Recent Trends on FACTS and D-FACTS

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***Abstract*--Modern power systems are continuously being expanded and upgraded to cater the need of ever growing power demand. But, in recent years, energy planners have faced financial and environmental difficulties in expanding the power generation and transmission systems. These difficulties included limited available energy resources, time and capital required and also the land use restrictions etc. These situations have forced planning engineers to look for new techniques for improving the performance of existing power system. This is a review paper to analyze the current trends in FACTS and D-FACTS to improve the performance of power system performance. It contains work which has been carried out by various researchers in the field of FACTS and D-FACTS.**

***Index Terms*--DSSC-Distributed static series compensator, DSI-Distributed static impedances.**

I. Introduction

Power systems over the worldwide becoming complex day to day and continuous requirements are coming for stable, secured, controlled, economic and better quality power. These requirements become more essential when environment becoming more vital and important deregulation. Power transfer capacity in transmission system is limited due to various factor such as steady state stability limit, thermal limit, transient stability limit and system damping or even negative damping. The scenarios of the magnitude of various limits are given in figure 1[1].

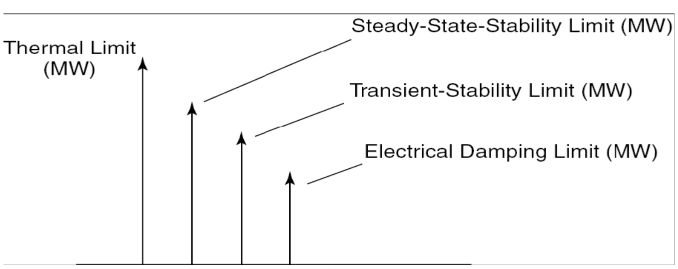

Fig.1.

The electrical damping of power system requires to be mitigate to stable oscillations free power transfer. Flexible AC Transmission System and Distributed Flexible AC Transmission System provides feasible and cost-effective solution to these problems and so these devices are required to use worldwide for improving performance of power system[2]-[3].

II. REVIEW OF FACTS AND D-FACTS CONTROLLER

FACTS CONTROLLERS

A. Edris et.al.[4] are defined FACTS as "Alternating current transmission systems incorporating power-electronic based and other static controllers to enhance controllability and increase power transfer capability ."

FACTS are used to fulfill the given objectives:

- To improve the transient stability limit of the line
- To Enhance the damping of existing system
- To improve voltage stability
- To mitigate sub synchronous resonance [5]
- To minimize short circuit currents
- To improve integrity of wind power generation
- To improve terminal performance of HVDC converter

an overview of nowadays available network controllers and FACTS-devices are as below [79].

A. Shunt Device

(1)Static Var Compensator:
(2)Static Synchronous Compensator (svc light/statcom)
(3)STATCOM

B. Series Device

(1) Thyristor Controlled Series Compensator (TCSC)
(2) Static Synchronous Series Compensator (SSSC, DVR, SVR)
(3) Fault Current Limiter (SC+FPD)

C. Hybrid device

(1) Dynamic Power Flow Controller (DFC)
(2) HVDC Light/HVDCLightB2B/UPFC

Thyristor based FACTS controllers are enough mature technology and SVC and TCSC are all ready been installed at many locations. Some new versatile FACTS controllers which more effectiveness are emerging in power system. These include Thyristor controlled phase shifting transformer (TCPST) [7] , inter phase power controller(IPC)[6],Thyristor control breaking resistor(TCBR)[24,4],Thyristor control voltage limiter(TCVL)[24,4],Battery energy storage system(BESS) and , superconducting magnetic energy storage system(SMES) [8],[9],[10].

II. A STATIC VAR COMPENSATOR

The SVC is a widely used FACTS controller, it is a shunt connected absorber or generator which exchange capacitive or inductive current to maintain/control specific parameter of power system.fig 2 shows SVC having controllable variable inductor with switchable capacitance.

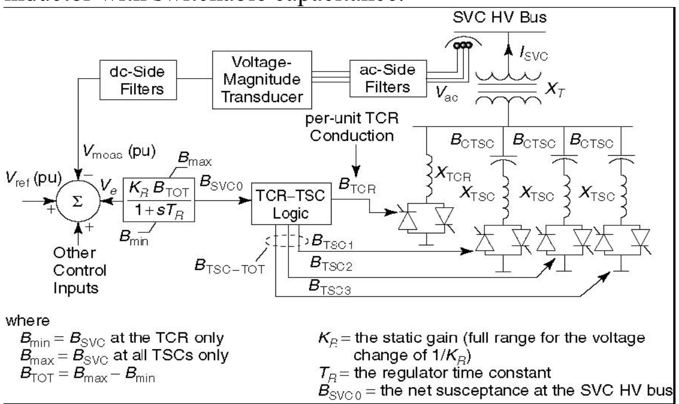

Fig. 2. SVC controllable variable inductor with switchable capacitance

svc may be of(a)Thyristor control Reactor(TCR)(b)Thyristor Switched Capacitor (c) combination of (a)and (b) (c)Fixed capacitor-TCR(d)TCR-Mechanically Switched Capacitor(TCR-MCR)[2] here the high voltage system bus voltage measured ,filtered and compared with reference voltage and the error voltage is processed and through gain time constant controller to provide a desired susceptance for SVC. This susceptance is now implemented by logic control to select no of TSCs or to determine firing angle for the TCR.

The modeling and simulation of TSR based SVC and TCR based SVC are investigated using Matlab fuzzy logic controller[64].Effect of both Thyristor switched Based Reactor and Thyristor Controlled Capacitor based VAR compensator on load voltage in a single machine infinite bus system are analyzed.

