Simulation and Analysis of GCSC in Power System

Prof.G D Kamalapur and Prof. V R Sheelavant
Faculty members, Department of Electrical and Electronics Engineering, Shri Dharmasthala Manjunatheshwara College of Engineering, Dharwad-580002, INDIA,gdkpur9@gmail.com

Deepika Reddy,Dixit Kumar R,Ragini Para and Arun Kanagolkar, Students Graduated from Shri Dharmasthala Manjunatheshwara College of Engineering, Dharwad-580002, INDIA

Abstract—**There is increasing demand for transmitting electrical power supply. The increase in power transmission also increases the complexity of electrical supply along with the increasing size. These results in the decrease of the performance of the power systems namely with load flow, power oscillations and voltage quality. Flexible AC transmission systems (FACTS) and High Voltage Direct Current (HVDC) technologies offer some effective schemes to meet these demands. In recent years, FACTS technology has been considered as one of feasible planning alternative in India, to increase power grid delivery capability and remove identified power system network bottlenecks. An attempt is made in this paper to discuss the development and types of FACTS. Simulation of GCSC, using SIMULINK is carried out for comparing voltage regulation and other power quality issues on Transmission lines and IEEE standard 5- bus system.**

Keywords— FACTS; GCSC,;Voltage Regulation;

I. Introduction

The present trends in renewable energy sources, such as PV and wind power, and connecting them to the distribution networks, has led to issues of maintaining system stability, power supply quality and reliability. Improved utilization of the existing power system is provided through the application of advanced control technologies. Power electronics based equipment, or Flexible AC Transmission Systems (FACTS), provide proven technical solutions to address these new operating challenges being presented today. FACTS technologies allow for improved transmission system operation with minimal infrastructure investment, environmental impact, and implementation time compared to the construction of new transmission lines.

The GTO Controlled Series Capacitor (GCSC) is very simple equipment, suitable for series compensation of power systems, improving their operation and performance. The principle of operation of GCSC, along with this they also point out some important differences between GCSC and TCSC like, GCSC has a great advantage if compared with the TCSC. The blocking angle of the GCSC can vary continuously, which varies continuously the fundamental component of the voltage VC. In contrast, the TCSC presents discontinuous equivalent impedance due to a prohibitive range of firing angle where parallel resonance appears between the TCR and the series capacitor. The work presents an analysis and evaluation of the GCSC with special emphasis is given to the harmonic analysis. [1].The duality of the GCSC with the well-known thyristor controlled reactor, used for shunt compensation Simulation results illustrates the time response of the equipment and its ability to control power flow in a transmission line. Comparison with the TCSC has shown that the GCSC is more compact, with lesser passive components: it does not need reactors and its capacitor bank is much smaller. Also, the switches and capacitor currents are smaller in the GCSC. Besides that, the semiconductor of the GCSC should be rated to a slightly higher voltage than the SCR valves of the TCSC. The main focus is the need of development of a high-power valve comprising series connected self-commutated switches capable of blocking reverse voltage. Attention should also be given to the rate of rise of current in the valves [2].

The GCSC is supposed to be an excellent transmission line series compensator. In practical applications, the GCSC would be used typically for EHV transmission lines compensation, requiring high power GTO valves. To overcome the limitations due to the power range of the GTO valves, multi-module GCSC (MGCSC) can be used in a way that several small GCSCs are connected in series with one another in order to provide the desired series compensation level. A detail analysis and evaluation of the MGCSC while the special emphasis is given to the harmonic analysis of this device showing that how much of harmonic levels are generated by this device, and how they can be reduced. In addition, the harmonics of the power system, to where the MGCSC is connected, is studied. In order to consider the sub synchronous resonance (SSR) phenomenon, which is a potential problem in series compensated transmission lines, all analysis are performed in the IEEE First Benchmark Model, a highly unstable power system to SSR, by studying the impact of the MGCSC on the SSR mitigation [3].

A comparative study of the performance of distance relays for transmission line high voltage 400 kV in Eastern Algerian transmission networks at Group Sonelgaz compensated by two different series FACTS i.e. GCSC and Thyristor Controlled Series Capacitor (TCSC) connected at midpoint of an electrical transmission line and the paper studies the effects of GCSC and TCSC insertion on the total impedance of a transmission line protected by MHO distance relay [4].

