Power Transfer Capacity Achievement using Thyristor Controlled Series Capacitor

Neel Kamal, Sujit Kumar, Pankaj Kumar, Chandan Kumar, Vikash Tiwari

Abstract*: Power system is the assembly of electrical networks, generating stations and different load centers. Load demand on the power system varies with respect to time parameter. Therefore more and more power requirements occur due to the power consumption. This can be achieved either by increasing the power carrying capability or by the re-evaluation of the electrical networks. It is observed that re-evaluation of the power system network is costlier than that of increasing the power transfer capability. In this research work a review of the salient features of power flow with thyristor controlled series capacitors are elegantly discussed. PSCAD-4.0 / MATLAB Program are used to observe how active and reactive power flow varied with different variable parameters and set of data. For each set of data, output result is obtained. Load flow solution of a 6-bus network by using Newton-Raphson method for control of power flow with TCSC (thyristor controlled series capacitor), in which the original 6-bus network is modified to 7-bus network to accommodate one TCSC / two TCSC. The load flow solution is found for the modified 6-bus / 7-bus network. The result of load flow solution shows that active power flow is controlled by TCSC. The salient feature of the research work is the fact that MATLAB and PSCAD-4.0 has been thoroughly used to investigate the different aspects of power flow control.

Keywords: Active and reactive power flow, Bus networks, FACTS controller, Power flow controller-TCSC (Thyristor Controlled Series Capacitor).

I. INTRODUCTION

The power flow involves the parameters-(a) Load angle (b) Transmission line impedance (c) Operating variables.
To control the power from one bus to another bus, either of three parameters to be controlled. To maintain both dynamic and steady state operation, the new technology i.e FACTS (Flexible ac Transmission System) is used.

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FACTs increase the controllability and power transfer capability in power system.
There are four different types of FACTs: (a) Series (b) Shunt (c) Combined series-series (d) Combined series-shunt Controllers. In this research work, Thyristor controlled series capacitor is considered to control the power
flow in the transmission line. Thyristor controlled series capacitor consist of series capacitor bank these are shunted by thyristor-controlled reactor which provide a smooth variable series capacitive reactance with the change of firing angle of Thyristor-controlled reactor.
Using PSCAD software, we will analysis how power flow from one end to other end of a two bus system can be controlled or varied. The various parameters involved for power flow control are :(a) Load angle (δ) (b) Transmission line impedance variation (Z) (c) Voltage variation between two ends. From the simulation result using PSCAD, it can be conclude that power flow in transmission lines varies with various parameters such as load angle, line impedance and terminal voltage. So power flow control involves the control of various parameters such as load angle, transmission line impedance and terminal voltage. A voltage in series with the transmission line can be introduced to control the current flow and thereby the power transmissions from sending end to receiving end [2]. The active power through transmission line is given by equations as

$$Pc = VcI = \frac{V^2}{X_{eq}}\sin\delta = \frac{V^2}{(1-r)X}\sin\delta \qquad (1)$$

The reactive power Qc at the source Vc terminal is given by

$$Qc = I^2 X_{comp} = \frac{2V^2}{X} \times \frac{r}{(1-r)^2}(1-\cos\delta) \qquad (2)$$

For capacitive compensation the line current leads the voltage Vc by 900 whereas for inductive compensation the line current lags the Vc by 900. Series capacitive impedance decreases the overall transmission line impedance and thereby increases the transmittable power. Whereas series inductive impedance increases the overall transmission line impedance, thus decreases the transmittable power.

II. OBJECTIVE OF PROPOSED WORK

Using Power flow study, the steady state operating condition of the electrical power systems can be determined. By these conditions, active and reactive power of the entire power system voltage magnitude and phase angles can be calculated [6]. Power flow study show that there are voltage magnitudes outside at certain points of the network, and then control actions become necessary to regulate the voltage magnitude. With the objective of controlling the power flow in the transmission line using TCSC, it is essential to know the power flow between two buses and the various parameters involved in the power flow equation. Power Electronic control in electrical systems offers a solid theoretical foundation for the electronic control of active and reactive power in the transmission line. Thus use of Flexible AC Transmission System FACTS controller, has strong impact on power flow control.