The three modeling of SVC generator fixed susceptance model, total susceptance model and firing model are compared [65].the dimension under which comparison done was voltage at regulated bus, equivalent SVC susceptance at the fundamental frequency, and load flow convergence rate when SVC is operating both with in and on the limit Two modified models are also proposed to improve SVC regulated voltage under static condition and better convergence rate gas been achieved.

II B STATCOM

Many VSC-based topologies and configurations are adopted in the state-of-the-art STATCOM controllers and significantly, multi-pulse and/or multi-level topologies [11–52] are widely accepted in the design of compensators. For example, a two-level multi-pulse topology is a mature topology and commercially adopted in +100 MVA STATCOM at 500/161 kV Sullivan S/S of Tennessee Valley Authority (TVA),US [53-56] and in +80MVA SVG at 154 KV Inuyama switching station of Kansai Electric Power Co.

(KEPC), Japan [57]. An elementary six-pulse VSC which consists of three legs (phases) with two valves per leg and an electrostatic capacitor on the DC bus is illustrated in Fig. 3.

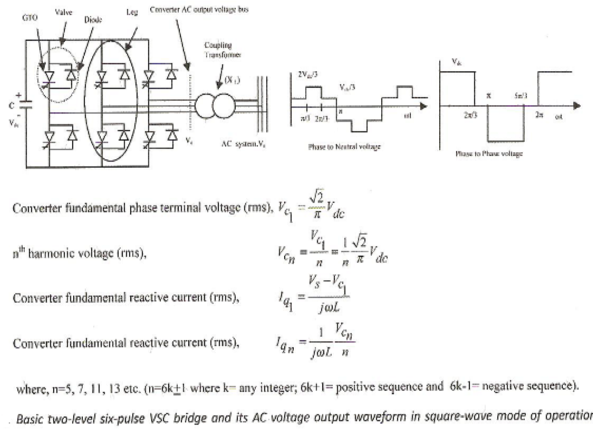

Fig. 3. Six pulse VSC

Each valve consists of a self-commutating switch with a reverse diode connected in parallel. In square-wave mode, eight possible switching states are possible with respect to the polarity of DC voltage source (Vdc). A set of three quasi square waveforms at its AC terminals, displaced successively by 120, is obtained using fundamental frequency switching modulation. The phase to neutral (0, +Vdc/3, +2Vdc/3) and line-to-line voltage (0, +Vdc) of the converter shown in Fig. 1 contain an unacceptable current harmonics causing severe harmonic interference to electrical system. To reduce THD, multi-pulse converter topology derived from the combination of multiple number (N-numbers) of elementary six-pulse converter units to be triggered at specific displacement angle(s), is widely adopted, and output AC voltage waveforms from each unit is electro-magnetically added with an appropriate phase shift by inter-phase transformer(s) to produce a multi-pulse (6 _ N pulses) waveform close to sinusoidal wave.

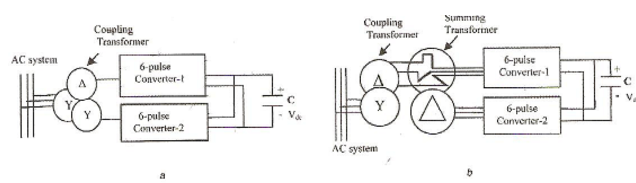

Fig. 4. Multi-pulse parallel and series converter configurations
a. 12- pulse parallel converter configuration
b. 12-pulse series converter configuration

In a multi-pulse converter configuration, the displacement angle between two consecutive six-pulse converter is 2p/ (6N) and three-phase voltage contains odd harmonics component of the order of (6Nk+1), where k ¼ 1, 2,3, ... With the increase in pulse number, lower-order harmonics are neutralized and a very close to sinusoidal AC output voltage waveform can be realized. Compared with basic six-pulse converter, the multi-pulse configuration of STATCOM increases the achievable VAR rating, improves the harmonic performance, decreases the DC side current harmonics and reduces significantly the overall filter requirements. Basic two-level 12 (2 _ 6-pulse), 24 (4 _ 6-pulse) and 6N (N _ 6-pulse)-pulse converter configurations are depicted Figs. 4a–4b, 5 and 6, respectively.

Basic configurations of magnetics in multiples converters are discussed in [12, 57, 54]. It is noted that increase in pulse order increases the number of electronics devices, magnetics and associated components and thus added to the cost. However, the high pulse-order STATCOM enables to improve harmonics and operational performances. Pulse configuration [11, 57, 51, 54, 55, 56] where magnetics are designed generally in two stages using transformers. The inter-phase transformers (as many as VSCs) are employed to sum-up the output AC voltages of converters, which is further stepped-up through a main coupling transformer to match with the main AC system. The typical two stages of magnetics architecture of the existing +80 MVA SVG [57] at the Inuyama switching station are depicted in Figs. 7a and 7b.

II C TCSC

A new control design for the Thyristor Controlled Series Compensator (TCSC) based on Nonlinear PI Predictive Control scheme (NPIPC) to improve the transient and dynamic performance of power system has been proposed. Here the control scheme considered uncertainty of power system. The stability of the closed loop system under this nonlinear controller is guaranteed by the control law. This includes a predictive part that can predict the future of the system's output caused by the system dynamics. A local control approach is used so that all input variables can be obtained locally and easily. To validate the proposed control scheme, simulations is done on single machines double line infinite bus power system equipped with TCSC using PSCAD/EMTDC software package under steady state and dynamic stability. The simulation results show the superiority and robustness of the proposed control compared to conventional control systems. The results verified that the proposed TCSC controller is effective in damping low frequency oscillations resulting from small disturbances condition like decrease in mechanical power input.[64]

