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Power Flow Control using TCSC Facts Controller

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ABSTRACT

Power system engineers are currently facing challenges to increase the power transfer capabilities of existing transmission system. This is where the Flexible AC Transmission Systems (FACTS) technology comes into effect. With relatively low investment, compared to new transmission or generation facilities, the FACTS technology allows the industries to better utilize the existing transmission and generation reserves, while enhancing the power system performance. Moreover, the current trend of deregulated electricity market also favors the FACTS controllers in many ways. FACTS controllers in the deregulated electricity market allow the system to be used in more flexible way with increase in various stability margins. FACTS controllers are products of FACTS technology; a group of power electronics controllers expected to revolutionize the power transmission and distribution system in many ways.

In this paper an overview to the general types of FACTS controllers is given along with the simulation of TCSC FACTS controller using SIMULINK. Analysis of the simulated TCSC shows similar functions as a physical one. Objective of the whole work is to control the power flow in the transmission line. This can be achieved by knowing the various parameters which are involved in power flow in the transmission line

General Terms

Flexible AC Transmission System, Thyristor Controlled Series Compensator, power transfer capabilities

Keywords

FACTS, Power system, Stability, Transient stability, Transient stability limit, Voltage stability, Thermal rating, Power system flexibility, Synchronism

1. INTRODUCTION

Modern electric power utilities are facing many challenges due to ever-increasing complexity in their operation and structure. In the recent past, one of the problems that got wide attention is the power system instabilities. With the lack of new generation and transmission facilities and over exploitation of the existing facilities geared by increase in load demand make these types of problems more imminent in modern power systems. Demand of electrical power is continuously rising at a very high rate due to rapid industrial development. To meet this demand, it is essential to raise the transmitted power along with the existing transmission facilities[1]. The need for the power flow control in electrical power systems is thus evident with the increased loading of transmission lines; the problem of transient stability after a major fault can become a transmission power limiting factor. The power system should adapt to momentary system conditions, in other words, power system should be flexible.

2. POWER SYSTEM STABILITY

Power system stability may be broadly defined as the ability of a power system to remain in a state of operating equilibrium under normal operating conditions and to regain an acceptable state of equilibrium after being subjected to a disturbance. Traditionally, the stability problem has been one of maintaining all synchronous machines in synchronism. This aspect of stability is influenced by the dynamics of generator rotor angles [2].

Stability of power system has been a major concern in system operation. The stability of a system determines whether the system can settle down to the original or close to the steady state after the transients disappear. In general, power system stability is the ability to respond to a disturbance from its normal operation by returning to a condition where the operation is again normal.

A power system is said to be steady state stable for a particular operating condition if, following any small disturbance, it reaches a steady state operating condition which is identical or close to the pre-disturbance operating condition. Transient stability is defined as the ability of the power system to maintain synchronism when subjected to a severe transient disturbance. A system is transiently stable if it can survive the initial disturbance but it is transiently unstable if it cannot survive. For the transiently stable system, a large disturbance suddenly occurs; the system angle spread starts to increase but reaches a peak and then starts to decline, making the system transiently stable. The resulting system response involves large excursions of generator rotor angles.

3. TRANSIENT STABILITY IMPROVEMENT BY FACTS

By the means of flexible and rapid control over the AC transmission parameters and network topology, FACTS technology can facilitate the power control, enhance the power transfer capacity, decrease the line losses and generation costs, and improve the stability and security of the power system.

According to IEEE, FACTS Controller is "A power electronic based system and other static equipment that provide control of one or more ac transmission system parameters." [3]

FACTS technology opens up new opportunities for controlling and enhancing the useable capacity of present, as well as new upgraded lines. FACTS are an evolving technology and can boost power transfer capability by 20–30% by increasing the flexibility of the systems. By providing added flexibility, FACTS controllers can enable a line to carry power closer to its thermal rating.

FACTS device offers continuous control of power flow or voltage, against daily load changes or change in network topologies.

4. TYPES OF FACTS CONTROLLERS

In general FACTS controllers can be divided into the following four categories [4]:

4.1 Series Controllers

In principle all the series controllers inject voltage in series with the line. Series connected controller impacts the driving voltage and hence, the current and power flow directly. Static Synchronous Series Compensator (SSSC), Thyristor Controlled Series Compensator (TCSC) etc. are the examples of series controllers.