The design of a dynamic neuroidentifier for the newly invented GCSC FACTS device incorporated in a multi machine power system. The design of a dynamic neurocontroller for the GCSC FACTS device using the approximate dynamic programming based HDP approach. Comparison of the performance of the optimal dynamic neurocontroller with the conventional PI controller for a number of operating conditions [5].

To design of an optimal Auxiliary Transient Neurocontroller (ATNC) for the GCSC in a multi-machine power system. An optimal auxiliary transient neurocontroller has been developed for a new type of FACTS device and implemented in real- time using Real time digital power system and Digital signal processing platform [6].

The capability of the GCSC to mitigate SSR and electromechanical oscillations that occur when a steam turbine generator is connected to a long transmission line with series compensation is dealt. Series compensation of power transmission line is an important way to improve power transfer capability, to control load sharing among parallel lines and to enhance steady state stability of a long transmission lines. SSSC is more flexible device than the TCSC and GCSC. Another FACTS device that can mitigate SSR is the unified power flow controller (UPFC). However, it has a series and shunt converter, it is more expensive and complex than the SSSC. It is shown that by using GCSC with controlled capacitor the stresses due to torsional sub synchronous oscillations can be damped [7].

GCSC can damp SSR even without a specific control. It is observed that, using a simple controller, SSR as well as electromechanical oscillation can be damped. It has shown some results of the performance of the GCSC mitigating SSR in a highly unstable power system through simulation. It is shown that the turn-off angle generator based on zero-crossing detector was the responsible for this natural damping characteristic. However, for this example the GCSC equivalent reactance had to be twice larger than the fixed capacitor. On the other hand, it was shown that a smaller GCSC with a simple external power oscillation control was also able to improve sub synchronous resonance mitigation capability. The controller used the electric power as a feedback signal because this signal is easier to measure than the deviation in frequency. The proposed controller for the GCSC was able to guarantee SSR mitigation and increase the operating range of the system. To damp electromechanical oscillations another controller was proposed and tested showing that GCSC can be also effective to damp this kind of oscillations. It has shown that the gain of the controller has an important influence on the GCSC performance [8].

To carry out analysis as to how capacitor can be used to compensate in the IEEE standard 3-bus system and series capacitor bank can theoretically be located anywhere along the line. Factors influencing choice of location include cost and also help to draw IEEE standard 5-bus system in MATLAB Simulink [9]

Subsynchronous resonance (SSR) damping in fixed-speed wind turbine generator systems (FSWTGS) by using two series flexible ac transmission system (FACTS) devices, the thyristor-controlled series capacitor (TCSC), and gate-controlled series capacitor (GCSC) are studied. The former is a commercially available series FACTS device, and the latter is the second generation of series FACTS devices using gate turnoff (GTO) or other gate-commuted switches. The GCSC is characterized by a fixed capacitor in parallel with a pair of antiparallel gate-commuted switches enabling rapid control of series impedance of a transmission line. It is shown that the SSR damping with a GCSC is limited to changing the resonance frequency, in comparison with a fixed capacitor, which may not be adequate to damp out the SSR. Therefore, a supplementary SSR damping controller (SSRDC) is designed for the GCSC. Moreover, it is proven that the GCSC equipped with a well-designed SSRDC can effectively damp the SSR in FSWTGS. In order to verify the effectiveness of the GCSC in SSR damping, its performance is compared with the TCSC, which is an existing series FACTS device. In addition, time-frequency analysis is employed in order to evaluate and compare the SSR time-varying frequency characteristics of the GCSC and TCSC. The IEEE first benchmark model on SSR is adapted with an integrated FSWTGS to perform studies, and extensive simulations are carried out using PSCAD/EMTDC to validate the result.[10]

