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Comparative study of Enhanced Power Flow Controller and TCSC

VivekKumar[1], Ashish Jaiswal[2], Dheeraj Kumar Dhaked[3], Yatindra Gopal[4]

[1]Research Scholar, Rajasthan institute of Engineering & Technology, Jaipur, India.
[2]Asst. Professor, Rajasthan institute of Engineering & Technology, Jaipur, India.
[3]Asst. Professor, SS College of Engineering, Udaipur, India.
[4]Ph.d Research Scholar, University College of Engineering, Kota, India.

Abstract

Flexible AC Transmission System (FACTS) controllers are based on technology which provides better control, reliability, system stability; power transfer capability for transmission network by using power electronics (PE) based switches. Their high capital cost and reliability problems have limited the use of FACTS controllers in smart grid systems. In recent times, a new approach of Distributed-FACTS (D-FACTS) was known as anew methodology to recognize cost-effective power flow control through multiple modules, small in size, fixed series impedance injections in power transmission network. These small D-FACTS controllers are distributed over whole transmission line as modules at every small short span of length which are mounted on the transmission line.D-FACTScontrollers can dynamically and statically change the impedance of the connected transmission line to control the power flow. A new D-FACTS device Enhanced Power Flow Controller (EPFC), which is distributed version of Thyristor Controlled Series Compensator (TCSC) FACTS controller, has been analysed on MATLAB model and the results are compared with conventional TCSC controller. The comparative results are shown in the manuscriptafter MATLAB simulation which concludes that D-FACTS are more beneficial to use.

Keywords: Power Flow Control, FACTS controller, D-FACTS, TCSC, EPFC.

INTRODUCTION

The control of power system is becoming complex day by day and there is continuous requirements are coming for secured, stable, economic, controlled and quality of power supply. Due to the various factors such as thermal limit, steady state stability limit, transient stability limit and system damping or negative damping. To get stable oscillation free power the electrical damping of power system is requires to be mitigated. The FACTS and D-FACTS require providing cost-effective and feasible solution to these problems and required to be used worldwide to enhance the stability and performance of power system.The different stability limits scenarios of magnitudes are shown in the **Figure** 1 [1-3].

To control the power flow in power system the FACTS comprises the PE controllers and devices. This paper discusses about the comparison of TCSC and distributed version of TCSC, known as EPFC that uses multiple low power single phase converters that connects to transmission line conductor directly. The EPFC dynamically and statically controls the impedance of transmission line and allows the active power flow control on the transmission line [4-5].

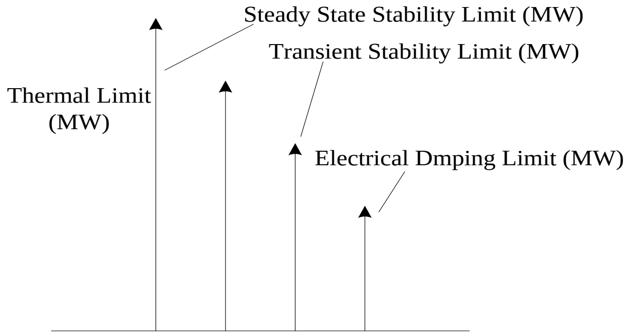

Figure 1. Different stability limits scenarios of magnitudes

THYRISTOR CONTROLLED SERIES COMPENSATOR

A capacitive reactance compensator which contains a series capacitor bank shunted by a thyristor controlled (TCR) reactor in order to provide a smoothly variable series capacitive reactance.

The TCSC is based on thyristors without the gate turn off capability. A TCR which is an variable reactor is connected across a series capacitor. When the TCR firing angle is 180 degrees, the reactor becomes non-conducting and the series capacitor has its normal impedance. As the firing angle forward looking from 180 degrees to less than 180 degrees, the capacitive impedance goes up. At the other end, the reactor becomes entirely conducting when the TCR firing angle is 90 degrees, and the total impedance turn out to be inductive, because the reactor impedance is designed to be much lower than the series capacitor impedance. With 90 degrees firing angle, the TCSC helps in limiting fault current. The TCSC may be a single, large unit, or may consist of numerous equal or different-sized small capacitors (for low cost) in order to achieve a higher enactment [6].