III. LITERATURE REVIEW

A review of earlier papers published on the FACTS controller show that a lot of work done on different FACTS controller. Also several papers published on Thyristor Controlled Series Capacitor (TCSC) which is used for different application as mentioned below. Still a lot of work to be done to improve the power flow control in long transmission line.

Jumaat, S., Zulkifli S.A explained in their paper that TCSC should be in control in reaction to distribution model, and impedance of the capacitance could varied according to rotating speed and vibrations[1].

Sarat Chandra Swain & Prafulla Chandra Panda analyzes static voltage stability by without and with FACT devices such as by using TCSC, which is aimed at detection of the voltage stability [4].

P.Moore & p. Ashmole described in IEE publication [5] about the FACTS controllers and its utility. In his discussion in "Introduction to FACTS" researcher explained that FACTS are mainly to control voltage, phase angle and impedance. According to him the various advantages of the FACTS devices are :(a) Potential to control flows as required (b) Lesser environmental effect than that of alternative techniques of transmission reinforcement. (c) Depending on the cost benefit analysis could cost less than other alternatives.

Fuerte-Esquivel [6] presented a paper on TCSC model for the power flow solution of power system interconnections in which power flow from one bus to another bus is determined. In this paper he discussed how TCSC can be incorporated into electrical network having large number of buses. Also he found load flow solution using Newton-Raphson method within the specified tolerance.

Also he described about the various FACTS controller, in which TCSC is one of the FACTS controller. Development stage of various FACTS controllers also presented in that publications.

Taleb, M., Salem, A. depict two Evolutionary Optimization Techniques, in particular Differential Evolution and Genetic Algorithm to set the best location and the correct parameter setting of TCSC which control the dynamic power losses in control system, and exhibitions [7].

Abdel-Moamen[8] explain in his paper on Multi-objective optimal power flow model with TCSC for practical power networks. He discussed how the transmission line loss in a 30-bus system can be minimized using Newton's method.

Jonas Person, Lennart Soder [9] developed a linear model for TCSC and he found that simulation with linear model takes few secs as compared to actual model takes an hour to complete. Narain G. Hingorani, Laszlo Gyugyi, [3] has described about all FACTS controller in his book "Understanding FACTS". Among many FACTS controller, TCSC is the important FACTs controller about which he described in details how its range of reactance varies from inductive to capacitive region.

The research work is endless on Thyristor controlled series capacitor to improve it characteristics and to apply in many more electrical technology to improve the power flow stability, power flow control and in related applications.

IV. MATERIALS AND METHODS

The Thyristor controlled series capacitors have three fundamental modes of operation as follows: (a) Thyristor-blocked mode: In this mode, TCR is open circuited and TCSC act as capacitive reactance Xc. (b)Thyristor-bypassed mode. In this operation, thyristor valves are fired with no delay and TCSC has small inductive impedance. (c)Thyristor- phase controlled mode: In this, firing angle determines the current direction in TCR& capacitor, and its working enable it to work as either a capacitive or an inductive reactance.

A MATLAB program is written for analyzing the active and reactive power flow control by TCSC. From the analysis it is clear that height of load angle curve increases with the more capacitive reactance of TCSC. But the height of the load angle curve decrease with more inductive reactance of TCSC.

Similarly the reactive power curve for capacitive compensation is positive and reactive power curve for inductive compensation is negative. Also both the power decreases with the increase of firing angle up to certain value where the reactance of TCSC is inductive. At 90º of firing angle the reactance of TCSC becomes capacitive and both type of power increases. In the figure shown, a two bus has been taken for simulation and analyzing the power flow control. For the given block in Figure 1, set of data are given and simulation result is shown.