The power oscillation damping (POD) concept is utilized in this proposed scheme. The (POD) controllers implemented in the two thyristor controlled series compensators of the Brazilian North-South (NS) interconnection, in the year 1999, were solely intended to damp the low-frequency NS oscillation mode. These controllers are still under operation and are derived from the modulus of the active power flow in the NS line that is phase-lagged at the frequency of the NS mode and may experience relatively large excursions generated by exogenous disturbances. The same 1999 data used to compare the performance of a proposed robust POD controller design with those of two conventional designs. A recent robust control synthesis algorithm used in this work is based on a non smooth optimization technique and has the capability to handle various controller structures, including reduced-order, and to deal with time-domain constraints on both controlled and measured outputs. Moreover, the nonsmooth design technique encompasses multiple operating conditions subject to various test signals, hence building a truly time-domain multi-scenarios approach. According to the results discussed hereafter, this is a key advantage in the industrial context of increasing demand for performance and robustness. The described results relate to a large-scale system model used in the feasibility studies for that interconnection. [66]

A new approach of oscillation transient energy function (OTEF) is proposed for the analysis and damping of power system area-mode oscillations. The OTEF interprets an area-mode oscillation as the conversion between oscillation kinetic energy and potential energy. Based on this interpretation, an OTEF descent method has been developed to design a supplementary fuzzy-logic thyristor controlled series compensator (TCSC) controller to damp the area-mode oscillation. Since the proposed method guarantees the continuous descent of oscillation energy, the fuzzy-logic TCSC damping controller designed is robust to the variations of power system operating conditions. **A** 4-generator 2-area interconnected power system is presented to demonstrate the effectiveness and robustness of the TCSC fuzzy logic damping controller installed in the power system.[67]

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. The FACTS controllers clearly enhance power system performance, improve quality of supply and also provide an optimal utilization of the existing resources. Thyristor Controlled Series Compensator (TCSC) is a key FACTS controller and is widely recognized as an effective and economical means to enhance power system stability. 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. The simulated TCSC shows that the oscillations are damped out on increasing the damping coefficient. Change in value of reactance of the TCSC also affects the stability of the system. [68]

II D SSSC

An investigation on transient stability of power systems equipped with a Flexible Alternating Current Transmission System (FACTS) device stressed. A Static Synchronous Series Compensator (SSSC) is considered as a FACTS device. In a power system transmission, the SSSC has two functions; first, it compensates reactive power, second, it improves transient stability. The second functionality of the SSSC system is due to its capability to raise the maximum transferable electric power (*Pmax*) from generator to infinite bus. To raise the maximum transferable electric power (*Pmax*), the SSSC actively and appropriately changes the line reactance. Since the control of the power system is a nonlinear problem, therefore, a nonlinear controller for the SSSC is designed and presented in this paper. The proposed nonlinear controller of the SSSC increases critical clearing time of the power systems' faults and damps out rotor oscillations of a single machine connected to an infinite bus. Unlike linear controllers, performance and operating region of the proposed nonlinear controller of the SSSC system is not restricted to a close vicinity of the generator operating point, but includes the entire region of operation. The Matlab simulations for computational analysis and the Lyapunovcriteria of stability for analytical investigations are used to examine the response time and robustness of the proposed nonlinear controller. [65]

The problem of controlling and modulating power flow in a transmission line using a Synchronous Static Series Compensator (SSSC) has been considered. The studies, which include detailed techniques of twelve pulse and PWM controlled SSSC, are conducted and the control circuits are presented. The developed control strategies for both twelve-pulse and PWM-controlled SSSC use direct manipulations of control variables instead of typical d-q transformations. The complete digital simulation of the SSSC within the power system is performed in the MATLAB/Simulink environment using the Power System Blockset (PSB). Simulation results validate that Voltage and Power Oscillation can be damped properly using of Synchronous Static Series Compensator (SSSC). [69]

The novel fault-tolerant optimal neurocontrol scheme (FTONC) for a static synchronous series compensator (SSSC) connected to a multimachine benchmark power system. The dual heuristic programming technique and radial basis function neural networks are used to design a nonlinear optimal neurocontroller (NONC) for the external control of the SSSC. Compared to the conventional external linear controller, the NONC improves the damping performance of the SSSC. The internal control of the SSSC is achieved by a conventional linear controller. A sensor evaluation and (missing sensor) restoration scheme (SERS) is designed by using the auto associative neural networks and particle swarm optimization. This SERS provides a set of fault-tolerant measurements to the SSSC controllers, and therefore, guarantees a fault-tolerant control for the SSSC. The proposed FTONC is verified [70] by simulation studies in the PSCAD/EMTDC environment.

Analytical and simulation results of the application of distance relays for the protection of transmission employing Static Synchronous Series Compensator (SSSC) has been provided. Firstly a detailed model of the SSSC and its control is proposed and then the situation is studied analytically, where the errors introduced in the impedance measurement due to the presence of SSSC on the line are analyzed. The simulation results show the impact of SSSC on the performance of a distance protection relay for different fault conditions; the studies also include the influence of the operational mode of SSSC, its location on the transmission system and fault resistance. The complete digital simulation study using the full 48-pulse GTO SSSC model. The digital simulation is performed in the MATLAB/Simulink software environment using the Power System Blockset (PSB). [71]

The distance relay overreaching in the case of installation of Static Synchronous Series Compensator (SSSC) which is categorized as a series connected Flexible Alternating Current Transmission System (FACTS) device, on second circuit of a double circuit transmission line. This is done by presenting the measured impedance at the relaying point in the case of SSSC presence at the far end of the second circuit. The measured impedance at the relaying point is greatly influenced in the presence of SSSC on the transmission line or even in the case of installing SSSC on the far end of the second circuit. The measured impedance at the relaying point depends on many factors including power system structural conditions, the pre-fault loading, and the ground fault resistance, SSSC structural and controlling parameters. [72]