The FACTS controller devices based Voltage Source Converter (VSC) for shunt and series compensation, allocated in a substation, among the multiline transmission systems is presented in this paper. The paper proposes the full model comprising of the 60-pulse Gate Turn-Off (GTO) thyristor VSC that is constructed becomes the FACTS devices in digital simulation system and investigates the dynamic operation of control scheme for shunt and two series VSC for active and reactive power compensation and voltage stabilization of the electric grid network. The complete digital simulation of the shunt VSC operating as a Static Synchronous Compensator (STATCOM) controlling voltage and Var at bus, the series VSC operating as a Static Synchronous Series Capacitor (SSSC) controlling injected voltage while keeping injected voltage in quadrature with current, the two series VSCs operating as a Interline Power Flow Controller (IPFC) controlling injected voltage for power flow and the shunt VSC with the one series VSC operating as a Unified Power Flow Controller (UPFC) within the power system are performed in the MATLAB/Simulink environment using the Power System Block set. The FACTS control system scheme and the network are modeled by specific electric blocks from the power system block set. The controllers for the shunt VSC and two series VSCs are presented in this paper based on the decoupled current control strategy. The performance of the proposed FACTS device schemes connected to the 500-kV grid are evaluated and fully validated by digital simulation. [11]

II. GTO Thyristor-Controlled Series Capacitor

A. Gate Turn-Off Thyristor (GTO)

The Gate turn off thyristor (GTO) is a four layer PNPN power semiconductor switching device that can be turned on by a short pulse of gate current and can be turned off by a reverse gate pulse. Basically, the gate turn-off (GTO) thyristor is similar to the conventional thyristor [1].Consider the equivalent circuit, Fig.1(c) If a large pulse current is passed from the cathode to the gate to take away sufficient charge carriers from the cathode, i.e., from the emitter of the upper pnp transistor, the npn transistor will be drawn out of the regenerative action. As the upper transistor turns off, the lower transistor is left with an open gate, and the device returns to a non-conducting state.

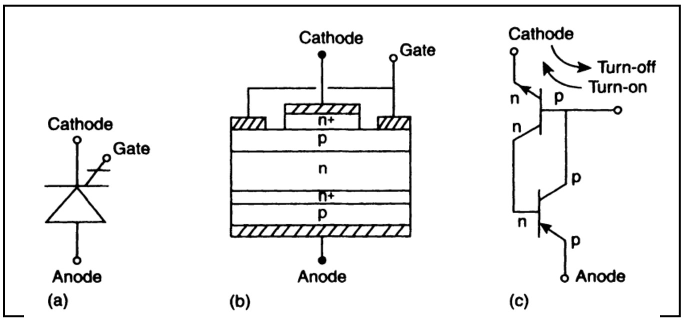

Fig 1: Gate turn-off (GTO) thyristor: (a) GTO symbol, (b) GTO structure, and (c) GTO equivalent circuit.

B. *GCSC and its principle of operation*: [10]

An elementary GTO Thyristor-Controlled Series Capacitor, proposed by Karady with others in 1992, is shown in Figure 2(a). It consists of a fixed capacitor in parallel with a GTO thyristor valve that has the capability to turn on and off upon command. This compensator scheme is interesting in that it is the perfect combination of the well-established TCR, having the unique capability of directly varying the capacitor voltage by delay angle control. The objective of the GCSC scheme shown in Figure 2(a) is to control the ac voltage V_C across the capacitor at a given line current *i*, evidently, when the GTO valve, *SW*, is closed, the voltage across the capacitor .is zero, and when the valve is open, it is maximum. For controlling the capacitor voltage, the closing and opening of the valve is carried out in each half-cycle in synchronism with the ac system frequency. The GTO valve is stipulated to close automatically (through appropriate control action) whenever the capacitor voltage crosses zero. However, the turn-off instant of the valve in each half-cycle is controlled by a (turn-off) delay angle γ ($0 \leq \gamma \leq \pi/2$),, with respect to the peak of the line current. Refer to Figure 2(b), where the line current *i*, and the capacitor voltage $V_c(\gamma)$ are shown at $\gamma = 0$ (valve open) and at an arbitrary turn-off delay angle γ , for a positive and a negative half-cycle. When the valve *sw* is opened at the crest of the (constant) line current ($\gamma = 0$), the resultant capacitor voltage Vc will be the same as that obtained in steady state with a permanently open switch. When the opening of the valve is delayed by the angle γ with respect to the crest of the line current, the capacitor voltage can be expressed with a defined line current, i(t) = I cosωt on, as follows:

$$v_C(t) = \frac{1}{C}\int_{\gamma}^{\omega t} i(t)\,dt = \frac{I}{\omega C}(\sin \omega t - \sin \gamma) \quad \ldots (1)$$