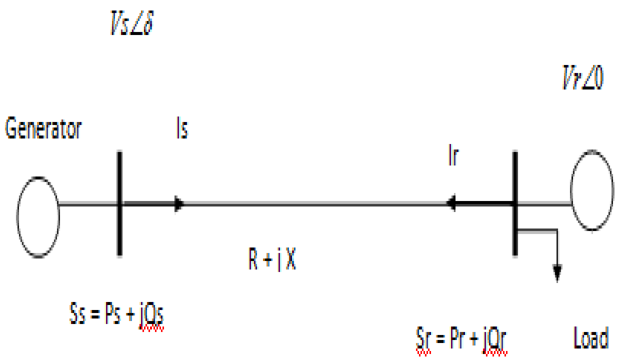

Fig.1.Two bus system

Firing angle of thyristor (alpha) =130º
Voltage of sending end(L-L) = 11 kV
Voltage of receiving end(L-L) = 10 kV
Sending end phase angle = 30 º
Receiving end phase angle = 0 º
Isr = Sending end current
Sending end active power=Psr
Receiving end reactive power=Qsr
Tr.line inductance = 0.45 H/ phase
Fixed capacitor of TCSC = 212 µF
Series inductance of TCSC = 0.015 H

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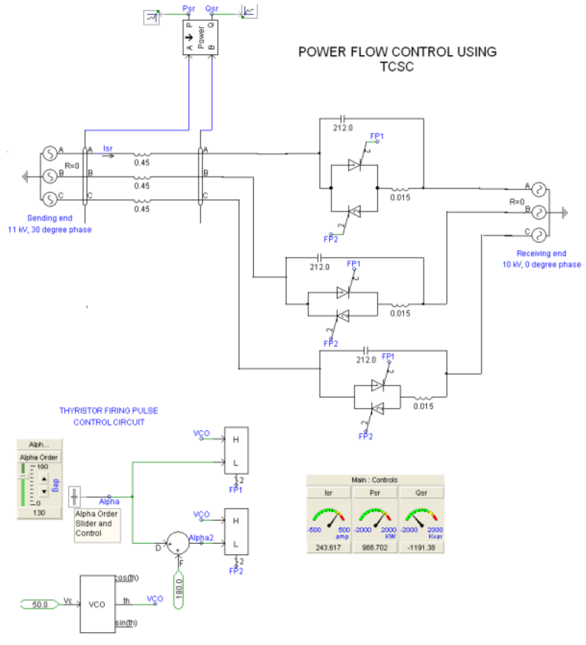
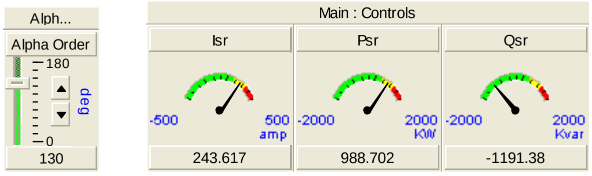
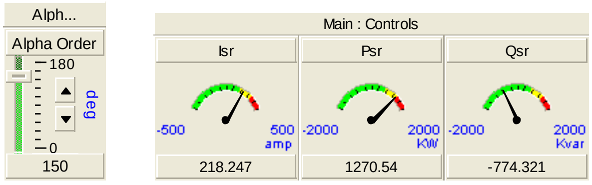