II E Hybrid devices

Two new methods for power flow calculation of power systems in presence of Dynamic Flow Controller (DFC), which is a new member of FACTS controllers. In first method A new steady state model of DFC is introduced for the implementation of the device in the conventional Newton-Raphson power flow algorithm. The impact of DFC on power flow is accommodated by adding new entries and modifying some existing ones in the linearized
Jacobian equations of the same system without DFC. The focus of second method is on the discrete nature of the DFC and including its effects on power flow. This method is based on Nabavi model for FACTS devices. A case study on a power system located in northern of IRAN shows the effectiveness of proposed methods. [73]

A new procedure for power flow calculation of power systems in presence of Dynamic Flow Controller (DFC) is discussed which a new member of FACTS controllers is. The focus of the paper is to explore how to systematically extend and modify Newton-Raphson power flow method to include DFC. A new steady state model of DFC is introduced for the implementation of the device in the conventional Newton-Raphson power flow algorithm. The impact of DFC on power flow is accommodated by adding new entries and modifying some existing ones in the linearized Jacobian equations of the same system without DFC. A case study on North of IRAN power system shows the effectiveness of proposed method. [74]

The synthesis and physical implementation of decentralized supervisory controller of the Dynamic Flow Controller (DFC) as a discrete-event system is presented .The local plants have been used for synthesizing of decentralized supervisory controller for easier implementation of overall control system. A heuristic method is developed for easier implementation of the supervisor on a Programmable-Logic-Controller (PLC), to overcome the implementation problems in the auto/manual mode of DFC operation. A step -by- step procedure is developed to generate a ladder diagram which implements the DES supervisory control on a PLC. The proposed approach for implementation of modular controllers can be used to implement any modular supervisory control in practice. [75]

In this work supervisory control of a dynamic flow controller (DFC) based on the discrete-event systems (DES) theory. A DFC can be considered as a flexible ac transmission system controller and includes a mechanically-switched phase-shifting transformer, a multimodule thyristor-switched capacitor, a multimodule thyristor-switched reactor, and a mechanically switched capacitor. Owing to the inherent discrete switching nature of a DFC, its components are modeled as finite automata; then, a DES supervisory control is designed to implement the control logic of the DFC system in different modes of operation (i.e., “automatic” and “auto/manual”). It is shown that the specifications are controllable and the synthesized supervisors are nonblocking in both modes and the modular supervisors nonconflict in auto/manual mode. [76]

II F: D-FACTS

Flexible ac transmission system devices are capable to control power flow to relieve transmission line from congestion and to limit loop flow but the high cost and reliability are main hindrances in deployment these devices. D. Diwan et.al [61] suggested a new concept of Distributed facts (D-FACTS) as an alternative solution which is cost effective power flow control. The concept of Distributed Series Impedance (DSI) introduced that can realize variable impedance of line to control active power flow. A typical 138 KV transmission line having impedance X_L approximately 0.79 ohms/miles [76]. At the line thermal capacity of 770 amperes corresponding to 184 MVA of power flow, the voltage drop across the line impedance is thus 608 volts/mile. A 2% change in line impedance would thus require injection of 12.16 volts or 0.0158 ohms/mile. This translates into an inductance of 42 μH or 9.24 KVAR (12 volts at 770 Amperes). [76] This is surprisingly small value of impedance and could be accomplished with one single 9.24 KVAR module deployed per mile of the line. This unit could be small and light enough to be plugged in power line and feasible electrically and mechanically (as shown in figure 5)

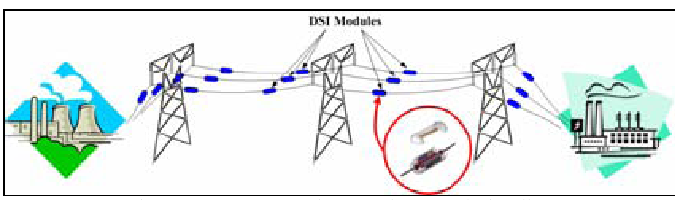

Fig. 5. D-FACTS Implemented Transmission line

D-FACTS controller:

(A)Distributed Series Impedance:

Principle: three switches, a capacitor, an inductor and single turn transformer are utilized as shown in figure 6.

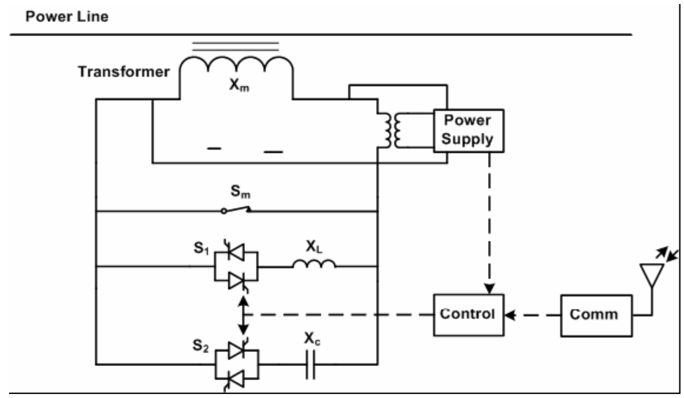

Fig. 6 D-FACTS Controller Unit

Static switches should be used for fast response in fault.control power can be derived from the line itself using a current transformer [76].