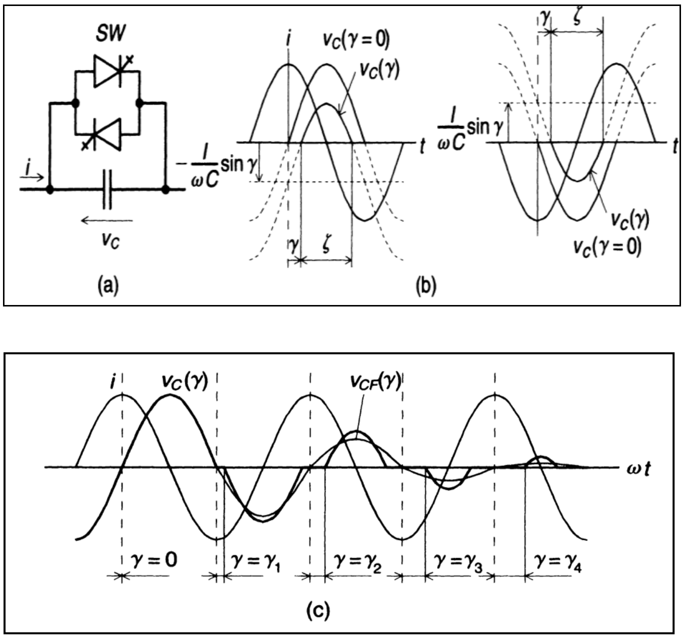

Fig 2 Basic GTO-Controlled Series Capacitor (a), principle of turn-off delay angle control (b), and attainable compensating voltage waveform(c).

Since the valve opens at γ and stipulated to close at the first voltage zero, (1) is valid for the interval ($\leq\omega\leq\pi- \gamma$). For subsequent positive half-cycle intervals the same expression remains valid. For subsequent negative half-cycle intervals, the sign of the terms in (1) becomes opposite. In (1) the term (I/ωC) sinγ is simply a γ dependent constant by which the sinusoidal voltage obtained at $\gamma = 0$ is offset, shifted down for positive, and up for negative voltage half-cycles, as illustrated in Figure 2(b). Since the GTO valve automatically turns on at the instant of voltage zero crossing (which is symmetrical on the time axis to the instant of turn-off with respect to the peak of the capacitor voltage), this process actually controls the non-conducting (blocking) interval (or angle) of the GTO valve. That is, the turn-off delay angle γ defines the prevailing blocking angle ∫:∫ = π-2 γ . Thus, as the turn-off delay angle γ increases, the correspondingly increasing offset results in the reduction of the blocking angle ∫ of the valve, and the consequent reduction of the capacitor voltage. At the maximum delay of $\gamma = \pi/2$, the offset also reaches its maximum of *I/ωC,* at which both the blocking angle and the capacitor voltage become zero. It is evident that the magnitude of the capacitor voltage can be varied continuously by this method of turn-off delay angle control from maximum *(*γ =0) to zero ($\gamma = \pi/2$), as illustrated in Figure 2(c), where the capacitor voltage $V_C(\gamma)$, together with its fundamental component $V_{CF}(\gamma)$,are shown at, various tum-off delay angles γ. Note, however, that the adjustment of the capacitor voltage

