A Review: Capability of FACTS Device for Performance Improvement of Power System

Subrat Kumar Bihari[1], Arnab Chowdhury[1], Shiva Pujan Jaiswal[2], Vivek Shrivastava[2]
Sharda University, Greater Noida, Uttar Pradesh[1], UCE, Rajasthan Technical University, Kota, Rajasthan[2]

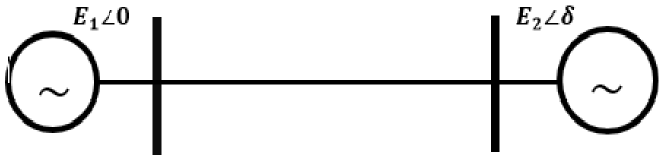
ABSTRACTS-This paper present various causes of voltage problem stability and how this can be mitigate by integration of power electronics based FACTs technology. FACTs devices are using since 1970 and till date, because of rapid and accurate corrective action for voltage stability enhancement. This article giving a review of developments of FACTs technology and its application for performance enhancement of system. Reviewers discuss merits and limitations of numerous FACTs and its integrations in different modes for improvement of voltage profile at all buses. Authors find UPFC is a most versatile FACTs tool because of its capability to control, all three parameters such as voltage, impedance and phase angle. Authors demonstrate the different models and their capabilities of UPFC and its application in different condition.

1. INTRODUCTION

Now a days the demand on power is more in all sectors. In such condition the power system stability is the main problem with power players. Many types of generators and motors, various types of loads, filter circuits are used in the power sectors which leads to unbalancing the voltage that induces voltage instability in system. Improvement of voltage stability in power sectors is a major issue for clearing the faults in transmission line.

The transmission line capacity should obtaining on higher limit to find maximum economic returns for the owners. Such situation the system stability neutralize because of overall grid reliability and security.

Voltage stability in the power sector is the major problem where power transfer capability is to improve. Such cases Shunt and series compensation is used (2-4). Reactive power compensation used to control the active power demand and maintain the voltage to its normal value. Line current should be minimized so that it reduces system losses.



Power transmission is the function of the line impedance. If the transmission line having low impedance then the higher power can be transmitted in transmission line, where as it falls with higher reactance.

$$P = \frac{E_1 E_2}{X}\sin\delta$$

The power system development leads to riseand controlthe power transfer capability in a transmission line (1). The controlling action being performed for achieving the system healthy condition or power quality control such as:-

1. Power transfer capability increases.
2. Improvement in voltage control in lines.
3. Improvement in power system stability.
4. Reliability of the system improved.
   Transmission line loading capacity increases.

The FACTS devices are used for voltage variation in steps to maintain the receiving and sending end voltages within the permissible limit. The advancement in semiconductor technology has a major role to use power electronic devices in power system (2-4).

Number of IEEE standards are written in book '5-8' relates to the modelling issues and the book '9-10' relates the voltage stability problem directly.

Main causes of voltage stability problems

1. The problems due to the improper location of FACTs devices.
2. Problem associated with multiple FACTs devices when their coordination is poor.
3. The higher reactive power consumed by loads.
4. Cases of problems happening in the future, but can't be predicted with certainty.
5. On Load Tap Changer (ONTC) operation in reverse operating event.
6. When load centres are near to voltage sources.

7. The voltage stability is adversely affected due to presents of constant power load in the power system.
8. When reactive power differs in transmission line due to heavy loads.

Taking action about Voltage Instability

1. Placing a series and shunt capacitor in proper position.
2. Proper connections of FACTs Controllers in a transmission line.
3. Proper coordination between all FACTs controllers must happen.
4. Rescheduling each generation unit in the power system.
5. Load shedding should happen for under voltage.
6. In reverse operation of transformer no tap change happening.
7. Installing synchronous condenser in a transmission system.

2. FACTS Devices

Problem associated with instability in power system can remove or minimizes by the use of Flexible AC Transmission Systems (FACTs) devices. Such devices are developed near past and which having best controlling device for power system stability in high voltage power transmission. FACTs controllers' also providing operating flexibility for transmission line in power system. Improve the power system performance for both delivering unit and receiving unit.

FACTs are high speed semiconductor devices that increases power system quality by absorbing or delivering reactive power at light load and heavy load respectively and simultaneously it can deliver or absorb real power. Main objectives of FACTs devices are growth of the power transfer capability of the transmission lines and provides direct control of power flow.