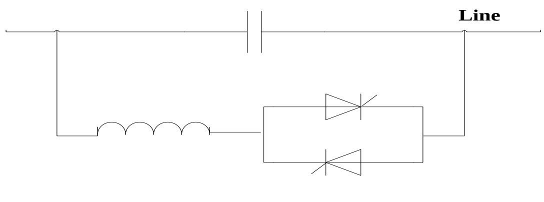

Figure 2. Schematic diagram of TCSC

ENHANCED POWER FLOW CONTROLLER (EPFC):

FACTS controllers can control the power flowing through transmission lines to improve utilization of power system, transmission loop flow control, reliability and relieve congestion. High cost, reliability and land restriction issues have limited FACTS controllers use in power system. The Distributed-FACTS (D-FACTS) controller is presented as a new approach to realize cost-effective power flow control through compound, small, fixed series impedance injections [7-9]. A new device which is distributed version of TCSC FACTS controller, EPFC connects directly to the existing high voltage or extra high voltage lines.

It can be manufactured at lower price than FACTS controllers from conventional low grade components. The EPFC is distributed over whole transmission line as modules at every short span of length of transmission lines to attain the required power flow control functionality by changing the transmission line reactance dynamically or statically [10-11].

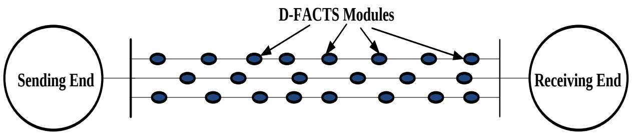

Figure 3. D-FACTS modules connected on transmission line

A simplified schematic of the proposed EPFC with conduction angle control is shown in **Figure** 6.1. The circuit schematic of EPFC nearly looks like that of a Distributed Seires Impedance (DSI), which can be seen. However, the control arrangements are meaningfully dissimilar in these two methodologies. In a DSI, inductance L is either inserted completely, or not inserted at all (switch S_L is either closed or open). Thus $X_{Linjected} = X_L$ or $X_{Linjected} = 0$. Whereas in an EPFC, the amount of inductance injection is controlled continuously by changing the conduction angle (σ) of PE based thyristors (switch S_L is operated under conduction angle control). Thus $X_{Linjected} = X_L(\sigma)$. Also in an EPFC, capacitance C is inserted entirely in a normal operating mode (switch S_C is normally closed). Thus $X_{Cinjected} = X_C$. However, this capacitance is so sized in an EPFC that, X_C combined with $X_L(\sigma)$ offers a continuously variable effective impedance $X_{LC}(\sigma)$ injected into the transmission line reactance (X_{line}) which results in a more precise power flow control.

EPFC works in two modes of operation *i.e.* by-pass mode and compensation mode

Whenever, any type of disturbance or fault takes place then this mode of operation works in EPFC. During compensation mode of operation the EPFC controller works to change the impedance of transmission line so the power flowing through the line can be changed. EPFC works in two modes of operation for compensation, impedance mode to decrease the power flowing through line by increasing the total impedance of line and capacitance mode, to increase the power flowing through line by decreasing the total impedance of line [12-14].

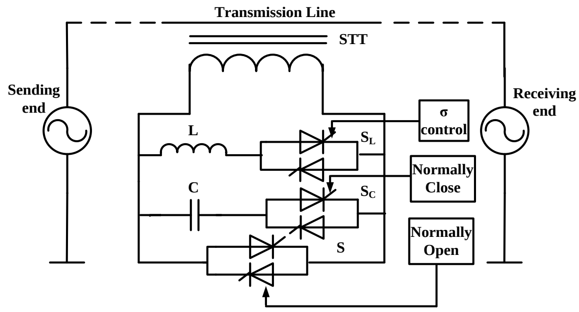

Figure 4. Simplified schematic of proposed EPFC controller

The results from an EPFC MATLAB/Simulink model are presented here on a transmission system which is connected with EPFC controller modules.