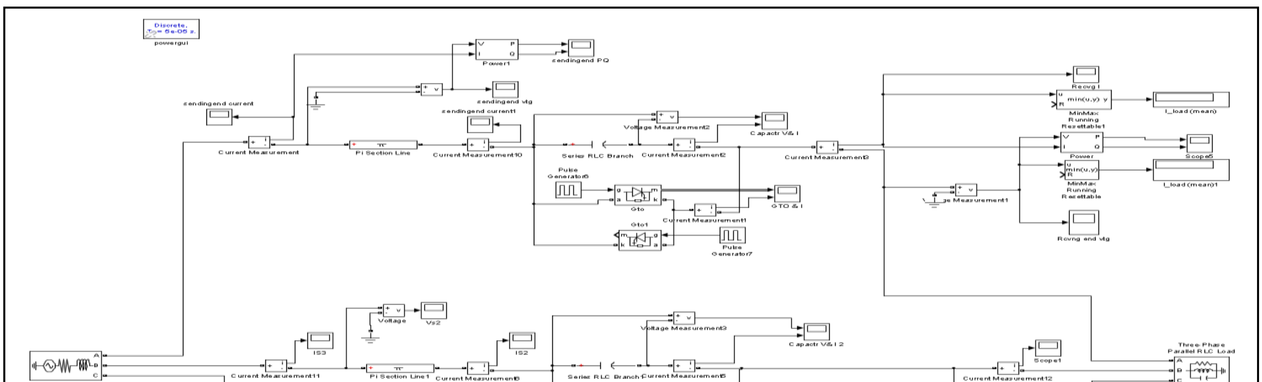

Fig. 3 Three Phase Transmission Line with GCSC Simulink Model

similar to the adjustment of the TCR current, is discrete and can take place only once in each half-cycle.

The amplitude $V_{CF}(\gamma)$ of the fundamental capacitor voltage $V_{CF}(\gamma)$ can be expressed as a function of angle:

$$V_{CF}(\gamma) = \frac{I}{\omega C}\left(1 - \frac{2}{\pi}\gamma - \frac{1}{\pi}\sin 2\gamma\right) \quad \text{......(2)}$$

where I is the amplitude of the line current, C is the capacitance of the GTO thyristor controlled capacitor, and ω is the angular frequency of the ac system. The GCSC, varying the fundamental capacitor voltage at a fixed line current, could be considered as variable capacitive impedance. Indeed, an effective capacitive impedance can be found for a given value of angle γ, or in other words, an effective capacitive impedance, Xc, as a function of γ, for the GCSC can be defined. This impedance can be written directly from (2), i.e.,

$$X_C(\gamma) = \frac{1}{\omega C}\left(1 - \frac{2}{\pi}\gamma - \frac{1}{\pi}\sin 2\gamma\right) \quad \text{.....(3)}$$

Evidently, the admittance Xc (γ)) varies with γ in the same manner as the fundamental capacitor voltage VCF (γ).

III.SIMULATION MODEL

The TCSC model is simulated using SIMULINK and the results are as shown. (Fig. 3 to Fig.6) and table I to IV.

Table I Voltage Regulation for different lengths of Transmission line

Transmission line length(km)	Voltage Regulation %		Difference
	Without GCSC	With GCSC	
500	7.33	1.861	5.469
600	8.47	3.335	5.135
700	9.76	4.60	5.152
800	10.66	5.877	4.783
900	11.64	6.984	4.656
1000	12.62	8.115	4.505
1100	13.51	9.264	4.246
1200	14.15	10.332	3.818