FACTs controllers are working individually in the power system or with links to another one to control the series impedance, shunt impedance, current, voltage, phase angle, oscillation damping. FACTs devices maintain the transmission system to be operated nearby to its thermal limit without decreasing the system's consistency. FACTs controllers also improve the safety and flexibility in power system. There are two type of technologies available in literature first related to Thyristor-Switched Capacitors and Reactors with Tap Changing Transformers and the second group is about Gate Turn Off (GTO), Thyristor-Switched Converters act like Voltage Source Converters (VSCs). The first technique is called as Static Var Compensator (SVC), Thyristor-Controlled Series Capacitor (TCSC) and Thyristor–Controlled Phase Shifter (TCPS). Secondly, it related to Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC), Unified Power Flow Controller (UPFC) and interline power flow controller (IPFC).

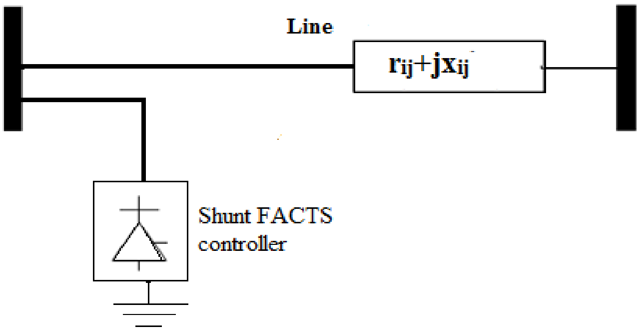
Connection ofFACTs devices are vary either in series or in shunt else combination of both. The SVC and STATCOM are always placed in shunt connection and the TCSC and SSSC are placed in series connection. UPFC is hybrid FACTS device which comprises both connections (series and shunt). These are classified as like -.

2.1 *Series controllers*

The damping oscillation present in power system are controlled by using series controller having variable inductive and capacitive impedance. This process is achieving the desired result by inducting a suitable voltage phasor in series with the line. The series controller absorbs or produce the reactive power when line voltage is in quadrature to line current. In other condition the controller can absorb or produce both real and reactive power. Some of the controller which are used in such situation are Static Synchronous Series Compensator (SSSC), Thyristor-Switched Series Capacitor (TSSC), and Thyristor-Controlled Series Reactor (TCSR).

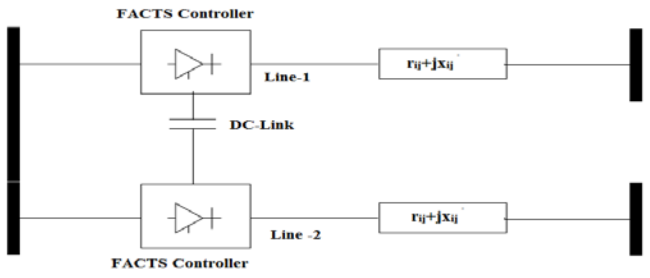
2.2 *Shunt controllers*

The functions shunt controllers and series controllers are similar, but with a difference is that shunt controller can inject the reactive power into the power system at its location. If the injected current and line voltage are in phase quadrature, then variation of power injection is feasible. In other case real power adjustment is carried out. This is possible with the help of such FACTs devices, which are as Static Synchronous Generator (SSG), STATCOM (Static Synchronous Compensator), Static Var Compensators (SVC).



2.3 *Combined Series-Series controllers*

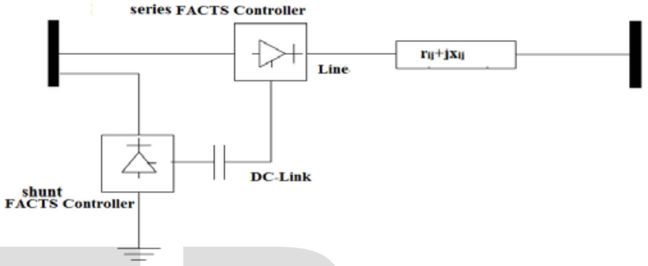
A combined series-series controller are of two types. A series controller is connected in a transmission line from one side and other one provide the independent reactive power for each line of a multi-line transmission system. All actions are to be taken by the controllers to control reactive power while the transfer of real power takes place at the same time. Such controllers are interline power flow control (IPFC), thus real and reactive power flows in the lines simultaneously.