SIMULINK MODEL OF TCSC:

The model taken from MATLAB2012 bconsists of 2100 MVA at 13.8 kV simplified synchronous machine with a 30,000 MVA at 735 kV voltage source are taken in to consideration and voltages are increased up-to 735 kV for transmission by using three phase step-up transformer connected with a 300-kM long transmission line. Two resistive load of 100 MW and 250 MW are also connected and a single load of inductive nature is also connected which has 66 MVAR loading capability at 735 kV voltage. The power delivered to 66 MVAR load when TCSC is not in operation and when it is connected is shown in the results and when EPFC is working in different modes of operation. Transmission line and other ratings are same as given in the MATLAB library browser it-self as mentioned below.

Line Parameter-No. of phases-3, Frequency- 50 Hz, Length-300 km

Resistance per unit length- [0.01273 0.3864]

The resistance (R) per unit length, as an N-by-N matrix in ohms/km (ohm/km) is given.

Inductance per unit length-[0.9337e-3 4.1264e-3]

The inductance (L) per unit length, as an N-by-N matrix in henries/km (henry/km) is given for a symmetrical line. For a two-phase or three-phase continuously transposed line, you can enter the positive and zero sequence inductances [L1 L0].

Capacitance per unit length- *[*12.74e-9 7.751e-9]

The capacitance (C) per unit length, as an N-by-N matrix in farads/km (F/km) is given for a symmetrical line. For a two-phase or three-phase continuously transposed line, you can enter the positive and zero sequence capacitances [C1 C0].

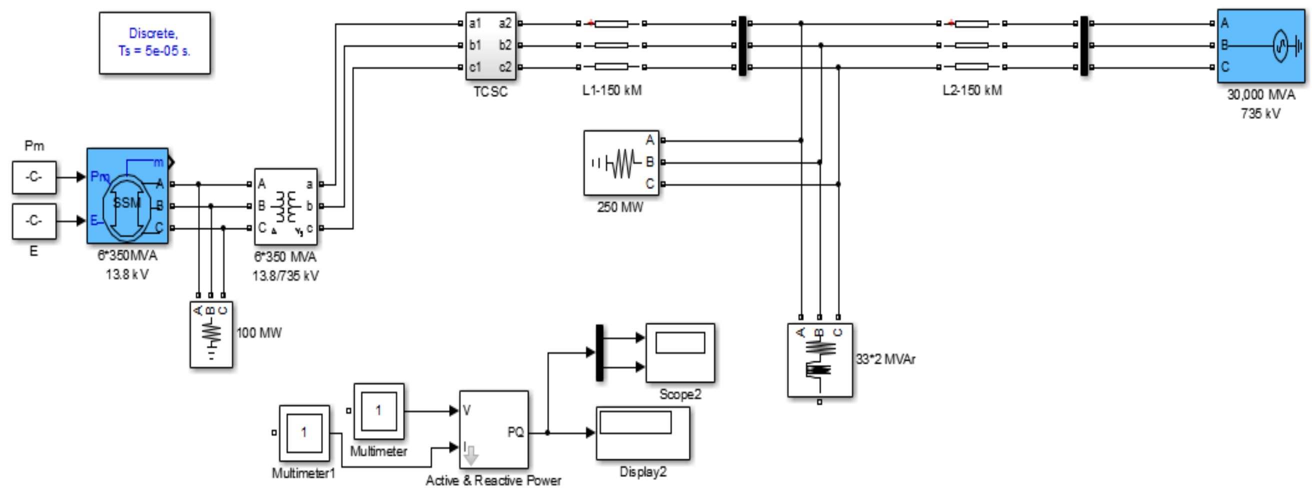

Figure 5. Simulink model of lumped TCSC-FACTS controller

This model has 300 km of transmission line which is divided into two parts of each 150 km and a unit of TCSC-FACTS controller. This TCSC single device has the same rating as the six EPFC modules are having in the next simulation model. The results are shown for the change in line impedance, current, active power and re-active power with conduction angle.

Simulink Result of TCSC:

During bypass mode of operation the power delivered at 66 MVAR load is around 61.5 MVAR at 735 kV voltages. TCSC can work in capacitive and inductive modes of operation, although the inductive mode of operation is rarely used in practice. The power delivered can be increased up to 62.33 MVAR during capacitive mode of operation and can be decreased at 46.57 MVAR during inductive mode of operation by changing the impedance of line. The nominal compensation is around 75% of transmission line impedance *i.e.* using only the capacitor.