(b)Distributed series reactor: Fig 7 gives simpler implementation of Distributed Series Reactor, it can be utilsed in interconnected or meshed power networks and can be individually controlled with no communication and dramatically increase in grid capacity. [62]

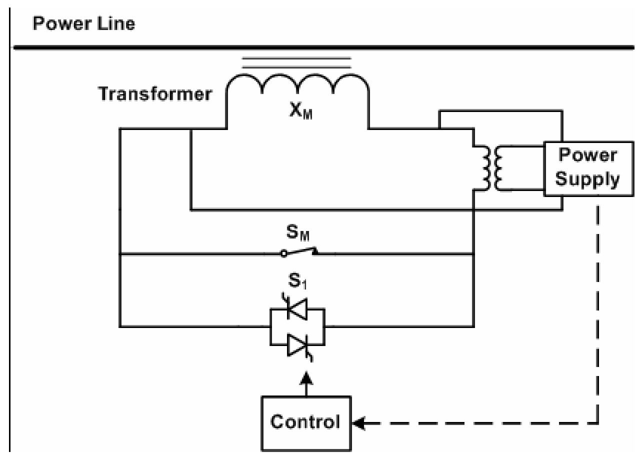

Fig. 7. DSR

At a system level, as current in particular line crosses the predefined values, numbers of DSR module switched in ,line impedance gradually increase and so current divert to under utilized. A control algorithm is well defined [76]

(c)Distributed Static Series Compensator:

DSSC figure 8[78] consist of a small single phase inverter (approx 10 kva), single turn transformer, power supply circuits, associated control and built in communication capability

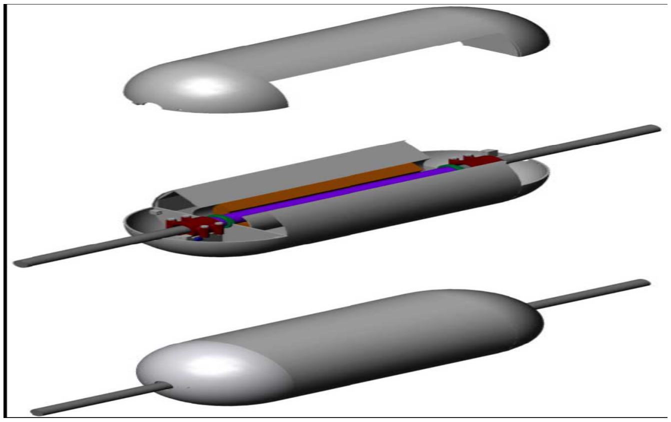

Fig. 8. DSSC concept showing clamp-on capability.

weight and size of DSSC are comparatively small and allowing it suspended mechanically from power line.Fig.9 shows schematic circuit of DSSC.Here inverter can inject a quadrature voltage into the AC line to simulate a positive and negative reactance .DC bus voltage regulation is maintained through a small in phase voltage component same as active filter controller[63]

The control of quadrature voltage injection done autonomously or can be organized by system operator. this will be a smart control in coordinated manner of multiple modules using communications.

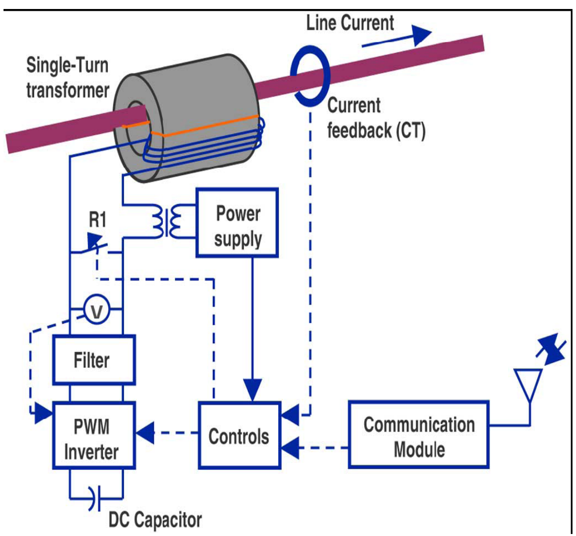

Fig. 9. Schematic circuit of DSSC.

III CONCLUSION

The above discussion reflects various work and philophies are covered in the area of FACTS and DFACTS.DFACTS Controller having more reliability and cost saving approach over FACTS controller .For the robust, sensitive and optimum approach and operation DFACTS controllers are better choice for improving power system transmission line performance

IV. REFERENCES

[1] Varma, R.K. "Introduction to FACTS Controllers" Power Systems Conference and Exposition, 2009. PSCE apos; 09. IEEE/PES Vol, Issue, 15-18 March 2009 pp., 1 – 6.

[2] R.M. Mathur and R.K. Varma, "Thyristor-Based FACTS Controllers for Electrical Transmission Systems", IEEE Press and Wiley Interscience, New York, USA, Feb. 2002.

[3] Wayne H. Litzenberger, ed., "An Annotated Bibliography of High-Voltage Direct-Current Transmission", 1989-1991, Bonneville Power Administration and Western Area Power Administration, Portland, OR,USA, 1992.

[4] A. Edris, R. Adapa, M.H. Baker, L. Bohmann, K. Clark, K. Habashi, L. Gyugyi, J. Lemay, A.S. Mehraban, A.K. Myers, J. Reeve, F. Sener, D.R.Torgerson, R.R. Wood, "Proposed Terms and Definitions for Flexible AC Transmission System (FACTS)", IEEE Trans. Power Delivery, Vol. 12,No.4, pp. 1848-1853, Oct. 1997.

[5] K.R. Padiyar, Analysis of Subsynchronous Resonance in Power Systems, Kluwer Academic Publishers, Boston, 1999.

[6] M.R. Iravani, D. Maratukulam, "Review of Semiconductor – Controlledm(Static) Phase Shifters for Power System Applications", IEEE Trans. On Power Systems, Vol. 9, No. 4, pp. 1833-1839, 1994.

[7] L. Gyugyi and C.D. Schauder and K.K. Sen, "Static synchronous series compensator: A solid-state approach to the series compensation of transmission lines", IEEE Trans. Power Delivery, Vol. 12, pp. 406-417, Jan. 1997.

[8] N.G. Hingorani and L. Gyugyi, Understanding FACTS, IEEE Press, New York, USA, 1999.

[9] IEEE Power Engg. Society/CIGRE, "FACTS Overview", Publication 95 TP 108, IEEE Press, New York, 1995.