Operating problem	**Corrective action**	**FACTs controllers**
Voltage limits:		
Low voltage during large demand	Delivering reactive power	STATCOM, SVC,
High voltage during low demand	Consume reactive power	STATCOM, SVC, TCR
High voltage due to an outage	Consume reactive power; avoid overload	STATCOM, SVC, TCR
Low voltage due to sudden load	Delivering reactive power; avoid overload	STATCOM, SVC
Thermal limits:		
Transmission circuit overload	Reduce overload	TCSC, SSSC, UPFC, IPC, PS
Tripping of parallel circuits	Limit circuit loading	TCSC, SSSC, UPFC, IPC, PS
Loop flows:		
Parallel line load sharing	Adjust series reactance	IPC, SSSC, UPFC, TCSC, PS
Post fault power flow sharing	Network rearrangement or uses thermal limit actions	IPC, TCSC, SSSC, UPFC, PS
Power flows direction reversal	Phase angle Adjustment	IPC, SSSC, UPFC, PS

2.4 *Combined Series-Shunt controllers*

A combined series-shunt controller are also of two arrangements like previous combined series-series controller. The shunt and series controllers operate in a coordinated manner. The shunt component injects current into the system and series component inject the voltage. The real power can be exchanged between these shunt and series component of controllers via the power line. Such controllers are in the category of Unified Power Flow Controller (UPFC) and Thyristor- Controlled Phase-Shifting Transformer (TCPST). The series-shunt controllers are more effective and can inject voltage and current without affecting power or current flow and line voltage control in the system.



The use of FACTs (Flexible Alternating Current Transmission Systems) controllers in power system operation

3. INTEREST ON FACTS IN AC TRANSMISSION LINE

The survey of the FACTS devices carried on and complied by two important databases such as IEEE/IEE electronic library and science direct electronic databases. The database has been compiled after continuous survey for last 19 years from year 1991 to 2009. This time period can be categorised into three sub periods such as 1991-1998, 1999-2004 and 2005-2009. Each publication discuss different power system including record of each step and its result. Such recorded information are quite clear about the application of FACTS devices for different power system studies.

The ability of FACTS devices is to enhance the power system stability as discussed by Noorozian and Anderson in book 22. The analysis of damping of power system, electromechanical oscillation analysis based upon FACTS devices is written by Wang and Swift in book 29. It describes about the damping torque related to FACTS devices. Various points of studies and research are taken about FACTS devices with the use of simulation and results are compiled.

4. APPLICATION OF FACTS DEVICES

By the year 1970 thyristor was well developed and used for application of high voltage application. Modern Static Var Compensators (SVCs) were developed using thyristor. In addition thyristor controlled/ switched series capacitors (TCSCs/TSSCs) and thyristor controlled phase shifter regulators (TCPSs) were also developed the principle of thyristor based switching controllers are passive components used for enhance its behaviour where compensation requirement is levelling slowly. Different number of reports are published for analysis of the FACTS devices effect on power systems such as SVC, TCSC and TCPS.

A Phillips Heffron model is developed by Wang and swift for the improvement of SVC/TCSC/TCPS in power system. In this model the damping torque coefficient is used. The effect of damping with different loading condition in FACTS devices is analysed by Abido and Abdel-Magid. This model is enhancing the power stability by the effectiveness of PSS and FACTS devices. The Eigen based objective function is used in this model for development of system damping. The model optimum stability parameter finds out from GA search method.

The scientist E.W. Kimbark pointed out that shunt capacitor should be used at the midpoint of transmission line for voltage compensation and midpoint is an optimum point for a transmission line. In this condition twice of the normal power can be transmitted through the compensation line. Many types of controlling devices are used in transmission line such as Thyristor-Controlled Series Capacitor (TCSC) and Thyristor – Controlled Phase Shifter (TCPS). Secondly, related to Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC), Unified Power Flow Controller (UPFC) and interline power flow controller (IPFC). We can use this in PWM asynchronous DC line Thyristor-Controlled Series Capacitor (TCSC) are used for control action(23-28).