The total impedance of transmission line is 40.15 ohms without the TCSC controller. The TCSC works in capacitive mode at 0° conduction angle, results in minimum impedance which is 10.01ohms. Impedance is maximum around 180° conduction angle, which is 77.9 ohms, when TCSC controller is in inductive mode. The resonance takes place in TCSC around 118° conduction angle, the operation is prohibited in conduction angle range 100-150°.The change in Impedance, line current, active power and re-active power with conduction angle are shown in Fig. 6 (a-d) and the variation in active and reactive powers are shown in Fig. 5-8 at different conduction angles:

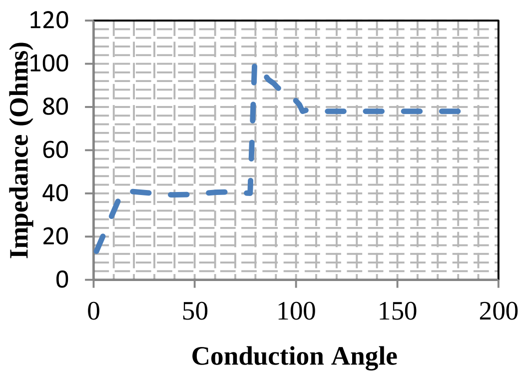

Figure6 (a). Change in impedance with conduction angle

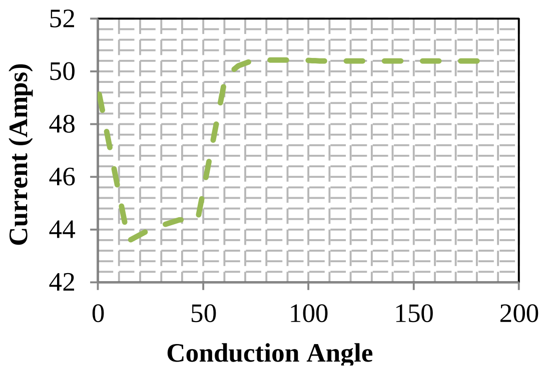

Figure 6(b). Change in line current with conduction angle

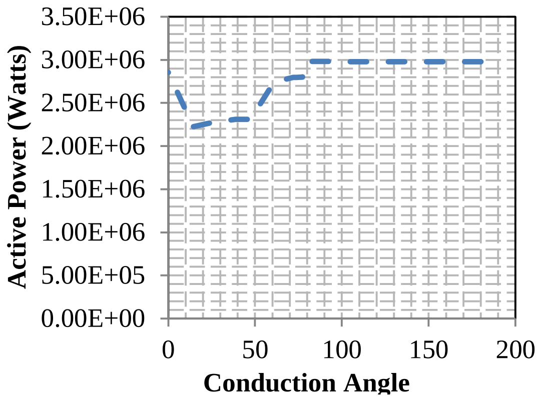

Figure 6(c). Change in active power at 66 MVAR load end with conduction angle

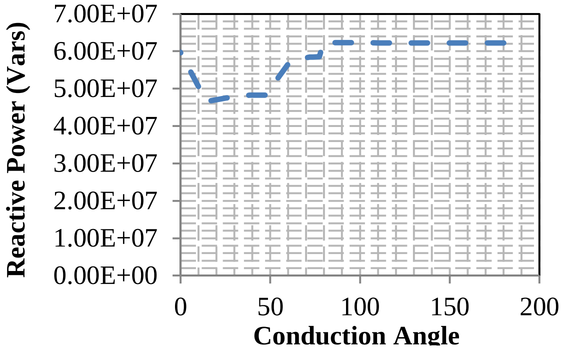

Figure 6(d). Change in re-active power at 66 MVAR load end with conduction angle

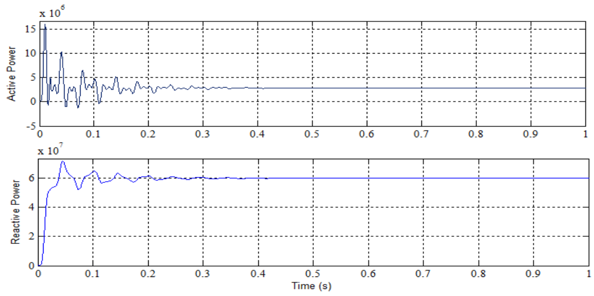

Figure 7. Active and re-active power at 0° conduction angle

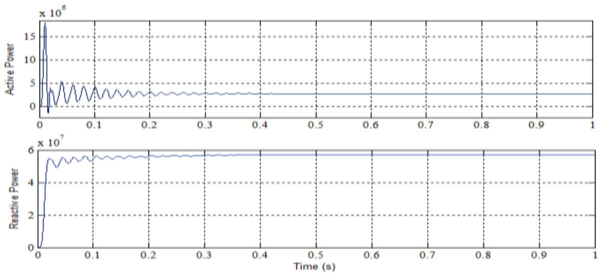

Figure 8. Active and re-active power at 60° conduction angle

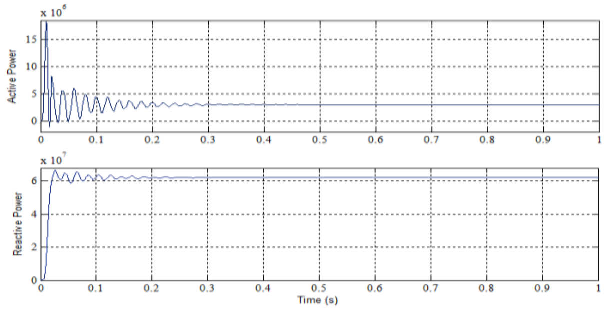

Figure 9. Active and re-active power at 120° conduction angle

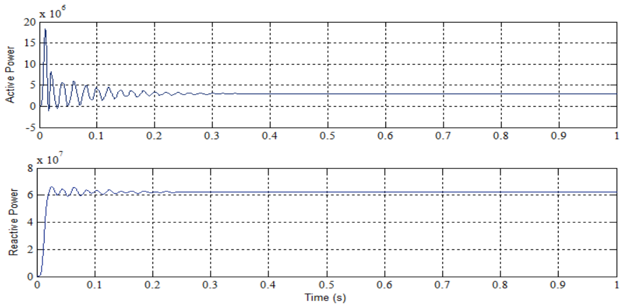

Figure 10. Active and re-active power at 180° conduction angle

The table shows the change in Impedance, line current, active power and re-active power with conduction angle which are shown in given table:

Table I. Change in impedance line current, active power, re-active power with conduction angle

Conduction Angle (Degrees)	Impedance (ohms)	Current (Amps)	3-Phase Active Power (Watts)	3-Phase Reactive Power (Vars)
180	77.9	50.4	2.98E+06	6.23E+07
160	77.9	50.4	2.98E+06	6.23E+07
140	77.9	50.4	2.98E+06	6.23E+07
120	77.9	50.4	2.98E+06	6.23E+07
100	82.88	50.42	2.98E+06	6.23E+07
80	100.2	50.43	2.98E+06	6.23E+07
60	40.51	49.82	2.73E+06	5.70E+07
40	39.4	44.37	2.31E+06	4.83E+07
20	40.81	43.63	2.25E+06	4.716E+07
0	10.01	49.36	2.86E+06	5.97E+07

SIMULINK MODEL OF EPFC:

This model of power system with EPFC is having the same rating of Generator, voltage source and load but the 300 km transmission line is divided into six parts of 50 km is merged into two parts of each 150 km. The sum of six EPFC modules are having the same power rating as TCSC device was having and the results are shown for the change in in Impedance, line current, active power and re-active power with conduction angle

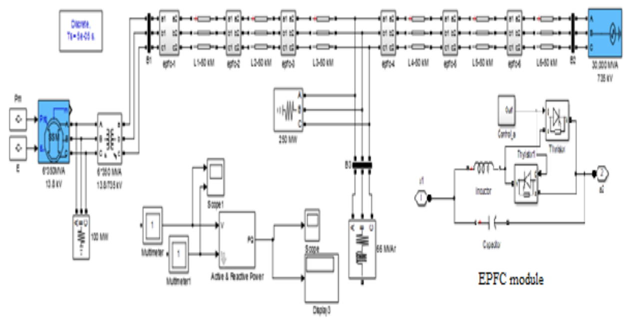

Figure 11.MATLAB/Simulink model with six EPFC controller modules

Simulink result of epfc:

During bypass mode of operation the power delivered at 66 MVAR load is around 61.5 MVAR at 735 kV voltages. The EPFC modules can work in capacitive and inductive mode of operation, although the inductive mode of operation is rarely used in practice. The power delivered can be increased up to 64.03 MVAR during capacitive mode of operation and can be decreased at 13.8 MVAR during inductive mode of operation by changing the impedance of line. The nominal compensation is around 75% of transmission line impedance *i.e.* using only the capacitor.