Fig. 2. Simulink block of two bus power flow control using TCSC

Case-1 Simulation result for firing angle = 130^0



Case-2 Simulation result for firing angle = 150^0



Case-3 Simulation result for firing angle = 110^0

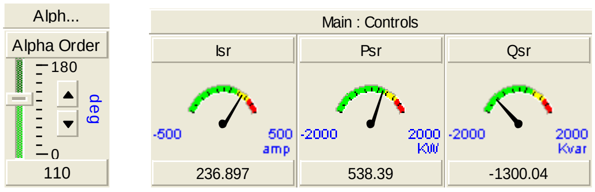


Fig. 3. Simulation results for different firing angels

From simulation results, it is clearly observed that as we increase the firing angle from 130 ° to 150 °, the TCSC causes capacitive compensation and the real power from sending end is increased from 988.72 KW to 1270.54 KW. Similarly when firing angle decreases from 130 ° to 110 °, TCSC increases the inductive reactance of the transmission line. Thus real power flow from sending end to receiving end is decreased from 988.72 KW to 538.39 KW. Therefore it is clearly observed that, both current and the power flow can be controlled by controlling the firing angle of TCSC.

A. Generalized Power Flow Solution For 5-Bus Network:

A 5-Bus network is given in the next page in Fig-4 to analyze the power flow solution and to determine the active power flow and reactive power flow from each bus. Also nodal voltage magnitude and nodal phase angle is determined where these quantities are not known. For this purpose a computer program is used to solve the power flow solution.

Total no of transmission line = 7

Tr. Line	**Fm**	**to**	**Resistance**	**Reactance**	**Susceptance**
(All values in in p.u.)					
Tline-1	Kottayam	Chengannur	0.02	0.06	0.06
Tline-2	Kottayam	Parumal	0.08	0.24	0.05
Tline-3	Chengannur	Parumala	0.06	0.18	0.04
Tline-4	Chengannur	Tiruvalla	0.06	0.18	0.04
Tline-5	Chengannur	Othera	0.04	0.12	0.03
Tline-6	Parumala	Tiruvalla	0.01	0.03	0.02
Tline-7	Tiruvalla	Othera	0.08	0.24	0.05

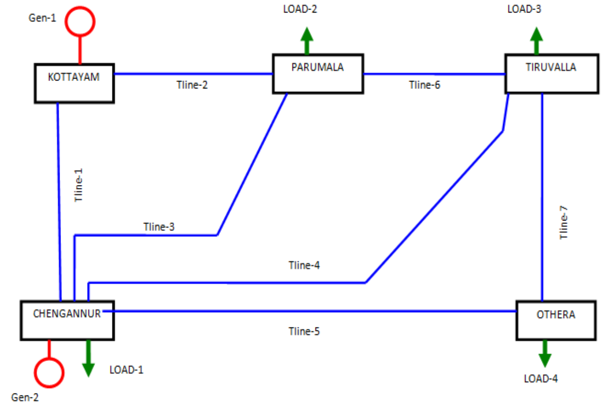


Fig. 4 A 5-Bus Network for analyzing the power flow solution

The summary of result are superimposed on the given 5-bus network shown in Fig-5, so that at each bus we can find out how much power flows from each bus and the losses on the transmission line are also mentioned. The summary of output shows that at each bus, power mismatch equation is satisfied. Also power flow solution is converges to a prescribed tolerance of 1e-12 within six iteration.

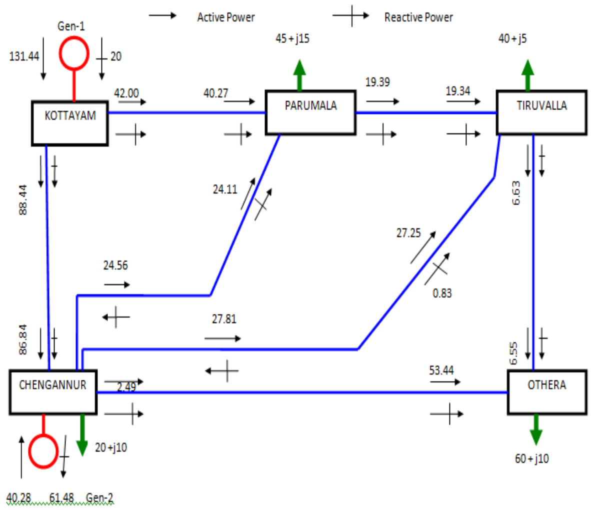


Fig-5 Active and Reactive power flow shown at each bus for 5-bus network.

