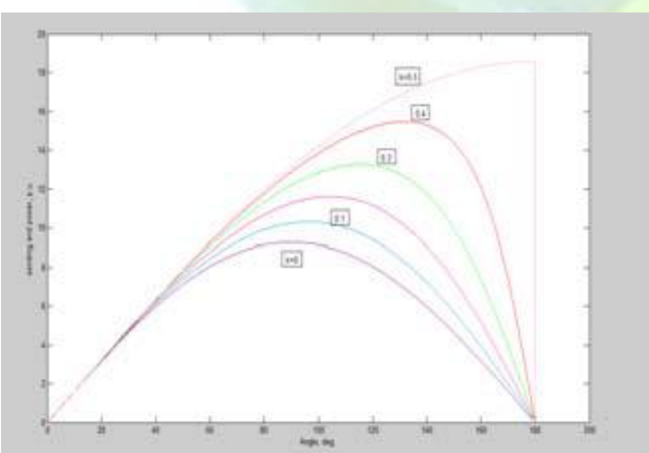

Figure 5 Power Angle characteristics for the simplified model

The maximum transmission angle corresponding to the maximum SE power is also plotted for different values of k.

Hence the sum of the value of δ s corresponding to the maximum value of P in the long section and δ_R at which maximum power occurs gives the maximum δ for the whole line.

The inverse of the sine term are multiple valued, each having two values in the range of δ from 0 to π.

The only way in which δ can increase and be a continuous function of P is to go up one branch and down the other of the lower sinusoid and at the same time go up and down the same (left-hand) branch of the taller sinusoid.

VI. CONCLUSIONS

The results found in this paper would be useful in selecting the best location for various shunt FACTS devices to get the highest possible benefit when the pattern of power flow of the line is known. It is also found that some of the results obtained or conclusions made for the simplified line model are not valid for the actual line model, especially when the FACTS device is placed at the midpoint.

In the future, FACTS devices could be installed on a wide scale by electrical utilities in an attempt to control the power flows through their networks. It is also recognized as a viable solution for controlling transmission voltage, power flow, and dynamic response.

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