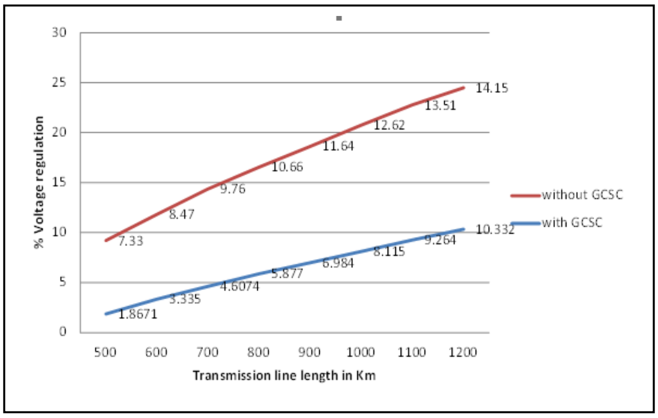

Fig. 4. Variation of voltage Regulation with line length

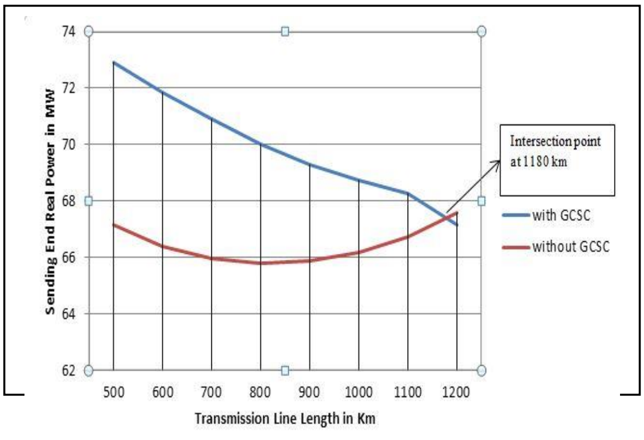

Fig.5 Sending end Real power with Line Length.

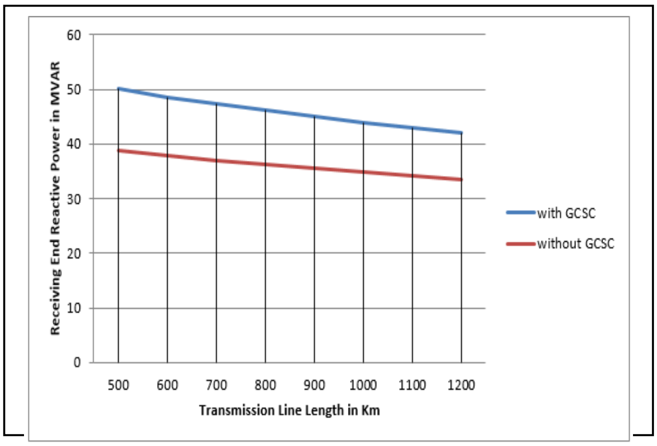

Fig. 6 Receiving end Reactive Power with Line Length.

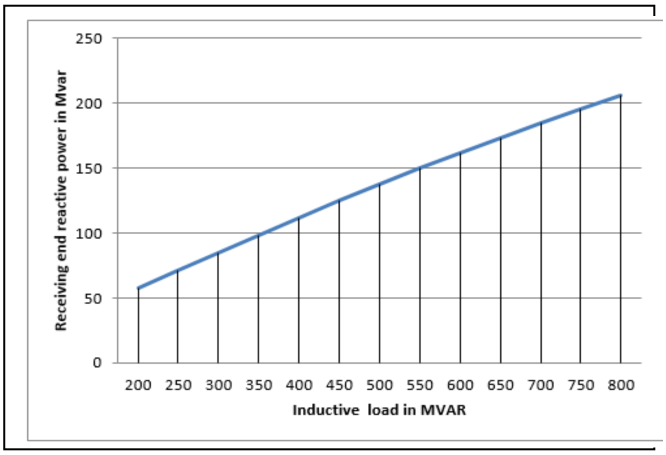

Fig. 7. Receiving End reactive power with Inductive Load

The following Table II and Table III are the standard 5 Bus data used.

Table II IEEE standard 5- bus

Line	1-2	1-5	2-3	3-4	3-5	4-5
Length(km)	64.4	48.3	84.8	128.7	80.5	96.5

Table III IEEE Bus Data

Bus	Generation		Load		V p.u
	P (MW)	Q (MVAr)	P (MW)	Q(MVAr)	
1- slack	--	--	65	30	1.04
2 -load	0	0	115	60	1.00
3- PV	180	--	70	40	1.02
4 -load	0	0	70	30	1.00
5 -load	0	0	85	40	1.00

Table IV Active (MW) & reactive power (MVAr) on Bus 2-3

With GCSC				Without GCSC			
Source side		Load side		Source side		Load side	
P	Q	P	Q	P	Q	P	Q
10.64	-8.42	5.20	4.13	10.6	-8.45	3.86	3.12

CONCLUSIONS

- The GCSC is characterized by a fixed capacitor in parallel with a pair of antiparallel gate-commuted switches enabling rapid control of series impedance of a transmission line.
- GCSC is an excellent transmission line series compensator that improves the voltage profile of the transmission line.
- Controls the power flow in the transmission line with effective monitoring of reactive power depending upon load requirement.
- Operating transmission line length is 1180km and the voltage harmonic distortion is slightly increased from 0.91% to 1.41%.
- It is able to guarantee SSR mitigation and increasing the operating range.
- The simulated model is, validated with IEEE 5- bus system indicates that reactive power injected in the load side is increased, thus leading to improvement in power quality.