4.2 Shunt Controllers

All shunt controllers inject current into the system at the point of connection. The shunt controller is like a current source, which draws/injects current from/into the line. Static Synchronous Compensator (SSC), Static Synchronous Generator (SSG), Thyristor Controlled Reactor (TCR) etc are the examples of shunt controllers.

4.3 Combined Series-Shunt Controllers

This could be a combination of separate shunt and series controllers, which are controlled in a coordinated manner. Combined shunt and series controllers inject current into the system with the shunt part of the controller and voltage in series in the line with the series part of the controller. Unified Power Flow Controller (UPFC) and Thyristor Controlled Phase Shifting Transformer (TCPST) are the examples of shunt series controllers.

4.4 Combined Series-Series Controllers

This could be a combination of separate series controllers, which are controlled in a coordinated manner, in a multi-line transmission system or it could be a unified controller, in which series controller provides independent series reactive compensation for each line but also transfer real power among the line via the power link.

5. THYRISTOR CONTROLLED SERIES COMPENSATOR

It is obvious that power transfer between areas can be affected by adjusting the net series impedance. One such conventional and established method of increasing transmission line capability is to install a series capacitor, which reduces the net series impedance, thus allowing additional power to be transferred. Although this method is well known, slow switching times is the limitation of its use. Thyristor controllers, on the other hand, are able to rapidly and continuously control the line compensation over a continuous range with resulting flexibility. Controller used for series compensation is the Thyristor Controlled Series Compensator (TCSC).

TCSC controllers use thyristor-controlled reactor (TCR) in parallel with capacitor segments of series capacitor bank (Figure 1). The combination of TCR and capacitor allow the capacitive reactance to be smoothly controlled over a wide range and switched upon command to a condition where the bi-directional thyristor pairs conduct continuously and insert an inductive reactance into the line. TCSC is an effective and economical means of solving problems of transient stability, dynamic stability, steady state stability and voltage stability in long transmission lines. TCSC, the first generation of FACTS, can control the line impedance through the introduction of a thyristor controlled capacitor in series with the transmission line [5].

A TCSC is a series controlled capacitive reactance that can provide continuous control of power on the ac line over a wide range. The functioning of TCSC can be comprehended by analyzing the behavior of a variable inductor connected in series with a fixed capacitor, as shown in Fig 1.

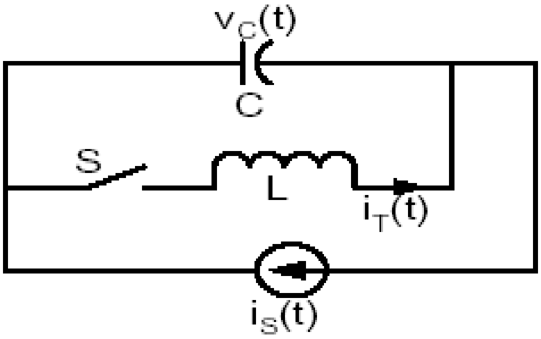


Fig. 1 A variable inductor connected in shunt with a fixed capacitor

The steady state thyristor current i_T can be given by

$$i_L(t)=\frac{1}{L}\int_{\alpha}^{wt} v(t)dt=\frac{1}{wL}Vm\left|\sin wt\right|_{\alpha}^{wt}=\frac{Vm}{wL}(\sin wt-\sin\alpha).(1)$$

$$i_T(t)=\frac{\varpi^2}{\varpi^2-2}I_m\left[\cos wt-\frac{\cos\beta}{\cos\varpi\beta}\cos w_r t\right](2)$$

The fundamental component, VC1, is obtained as

$$v_{C1}=\frac{\mathrm{Im}\,X_C}{\varpi^2-1}\left(\sin\beta-\varpi\cos\beta\tan\varpi\beta\right)(3)$$

$$v_C(t)=\frac{\mathrm{Im}X_C}{\varpi^2-1}\left(-\sin wt+\varpi\frac{\cos\beta}{\cos\varpi\beta}\sin w_r t\right);(4)$$

The equivalent TCSC reactance is given

$$X_{TCSC}=\frac{V_{CF}}{I_m}=X_C-\frac{X_C^2}{(X_C-X_L)}\frac{2\beta+\sin 2\beta}{\pi}+\frac{4X_C^2}{(X_C-X_L)}\frac{\cos^2\beta}{(\varpi^2-1)}\frac{(\varpi\tan\varpi\beta-\tan\beta)}{\pi}(5)$$

$$X_{TCSC}=-X_C+C_1\{2(\pi-\alpha)+\sin[2(\pi-\alpha)]\}-C_2\cos^2(\pi-\alpha)\{\varpi\tan[\varpi(\pi-\alpha)]-\tan(\pi-\alpha)\}(6)$$