The total impedance of transmission line is 40.15 ohms without the EPFC modules. The EPFC works in capacitive mode at 0° conduction angle, results in minimum impedance which is 12.37 ohms. Impedance is maximum around 180° conduction angle, which is 56.03 ohms, when EPFC module is in inductive mode. The resonance takes place in EPFC around 118 ° conduction angles, the operation is prohibited in conduction angle range 100-150°.

The change in Impedance, line current, active power and re-active power with conduction angle are shown in Figure 10 (a-d) and the variation in active and reactive powers are shown in Figure 5-8 at different conduction angles:

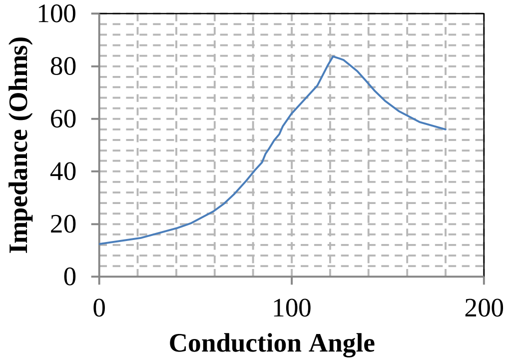

Figure 12(a). Variation in line impedance with conduction angle

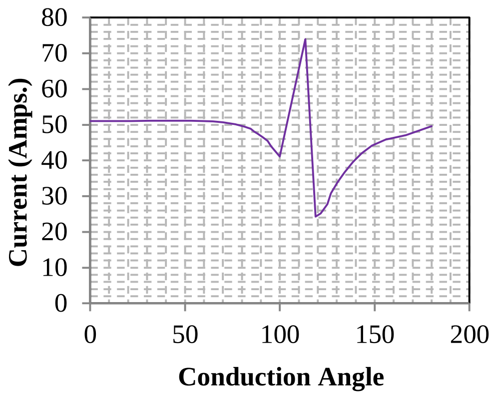

Figure 12(b). Variation in line current with conduction angle

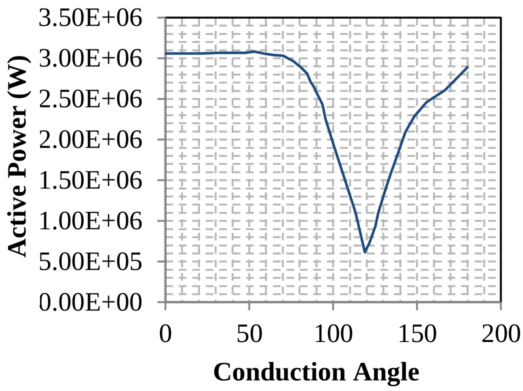

Figure 12(c) Variation in active power at load end with different conduction angles

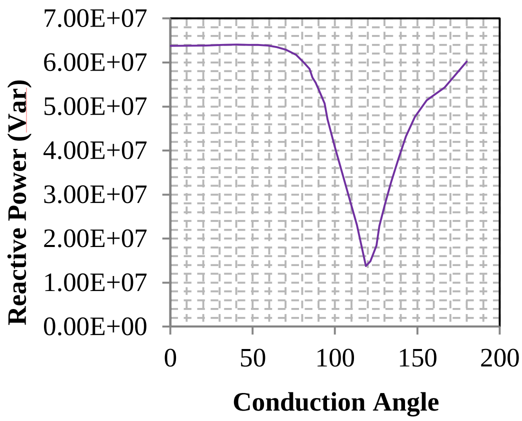

Figure 12(d) Variation in re-active power at load end with different conduction angles