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B. Power Flow Solution For 6-Bus Network:

Power flow solution for the network where TCSC is used in the network is solved in the similar way using Newton-Raphson method already discussed. 6-Bus network is drawn, in which a TCSC is used in between Paumala to Mannar. By writing a MATLAB code in the similar fashion for power flow solution, we analyze how TCSC is effective for controlling the active power between two buses.

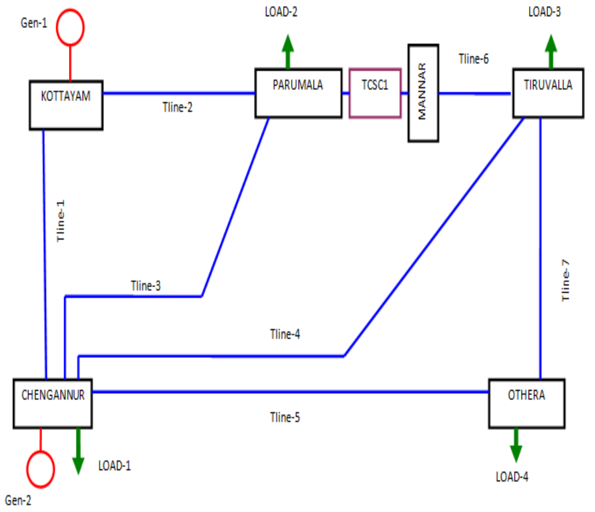

Fig.6 6-bus network where one TCSC is introduced in between PARUMALA bus and MANNAR bus

All units are p.u.

Tr. Line	Fm To	Resistance	Reactance	Susceptance
Tline-1	kottayam- Chengannur	0.02	0.06	0.06
Tline-2	kottayam- Parumala	0.08	0.24	0.05
Tline-3	Chengannur- Parumala	0.06	0.18	0.04
Tline-4	Chengannur- Tiruvalla	0.06	0.18	0.04
Tline-5	Chengannur- Othera	0.04	0.12	0.03
Tline-6	Mannar- Tiruvalla	0.01	0.03	0.02
Tline-7	Tiruvalla - Othera	0.08	0.24	0.05

The output is superimposed on the given 6-bus network in Fig. 6 for easy reference and modified figure is shown in Fig.

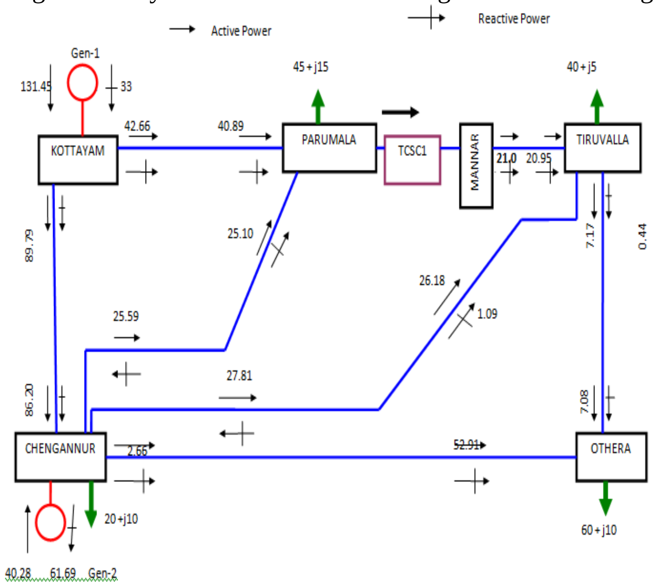

Fig.7. Active and Reactive power flow shown at each bus for 6–bus network where one TCSC is used to control the power flow.