6. TCSC MODELING USING SIMULINK

6.1 Power Flow Analysis of Two Bus Network

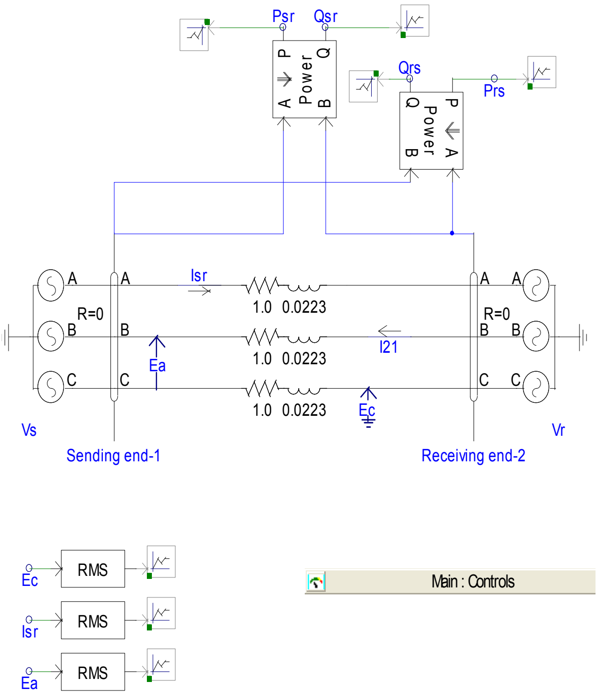


Fig. 2 Two bus systems connected one generators and load

Following data are assumed for the purpose of simulation of simple two bus network to analyze the power flow from one bus to another [6].

Vs = magnitude of sending end voltage = 208 volts

δs= phase angle of sending end = 30^0

Vr = magnitude of receiving end voltage = 173 volts

δr = phase angle of receiving end = 0^0

R = resistance of line = 1 ohm per phase

L = inductance of line = 0.0223 Henry per phase

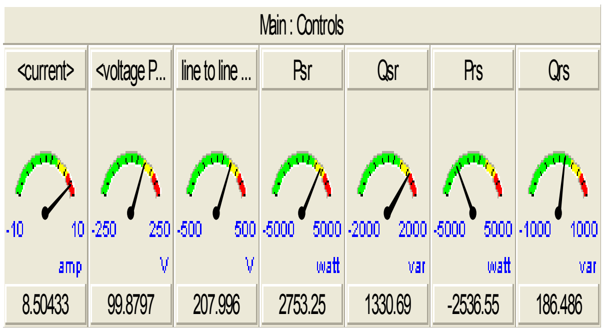
Psr = Active power flow from sending end to receiving end

Prs = Active power flow from receiving end to sending end

Qsr = Reactive power flow from sending end to receiving end

Qrs = Reactive power flow from receiving end to sending end

6.1.1 Simulation Result



Main : Controls

<current>	<voltage P...	line to line ...	Psr	Qsr	Prs	Qrs
-10 10	-250 250	-500 500	-5000 5000	-2000 2000	-5000 5000	-1000 1000
amp	V	V	watt	var	watt	var
8.50433	99.8797	207.996	2753.25	1330.69	-2536.55	186.486