[10] IEEE Power Engineering Society, "FACTS Applications", Publication 96 TP 116-0, IEEE Press, New York, 1996

[11] Lee C.K., Joseph, Leung S.K., Ron Hui S.Y., Chung H.S.-H.: 'Circuitlevel comparison of STATCOM technologies', IEEE Trans.Power Electron., 2003, 18, (4), pp. 208–219.

[12] Wuest D., Stemmler H., Scheuer G.: 'A comparison of different circuit configurations for an advanced static VAR compensator (ASVC)'. IEEE Power Electronics Specialists Conf., 23rd Annual PESC'92, 29 June–3 July 1992, vol. 1, pp. 521–529

[13] Menzies R.W., Yiping Z.: 'Advanced static compensation using a multilevel GTO thyristor inverter', IEEE Trans. Power Deliv., 1995, 10, (2), pp. 732–738

[14] Mwinyiwiwa B., Wolanski Z., Yiqiang C., BOON-TECK O.: 'Multimodular multilevel converters with input/output linearity'. IEEE 31st IAS Annual Meeting, Conf. Record,1996, vol. 2, pp. 988–992

[15] Lai J.-S., Peng F.Z.: 'Multilevel converters – a new breed of power converters', IEEE Trans. Ind. Appl., 1996, 32, (3), pp. 509–517

[16] Liang X., Liu W.-H., Jiang Q.-R. ET AL.: 'Development of a voltage source inverter based static VAR generator'.Energy Conservation Engineering Conf., IECEC 96 Proc. 31st Intersociety, 11–16 August 1996, vol. 1, pp. 611–616

[17] Peng F.Z., Lai J.-S., Mckeever J.W., Cloveering J.V.: 'A multilevel voltage–source inverter with separate DC source for static VAR generation', IEEE Trans. Ind. Appl., 1996, 32, (5), pp. 1130–1138

[18] Chen Y., Ooi B.-T.: 'Advanced static VAR compensator using multi-modules of multilevel converters with equalization control of DC voltage levels'. IEEE Power Electronics Specialists Conf., PESC'96, 27th Annual IEEE, 23–27 June 1996, vol. 1, pp. 747–752

[19] Tominaga S., Fujita H., Akagi H.: 'Application of zero voltage-switching to a DC voltage controlled static VAR compensator using quad-series voltage source inverters'. 27th Annual IEEE Power Electronics Specialists Conf., PESC'96, vol. 1, 23–27 June 1996, pp. 482–488

[20] Ekanayake J.B., Jenkins N.: 'A three-level advanced static VAR compensator', IEEE Trans. Power Deliv., 1996, 10, (2), pp. 655–661

[21] Hills J.E., Norris W.T.: 'Exact analysis of a multipulse shunt converter compensator or STATCOM. Part I: Performance', IEE Proc., Gener. Transm. Distrib., 1997, 144, (2), pp. 219–224

[22] Hills J.E., NorrisW.T.: 'Exact analysis of a multipulse shunt converter compensator or STATCOM. II: Analysis', IEE Proc. Gener. Transm. Distrib., 1997, 144, (2), pp. 219–224

[23] Ekanayake J.B., Jenkins N.: 'Mathematical models of a three-level advanced static VAR compensator', IEE Proc., Gener. Transm. Distrib., 1997, 144, (2), pp. 201–206

[24] Tennakoon S.B., Scheidecker D.: 'Multi-level converters for static VAR compensation'. Update on New Power Electronic Techniques (Digest No. 1997/091), IEE Colloquium, 23 May 1997, p. 4/1–4/6

[25] Peng F.Z., Lai J.-S.: 'Dynamic performance and control of a static VAR generator using cascade multilevel inverters', IEEE Trans. Ind. Appl., 1997, 33, (3), pp. 748–755

[26] Mwinyiwiwa B., Wolanski Z., Boon-Teck O.: 'Multilevel STATCOM with third harmonic elimination on the DC link capacitor voltages'. IEEE Power Electronics Specialists Conf., PESC'97 Record, 28th Annual Meeting, 1997, vol. 1,pp. 317–322

[27] Chen Y., Mwinyiwiwa B., Wolanski Z., Boon-Teck O.: 'Regulating and equalizing DC capacitance voltages in multilevel STATCOM', IEEE Trans. Power Deliv., 1997, 12, (2), pp. 901–907

[28] Hochgraf C., Lasseter R.H.: 'A transformer-less static synchronous compensator employing a multi-level inverter',IEEE Trans. Power Deliv., 1997, 12, (2), pp. 881–887

[29] Chatterjee K., Fernandes B.G., Dubey G.K.: 'A novel high power self-commutated static VAR compensator for load compensation'. IEEE Proc. Power Electronics and Drive Systems, Int. Conf., 26–29 May 1997, pp. 750–756

[30] Mwinyiwiwa B., Wolanski Z., Boon-Teck O., Chen Y.:'Multilevel converters as series VAR compensators'. IEEE Power Electronics Specialists Conf., PESC'97, 22–27 June 1997, vol. 1, pp. 338–343

[31] Sen K.K., Stacey E.J.: 'UPFC-unified power flow controller: theory, modeling, and applications', IEEE Trans. Power Deliv., 1998, 13, (4), pp. 1453–1460

[32] Das B., Ghosh A., Sachchidanand: 'Comparison of performance of two configurations of ASVC for powertransfer enhancement'. TENCON '98, IEEE Region 10 Int. Conf. Global Connectivity in Energy, Computer, Communication and Control, 1998, vol. 2, pp. 466–469

[33] Ainsworth J.D., Davies M., Fitz P.J., Owen K.E., Trainer D.R.: 'Static VAR compensator (STATCOM) based on singlephase chain circuit converters', IEE Proc. Gener. Transm. Distrib., 1998, 145, (4), pp. 381–386.