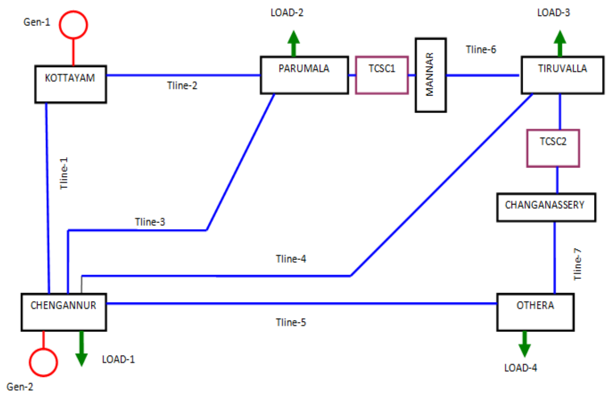

Fig. 8. 7-bus network where two TCSC is introduced in between PARUMALA bus to MANNAR bus and TIRUVALLA to CHANGANASSERY

C. Data For 7-Bus Network In Which Tcsc-1 & Tcsc-2 Is Connected:

Total no of transmission line = 7

All units are p.u.

Tr. Line	Fm To	Resistance	Reactance	Susceptance
Tline-1	Kottayam -Chengannur	0.02	0.06	0.06
Tline-2	Kottayam -Parumala	0.08	0.24	0.05
Tline-3	Chengannur -Parumala	0.06	0.18	0.04
Tline-4	Chengannur -Tiruvalla	0.06	0.18	0.04
Tline-5	Chengannur -Othera	0.04	0.12	0.03
Tline-6	Mannar- Tiruvalla	0.01	0.03	0.02
Tline-7	Changnassery- Othera	0.08	0.24	0.05

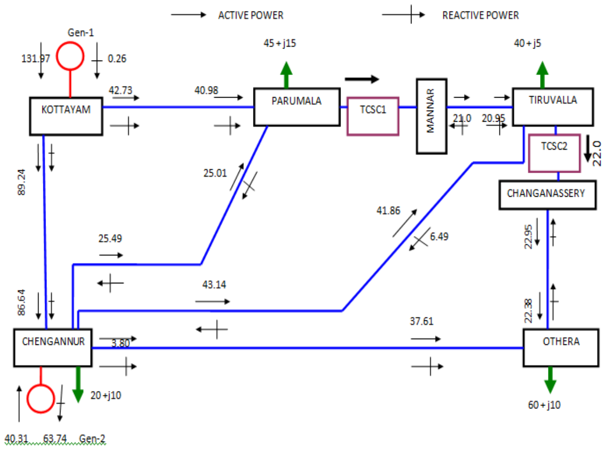

Fig-9 Active and Reactive power flow shown at each bus for 7–bus network where two TCSC is used to control the power flow.

V. RESULT ACQUISITION

Fig.5 is modified and reproduced in Fig. 7, in which one TCSC is connected between Parumala and Mannar to control 21 MW of power flow from Parumala to Tiruvalla. The power flow solution is obtained in 8 iteration to a power mismatch tolerance of 1e-^{12}.

The power flow results are represent in figure 7.Since the TCSC cannot generate active power; there is an increase in active power flow from Kottayam bus to Parumala bus (i.e. from 42.00 MW to 42.66 MW).

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Simultaneously, there is increase of active power chengannur bus to Parumala bus (i.e from 24.56 MW to 25.59 MW). In total there is increase of active power from Parumala to Tiruvalla (i.e from 19.39 MW to 21 MW).

It should be remarked that transmission line from Parumala to Tiruvalla is series compensated by the use of TCSC-1 and there is an increase of active power from 19.38 MW to 21 MW, which is just under 8% active power increase. Thus TCSC with firing angle control provides a good series compensation for controlling the active power flow.

The network shown in Fig. 8 consists of two TCSC for controlling the power flow. One TCSC is connected in between Parumala and Mannar. Other is connected in between Tiruvalla and Changanassery.