6.2 Simulation Block for Capacitive Compensation

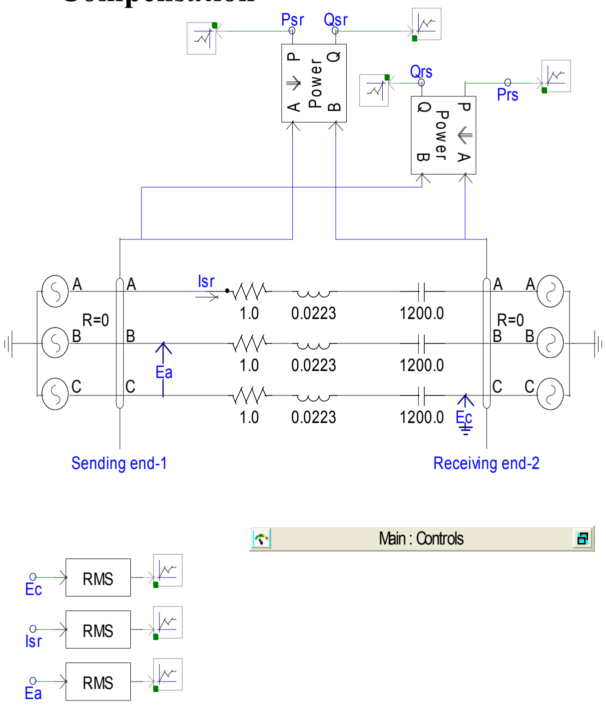


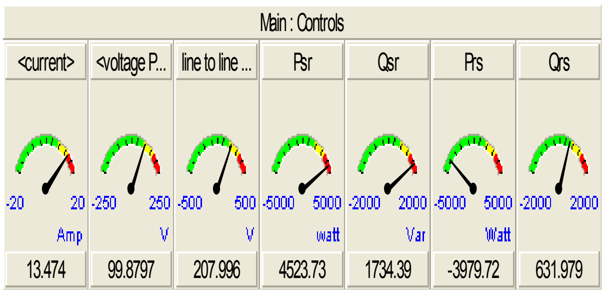
Fig. 3 Simulation block for capacitive compensation

R = resistance of line = 1 ohm per phase

L = inductance of line = 0.0223 Henry per phase

C = compensation capacitor = 1200 micro farad

6.2.1 Simulation Result



Main : Controls

<current>	<voltage P...	line to line ...	Psr	Qsr	Prs	Qrs
-20 20	-250 250	-500 500	-5000 5000	-2000 2000	-5000 5000	-2000 2000
Amp	V	V	watt	Var	Watt	
13.474	99.8797	207.996	4523.73	1734.39	-3979.72	631.979

From the result it is clear that active power flow from sending end is increased from 2753.25 watt to 4523.73 watt with the use of 1200 micro farad series capacitor

6.3 Simulation of TCSC Circuit Using PSCAD

In the block, a two bus system is considered for simulation and analyzing the power flow control

The TCSC varies the electrical length of the compensated transmission line with little delay [7]. Owing to this characteristic, it may be used to provide fast active power flow regulation. It also increases the stability margin of the system and has proved very effective in damping Sub-Synchronous Resonance (SSR) and power oscillation. The TCSC is the parallel combination of Thyristor Controlled reactor (TCR) and a fixed capacitor. So before discussing in details about TCSC, let us discuss about TCR [8].