REFERENCES

[1] Luiz Felipe Willcox de Souza, Edson Hirokazu Watanabe, and Maurício Aredes, "GTO Controlled Series Capacitors: Multi-Module and Multi-Pulse Arrangements", IEEE Transactions on Power Delivery, Vol. 15, No. 2, April 2000.pp 725 - 731

[2] E. H. Watanabe,L. F. W. de Souza, F. D. de Jesus,J. E. R. Alves, and A. Bianco,"GCSC - Gate Controlled Series Capacitor: a New Facts Device for Series Compensation of transmission Lines", IEEE Transmission and Distribution Conference, 8-11 Nov. 2004 vol 15,Issue1, pp 44 - 50

[3] Swakshar Ray, Ganesh K. Venayagamoorthy,Edson H. Watanabe, Fabio D. de Jesus, "Optimal Dynamic Neurocontrol of a Gate-Controlled Series Capacitor in a Multi-machine Power System" Proc. 13th Int. Con. on, Intelligent Systems Application to Power Systems 6-10 Nov. 2005 Arlington, VA. pp7

[4] Mohamed Zellagui, and Abdelaziz Chaghi ,"A Comparative Study of GCSC and TCSC Effects on MHO Distance Relay Setting in Algerian Transmission Line",Int. Journal of Engineering and Technology, Vol 2,No 2, Feb 2012,pp 220-228

[5] H. A. Mohammadpour, M. R. Alizadeh Pahlavani, and A. Shoulaie, "On Harmonic Analysis of Multi – Module Gate - Controlled Series Capacitor (MGCSC) Considering SSR Phenomenon", International Review of Electrical Engineering, vol. 4, No 4, July-August 2009pp 627-634

[6] Swakshar Ray, and Ganesh K.Venayagamoorthy, "Real-Time Implementation of an Optimal Transient Neurocontroller for a GCSC", Proc. IEEE International Joint Conference on Neural Network July 16-21, 2006, Vancouver, pp2261 - 2266

[7] B. S. Umre, J. B. Helonde , J. P. Modak,Sonali Renkey, "Application of Gate-Controlled Series Capacitors (GCSC) for Reducing Stresses due to Sub-Synchronous Resonance in Turbine- Generator Shaft" IEEE Energy Conversion Congress and Exposition 12-16 Sept. 2010, Atlanta pp2300 - 2305

[8] Fábio Domingues de Jesus, Edson Hirokazu Watanabe, Luiz Felipe Willcox de Souza, and José Eduardo R. Alves, Jr.,"SSR and Power Oscillation Damping Using Gate-Controlled Series Capacitors (GCSC)", IEEE Transactions On Power Delivery, Vol. 22, No. 3, JULY 2007. pp1806 - 1812

[9] Vinaya Chavan, Sunil K. Patil, "Load Flow Analysis Of Transmission Network With Seriescompensation"Int. Journal of Research in Engineering and Technology, vol 3.Issue 6,June 2014,pp526-530

[10] Narain G. Hingorani & Laszlo Gyugyi, "Understanding FACTS-Concepts and Technology of AC Transmission Systems."IEEE Press-1999, John Wiley and Sons, INC., Publication.

[11] Hossein Ali Mohammadpour; Md. Moinul Islam; Enrico Santi; Yong-June Shin "SSR Damping in Fixed-Speed Wind Farms Using Series FACTS Controllers "IEEE Transactions on Power Delivery Year: 2016, Volume: 31, Issue: 1 pp 76 - 86,

[12] Rakhmad Syafutra Lubis "Digital simulation of the FACTS system with 60-pulse GTO-based Voltage Source Converter" Second Int. Con. on Instrumentation, Communications, Information Technology, and Biomedical Engineering Bandung 8 -9 Nov. 2011,pp201 - 206,