The MATLAB code which is written for one TCSC is now modified with additional data for TCSC-2 and executed. The power flows varies in the transmission line and it is different from the case used for one TCSC.

From Fig-9, we observe that TCSC-1 provides series compensation in line between Parumala to Tiruvalla bus. This is because active power flow from Parumala to Tiruvalla is increased from 19.39 MW (shown in fig 7.5) to 21 MW. At the same time the active power from Kottayam to Parumala is increased from 42.00 MW to 42.73 MW and from Chengannur to Parumala is increased from 24.56 MW to 25.49 MW as TCSC doesn't generate any active power.

Similarly from Fig-9, we observe that TCSC-2 provides series compensation in the line between Tiruvalla to Othera. This is because active power flow from Tiruvalla to Othera is increased from 6.63 MW to 22 MW and the active power from Chengannur to Tiruvalla is increased from 27.81 MW to 27.81 MW and Chengannur to Othera is decreased from 54.75 MW to 38.31 MW as TCSC does not generate any active power. In addition to the power mismatch equation is satisfied at each bus, after using two TCSC. Thus from the analysis, it is can be said that both TCSC provide effective series compensation in the two different transmission line and in addition to the specified amount of active power is also controlled .

VI. SUMMARY OF WORK

In transmission line, Power flow control can be obtained by the various parameters involved in transmission line. Conventional method has been used to determine the various parameters. For each parameter we have used PSCAD-4.0/MATLAB application software to analyze the power flow. As TCSC, is a series compensator used in transmission line to control the active power flow. Principle of series compensation and simulation block is used to verify the truthfulness, how capacitor is effective element to reduce the series reactance. For this PSCAD-4.0 software is used. Then characteristics of TCSC have been analyzed. By using PSCAD software and we come to know how effectively, TCSC can control the current and active power in the transmission line by varying the firing angle.

A practical electrical network is having large number of buses. Thus in this work, a 6-bus imaginary network is considered for finding the power flow solutions. Newton-Raphson method is used to solve this network. By using MATLAB code for this network, power flow between each buses is determined. Power flow solution of this network satisfies the power mismatch equation at each bus.

Finally, Jacobian matrix is determined for 7-bus network in which one TCSC is used in between two buses. Again power flow solution is determined for this network and we come to know that it also satisfies the power mismatch equations at each bus. With it, a specified amount of active power is allowed flow between two buses by using the TCSC. In the next section again two TCSC is used to analyze the power in different transmission line. Here also MATLAB code is used for finding the power flow solution of given electrical network.

VII. CONCLUSION

The MATLAB programme has been made and execute for different simulations in PSCAD and MATLAB code. TCSC is the fast acting power electronic controllers which can provide current and power flow control in the transmission line with the control of its firing angle. Therefore TCSC can be used as a series capacitor to reduce the overall transmission line reactance. Power transmission capability can be changed and increased without disturbing the remaining system performance. Hence it may be conclude that TCSC increase overall power transfer capacity.

FURTHER SCOPE OF WORK

We all know that the research works on the topic never ends with limited application. This can also cover some more applications such as damping of the power swings from local and inter-area oscillations, reduction of short-circuit current, voltage regulation of local network etc.Various research works are going on control interaction between multiple Thyristor-Controlled Series Capacitor (TCSC). SVC-TCSC can be integrated and used within power systems to enhance inter-area stability. In this work MATLAB code is used for 5-bus network for power flow solution. PSCAD-4.0 can also be used for designing a physical 5-bus network to determine the exact power flow from one bus to another. PSCAD-4.0 software can be used for large bus network. In addition to further study can be made on the effect of TCSC on fault component distance protection and impact of TCSC on the protection of transmission lines. Therefore, TCSC can be used in various fields in control.

Software Used:

MATLAB-6.5
PSCAD-4.0

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