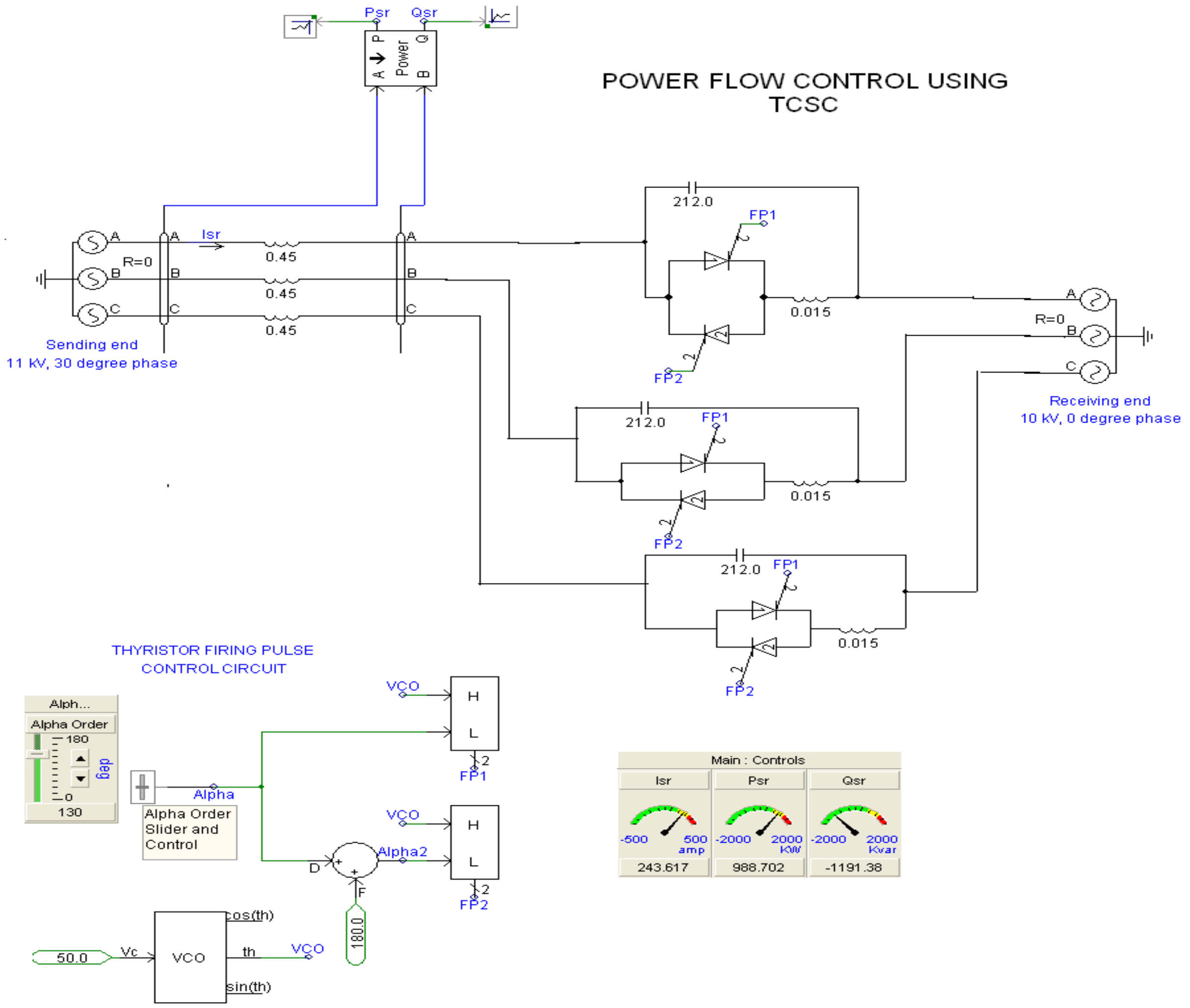


Fig. 3 Simulation block for TCSC compensation

The basic model of the TCSC is implemented in PSCAD in order to identify its main characteristics. For the purpose of the simulation, a constant AC voltage source Vs = 1 kV is used to supply a series R-L load. The thyristors are fired at an angle of 130 degree. The waveforms of the simulated TCSC model are obtained for each element used in the circuit. Of course with the help of slider used for varying the firing angle, we can vary the firing angle from 900 to 1800 and there will be change in waveform [9].

Firing angle for thyristor = alpha =130^0

Sending end voltage (line-line) = 11 kV

Receiving end voltage (line-line) = 10 kV

Sending end phase angle = 30^0

Receiving end phase angle = 0^0

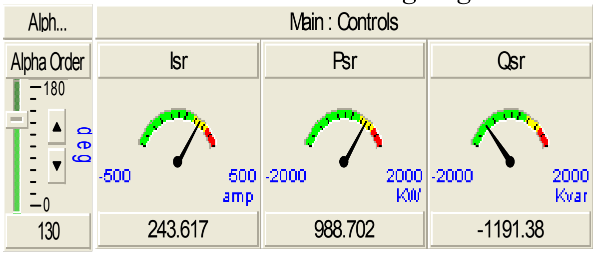
Qsr = Reactive power flow from receiving end

Transmission line inductance = 0.45 H (per phase)

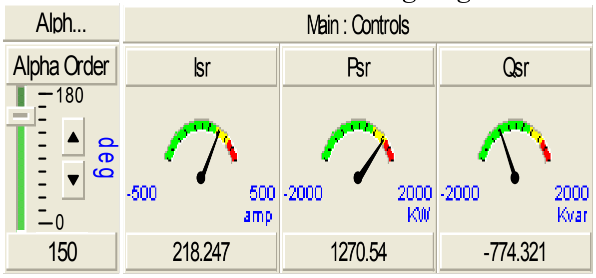
Fixed capacitor of TCSC = 212 micro farad

Series inductance of TCSC = 0.015 H

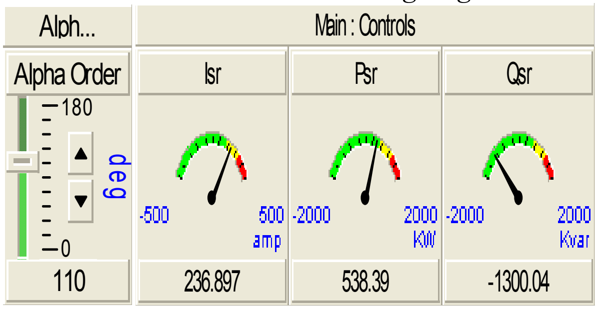
6.3.1 Simulation Result For Firing Angle = 130^0