[34] An T., Powell M.T., Thanawala H.L., Jenkins N.: 'Assessment of two different STATCOMconfigurations for FACTS application in power systems'. Proc. Power System Technology, POWERCON'98 Int. Conf., 1998. Vol., 1. pp.,307-312.

[35] Chen Y., Ooi B.-T.: 'STATCOM based on multimodules of multilevel converters under multiple regulation feedback control', IEEE Trans. Power Electron., 1999, 14, (5),pp. 959–965.

[36] Ooi B.-T., Joos G., Huang X.: 'Operating principles of shunt STATCOM based on 3-level diode-clamped converters', IEEE Power Deliv., 1999, 14, (4), pp. 1504–1510.

[37] Patil K.V., Mathur R.M., Jiang J., Hosseini S.H.: 'Distribution system compensation using a new binary multilevel voltage source inverter', IEEE Trans. Power Deliv., 1999, 14, (2), pp. 459–464.

[38] Das B., Ghosh A., Sachidanand : 'Suitable configuration of ASVC for power transmission application', Electr. Power Syst. Res., 1999, 49, (2), pp. 107–122.

[39] Stiemer P.K., Manjrekar M.D.: 'Practical medium voltage converter topologies for high power applications'. IEEE SM/WM, 2001, pp. 1723–1730.

[40] Mori H., Matsui K., Kondo K., Yamamoto I., Hasegawa M.:'Parallel-connected five-level PWM inverter', IEEE Trans. Power Electron., 2003, 18, (1), pp. 173–179.

[41] Hanson D.J., Woodhouse M.L., Horwill C., Monkhouse D.R.,Osborne M.M.: 'STATCOM: a new era of reactive compensation', Power Eng. J., 2002, 16, (3), pp. 151–160.

[42] Kincic S., Chandra A., Babic S.: 'Five level diode clamped voltage source inverter and its application in reactive power compensation'. IEEE Large Engineering Systems Conf. Power Engineering, LESCOPE, 2002, pp. 86–92.

[43] Soto D., Green T.C.: 'A comparison of high power converter topologies for the implementation of FACTS controllers', IEEE Trans. Ind. Electron., 2002, 49, (5),pp. 1072–1080.

[44] Peng F.Z., Wang J.: 'A universal STATCOM with delta connected cascade multilevel inverter'. IEEE 35th Annual Power Electronics Specialists Conf., PESC, 2004, vol. 5,pp. 529–3533.

[45] Qingru Q., Chang Y., Wai C.K., Yixin N.: 'Modeling and simulation of a STATCOM system based on 3-level NPC inverter using dynamic phasors'. IEEE PES GM, 2004, vol. 2, pp. 1559–1564.

[46] Deshpande N.R., Sasi N., Sawant R.R.: 'Modeling of multilevel voltage source converter', 1st Int. Conf. Proc.Power Electronics Systems and Applications, 2004,pp. 24–29.

[47] Yuan Z., Song Q., Liu W., Chen Y., Teng L.: 'Development ofa scaled STATCOM prototype based on 21-level cascade H-bridge inverter'. 32nd IEEE Annual Conf. Industrial Electronics Society, IECON, 2005, p. 6.

[48] Collins C.D., Bathurst G.N., Watson N.R., Wood A.R.: 'Harmonic domain approach to STATCOM modeling', IEE Proc. Gener. Transm. Distrib., 2005, 152, (2), pp. 194–200.

[49] Saeedifard M., Nikkhajoie H., Iravani R.: 'A space vector modulated STATCOM based on a three-level neutral point clamped converter', IEEE Trans. Power Deliv., 2007, 22,(2), pp. 1029–1039.

[50] Wen X., Yin X., Hanxiang C.: 'The general mathematical model and performance analysis of multi-pulse threelevel STATCOM'. IEEE Int. Conf. Electric Machines & Drives, IEMDC, 2007, vol. 1, pp. 760–765.

[51] Chong H., Zhanoning Y., BIN C., Huang A.Q., Bin Z., Ingram M.R., Edris A.: 'Evaluation of cascade-multilevel-converter based STATCOM for arc furnace flicker mitigation', IEEE Trans. Ind. Appl., 2007, 43, (2), pp. 378–385.

[52] Lauttaums P., Tuusa H.: 'Comparison of five-level voltage-source inverter based STATCOMs'. Power Conversion Conf. – Nagoya, PCC, 2007, pp. 659–666.

[53] Schauder C., Gernhardt M., Stacey E. ET AL.: '+100 MVARstatic condenser installation for TVA Sullivan substation'. EPRI Flexible AC Transmission System (FACTS 3) Conf., Baltimore, MD, 5–7 October 1994.

[54] Schauder C., Gernhardt M., Stacey E. ET AL.: 'Development of a +100 MVAR static condenser for voltage control of transmission systems', IEEE Trans. Power Deliv., 1995, 10, (3), pp. 1486–1496.

[55] Schauder C., Gernhardt M., Stacey E. ET AL.: 'TVA STATCON project: design, installation and commissioning'. CIGRE1996, Paper 14–106

[56] Schauder C., Gernhardt M., Stacey E. ET AL.: 'Operation of +100 MVAR TVA STATCON', IEEE Trans. Power Deliv., 1997, 12, (4), pp. 1805–1811

[57] Mori S., Matsuno K., Hasegawa T. ET AL.: 'Development of a large static VAR generator using self-commutated inverters for improving power system stability', IEEE Trans. Power Syst., 1993, 8, (1), pp. 371–377

[58] Schauder C.: 'STATCOM for compensation of large electric arc furnace installations'. IEEE Power Engineering Society SM, 1999, vol. 2, pp. 1109–1112

[59] Liu W., Liang X., Lin F., Luo C., GAO H.: 'Development of 20 MVA static synchronous compensator', IEEE PES WM, 2000, vol. 4, pp. 2648–2653

[60] Uzunovic E., Fardanesh B., Hopkins L., Shperling B., Zelingher S., Schuff A.: 'NYPA convertible static compensator (CSC) application phase I: STATCOM'. IEEE/PES Transmission and Distribution Conf. Exposition, 2001, vol. 2, pp. 1139–1143

[61 Arthur Bergen, 'Power System Analysis', Prentice Hall, 1986.