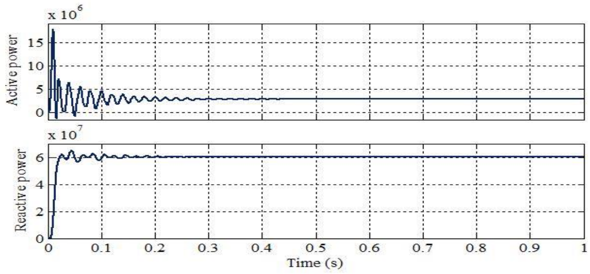

Figure 13. Active and re-active power at 0° conduction angle

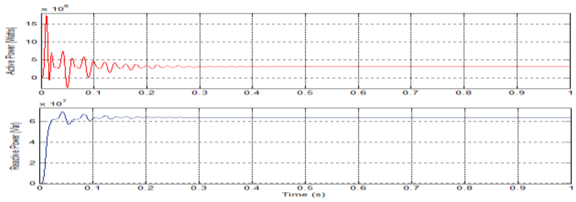

Figure 14. Active and re-active power at 60° conduction angle

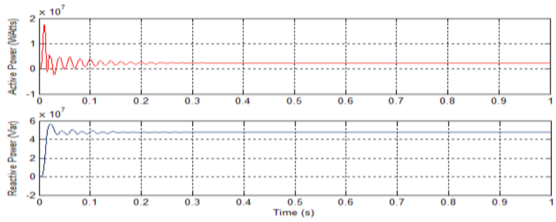

Figure 15. Active and re-active power at 150° conduction angle

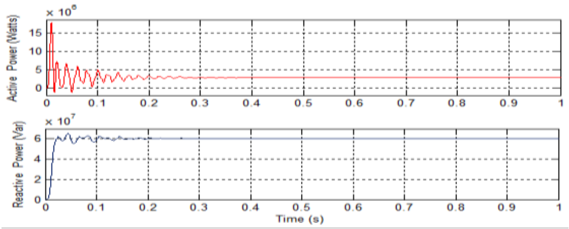

Figure 16. Active and re-active power at 180° conduction angle

The table shows the change in Impedance, line current, active power and re-active power with conduction angle which are shown in given table:

Table II. Change in impedance line current, active power, re-active power with conduction angle

Conduction Angle (Degrees)	Impedance (ohms)	Current (Amps)	Active Power (Watts)	Reactive Power (Vars)
180	56.03	49.57	2.89E+06	6.02E+07
170	58.09	48.09	2.61E+06	5.47E+07
150	66.78	44.12	2.29E+06	4.77E+07
100	61.95	41.09	1.95E+06	4.08E+07
80	40.5	49.48	2.88E+06	6.00E+07
60	24.78	51.03	3.05E+06	6.38E+07
40	18.44	51.12	3.07E+06	6.41E+07
20	14.66	51.04	3.06E+06	6.39E+07
0	13.8	51	3.06E+06	6.38E+07

It can be seen in the above table that the impedance is changing by conduction angle control and the current gets affected by impedance changing in the system. This also changes the active and re-active power delivered at the load and load demand is fulfilled. So this is a very efficient manner to control the power flow which has higher reliability due to redundancy of lumped controller and can control in very small fraction of changes in the system.

Simulation results of EPFC and TCSC controlled power system network is shown above. The active and reactive power at different conduction angles *i.e.* 0°, 60°, 120°, 180°, is shown in Figure 5 to 8 and 9 to 12 above for both TCSC and EPFC controlled power system networks. Table I and II are showing various results of current, impedance, active power and reactive power at different conduction angles which is also shown in Figure 4 (a) to 4 (d) and 8 (a) to 8 (d) for both EPFC and TCSC controller cases.

CONCLUSION

The EPFC is a distributed version of the conventional TCSC FACTS controller and inherently gets all the controlling characteristics from that. During EPFC controllers case the variation in all parameters smooth, means the controlling is easy and the changes are in large scale than the TCSC controller‘s case. During the TCSC controller case the changes are less smooth and the scale of change is also lesser than EPFC controller‘s case.

This EPFC controller is shown by comparing with the TCSC controller results and it has found that EPFC controller has better and smooth controlling.

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