Alpha Order 130
Isr 243.617
Psr 988.702
Qsr -1191.38

6.3.2 Simulation Result For Firing Angle = 150^0


Alpha Order 150
Isr 218.247
Psr 1270.54
Qsr -774.321

6.3.3 Simulation Result For Firing Angle= 110^0



From the three cases of simulation result, it is clear that as we increase the firing angle from 1300 to 1500, the TCSC causes capacitive compensation and the real power flow from sending end is increased from 988.72 KW to 1270.54 KW. Similarly when firing angle decreases from 1300 to 1100, 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 [10].

7. CONCLUSION

From the execution of simulation block in PSCAD. We reached at a conclusion that Thyristor-Controlled Series Capacitor is one of the fast acting power electronic controllers which can provide current and power flow control in the transmission line by varying its firing angle. Thus TCSC can be used as a series capacitor to reduce the overall transmission line reactance. Depending on the enhancement of power transfer desired at that time, without affecting other system-performance criteria, series compensation can be varied by TCSC. Thus TCSC is one of the important FACTS controller, which increases the overall power transfer capacity in the transmission line.

Thus with the discussion and simulation result it is very clear that, both current and the power flow in the transmission line can be controlled by varying the firing angle of TCSC to the desired value.

8. FUTURE SCOPE OF WORK

Works on the topic never ends with limited application. It has much more area of application such as damping of the power swings from local and inter-area oscillations, Voltage regulation of local network, reduction of short-circuit current etc. Various research works are going on control interaction between multiple Thyristor -Controlled Series Capacitor (TCSC). Also SVC-TCSC can be combined and used within power systems to enhance inter-area stability.. Though in this discussion PSCAD software is used for two bus systems, but it can be used for large bus network. Further study can be made on the Influence of TCSC on Fault Component Distance Protection and Impact of TCSC on the Protection of Transmission Lines. Thus TCSC can be used in many fields

9. REFERENCES

[1] P.Moore and P. Ashmole, "Flexible ac transmission systems: part 4-advanced FACTS controller," Power Engineering Journal, April 1998,pp.95-100

[2] Muhammad H. Rashid, "Power Electronics (concept of Flexible AC Transmission Systems)", Pearson Education-3rd Edition, 2004

[3] Fuerte-Esquivel, C.R.; Acha, E.; Ambriz-Perez, H.; "A thyristor controlled series compensator model for the power flow solution of practical power networks", Power Systems, IEEE Transactions on Power Delivery, Volume 15, Issue 1, Feb. 2000 Page(s):58 – 64

[4] Gama, C.; Tenorio, R.; "Improvements for power systems performance: modeling, analysis and benefits of TCSCs", Power Engineering Society Winter Meeting, 2000. IEEE Volume 2, 23-27 Jan. 2000 Page(s):1462 - 1467 vol.2

[5] Xie Da; Niu Hui; Chen Chen; Wu Jishun, "An algorithm to control the power flow in large systems based on TCSC ", Power System Technology, 1998. Proceedings. POWERCON '98. Volume 1, 18-21 Aug. 1998 Page(s):344 - 348 vol.1

[6] A. Ally, B.S Rigby, member, IEEE, "An Investigation into the Impact of a Thyristor Controlled Series Capacitor-Based Closed Loop Power Flow Controller under Fault Conditions", IEEE AFRICON 2004

[7] IEEE Power Engineering Society, "FACTS Application", IEEE press, New York, 1996

[8] Zhao Xueqiang and Chen Chen,"Circuit Analysis of a Thyristor Controlled Series Compensation", IEEE paper 1998, pages 1067-1072

[9] R. Billinton, M. Fotuhi-Firuzaba and S.O. Faried, " Power System Reliability Enhancement using a Thyristor Controlled Series Capacitor" , IEEE Transactions on Power Systems vol.14, No.1, February 1999.

[10] Xiaobo Tan, Luyuan Tong, "Characteristics and Firing angle control of Thyristor Controlled Series Compensation installations", IEEE Conf 1998, pages 672-676