[62] Harjeet Johal and D. M. Divan, "Current Limiting Conductors: A Distributed Approach for Increasing T&D System Capacity and Reliability," in Transmission and Distribution Conference 2005, New Orleans, Louisiana.

[63] Po-Tai Cheng, S. Bhattacharya and D. Divan, "Operation of the Dominant Harmonic Active Filter (DHAF) Under Realistic Utility Conditions," IEEE Transactions on Industry Applications, Vol. 37, No. 4, July-Aug. 2001, pp. 1037-1044.

[64] Rashed, G.I. Shaheen, H.I. Cheng, S.J." Nonlinear PI predictive control design for Thyristor Controlled Series Compensator" Transmission and Distribution Conference and Exposition, 2008. T&D. IEEE/PES 21-24 April, 2008, pp. 1-7.

[65] Poshtan, M. Singh, B.N. Rastgoufard, P. "A Nonlinear Control Method for SSSC to Improve Power System Stability" Power Electronics, Drives and Energy Systems, 2006. PEDES '06. International Conference on 12-15 Dec. 2006, pp., 1-7.

[66] Simoes, A.M. Savelli, D.C. Pellanda, P.C. Martins, N. Apkarian, P. "Robust Design of a TCSC Oscillation Damping Controller in a Weak 500-kV Interconnection Considering Multiple Power Flow Scenarios and External Disturbances" Power Systems, IEEE Transactions on: Feb.2009, Vol.,24, Issue:1, pp., 226-236.

[67] Fang, D.Z. Xiaodong, Y. Wennan, S. Wang, H.F. "Oscillation transient energy function applied to the design of a TCSC fuzzy logic damping controller to suppress power system interarea mode oscillations"; Generation, Transmission and Distribution, IEE Proceedings-March,2003,Vol., 150, Issue:2 , pp., 233- 238.

[68] Preeti Singh, Mrs.Lini Mathew, Prof. S. Chat "MATLAB Based Simulation of TCSC FACTS Controller" Proceedings of 2nd National Conference on Challenges & Opportunities in Information Technology (COIT-2008) RIMT-IET, Mandi Gobindgarh. March 29.

[69] Taheri, H.; Shahabi, S.; Taheri, S.; Gholami, A. " Application of Synchronous Static Series Compensator (SSSC) on enhancement of voltage stability and power oscillation damping" EUROCON 2009, EUROCON apos;09. IEEE Volume , Issue , 18-23 May 2009 pp:533 – 539.

[70] Wei Qiao Harley, R.G. Venayagamoorthy, G.K. "Fault-Tolerant Optimal Neurocontrol for a Static Synchronous Series Compensator Connected to a Power Network"Industry Applications, IEEE Transactions Jan.-feb. 2008Volume: 44, Issue: 1pp: 74-84.

[71] Khederzadeh, M.; Ghorbani, A.; Salemnia, A." Impact of SSSC on the digital distance relaying"Power & Energy Society General Meeting, 2009. PES apos;09. IEEE\Volume , Issue , 26-30 July 2009 pp:1 – 8.

[72] Jamali, S.; Kazemi, A.; Shateri, H.]" Distance relay over-reaching due to SSSC presence on second circuit of double circuit line" Industrial Electronics and Applications, 2008. ICIEA 2008. 3rd IEEE Conference , Issue , 3-5 June 2008 pp):918 – 923.

[73] Ahmadi, R.; Sheykholeslami, A.; Niaki, A.N.; Ghaffari, H." Power flow control and solutions with Dynamic Flow Controller" Electric Power Conference, 2008. EPEC 2008. IEEE Canada Vol., Issue , 6-7 Oct. 2008 pp:1 – 6.

[74] A.sheykholeslami Roya Ahmadi.A,S.A.Nabavi Niaki , Hamidreza Ghaffari "Power Flow Modeling/Calculation for Power Systems with Dynamic Flow Controller" IEEE Vehicle Power and Propulsion Conference (VPPC), September 3-5, 2008, Harbin, China 978-1-4244-1849-7/08/$25.00○C 2008 IEEE.

[75] Afzalian, A.; Noorbakhsh, M.; Nabavi, S.A.] "PLC implementation of decentralized supervisory control for Dynamic Flow Controller" Control Applications, 2008. CCA 2008. IEEE International Conference on Volume , Issue , 3-5 Sept. 2008 pp:522 – 527.

[76] Ali A. Afzalian,, S. Ali Nabavi Niaki, , M. Reza Iravani, W. M. Wonham, "Discrete-Event Systems Supervisory Control for a Dynamic Flow Controller" IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 24, NO. 1, JANUARY 2009 219.

[77] Divan, D.; Johal, H.]" Distributed FACTS—A New Concept for Realizing Grid Power Flow Control" Power Electronics, IEEE Transactions on Volume 22, Issue 6, Nov. 2007 pp:2253 – 2260.

[78] Deepak M. Divan; William E. Brumsickle; Robert S. Schneider; Bill Kranz; Randal W. Gascoigne; Dale T. Bradshaw; Michael R. Ingram; Ian S. Grant] "A Distributed Static Series Compensator System for Realizing Active Power Flow Control on Existing Power Lines" Power Delivery, IEEE Transactions on Volume 22, Issue 1, Jan. 2007 pp:642 – 64.

[79] X.-P. Zhang, C. Rehtanz, B. Pal, "FACTS-Modelling and Control," Springer 2006.