Objective of installing SVC is to increase operation efficiency, improve service quality and ensure a certain security level. The SVC is planned to an optimisation problem where two stage optimization method is used for such system and simulated annealing (SA) is used to solve placement location, in large power system [30-31]. Var compensation is used for system planning and the attention is focused upon the losses voltage deviation and expenditure.

The simplest methods used for Svc planning on model analysis is to define operating point should define in power system. The Eigenvalue analysis with a system Jacobean matrix can be used for the identification of buses where voltage collapse occur.

The SVC shunt compensation component is designed for voltage compensation in power system. Such devices are TCSC. Transient stability and damping performance in the power system can be improved for the above case [32-33]. STATCOM/ STATCON and ASVC /ASVG are used for reactive power compensation in many rotating machines. A STATCOM with an energy storing device can control both active and reactive power to obtain flexible power system operation. This article deals with the position of a shunt FACTS device to improve transient stability in long transmission line and to determine power flow.

Two types of reactive power compensator are used in power system such as SVC and STATCOM. The performance of STATCOM is better than SVC in view of continuous controllability and response time [34]. Real time and off line simulation tool and three simulation method available in PSB for efficient technique used for analysis of complex control system in FACTS devices.

Dynamic performance improvement in power system by using a UPFC is mentioned in the article [35-40]. The effect of FACTS devices with series compensation is essential to improve the dynamic performance of the power system. This can be achieved by connecting UPFC with different modes of operation as like impedance control mode, perpendicular voltage control mode and voltage angel control mode [41]. Perpendicular voltage control with series converter is most simple and practical mode of operation of a UPFC. Small disturbances in power system can be improved by damping and large disturbances bang-bang control is needed.

5. IMPLEMENTATION OF FACTS TECHNOLOLGY

The survey of the FACTS devices carried on and complied by two important databases such as IEEE/IEE electronic library and science direct electronic databases. The database has been compiled after continuous survey for last 19 years from year 1991 to 2009. This time period can be categorized into three sub periods such as 1991-1998, 1999-2004 and 2005-2009. Each publication discuss different power system including record of each step and its result. Such recorded information are quite clear about the application of FACTS devices for different power system studies.

The ability of FACTS devices is to enhance the power system stability as discussed by Noorozian and Anderson in book 22. The analysis of damping of power system, electromechanical oscillation analysis based upon FACTS devices is written by Wang and Swift in book 29. It describes about the damping torque related to FACTS devices. Various points of studies and research are taken about FACTS devices with the use of simulation and results are compiled.

6. UPFC MODELLING

UPFC is most complex and versatile FACTS devices which is a combination of STATCOM and SSSC (1). These equipment are control the basic power station variables such as transmission voltage, impedance and phase angle. UPFC contains two voltage source inverter connected with a DC link and the coupled transformer is connected to the power system.

The series converter coupled with the ac system through a transformer provides the main action. The control of real or reactive power flow in the transmission line by injecting AC voltage with proper magnitude and phase angle control. Second shunt converter transformer can generate or absorb reactive power and deliver shunt reactive compensation to control bus voltage at a specified value. DC link is used to exchange the active power between the two converters (51-52).

.

7. OPERATING MODES OF UPFC

1. *Shunt inverter*

It is operated to draw a controlled current from the line. One component of current balance the real power of the series inverter automatically and the other reactive component of power is set the desired level of inverter capability.

- *Var control mode*

To control reactive power a reference input is made which is inductive and capacitive as per VAR demand. The shunt converter control interprets the reference input signal into a shunt current request and adjusts the converter to maintain the current limit in the circuit. The closed loop arrangement uses a current feedback signal to achieve the output current of the shunt converter. Power FACTS IS known by mode of operation where feedback dc signal is present to safeguard it.

- *Automatic voltage control mode*

The shunt converter reactive current automatically controls the transmission line voltage to a desired value at the point of connection with respect to droop characteristics. Droop FACTS defines the per unit voltage error w.r.t. per unit reactive converter current at its existing state. The positive sequence component of bus voltage is usually used for voltage feedback signal for automatic voltage control.

2. *Series inverter*

Series inverter controls the magnitude and angle of the voltage of the transmission line. The flow of power on the line is directly proportional to the voltage injection.

- *Direct voltage injection mode*

The series converter generates the voltage vector (VS). Where its magnitude and phase angle are calculated based on input. Special functional applications are used in this case. The magnitude control is based upon the injected voltage vector (VS) which is in phase of system voltage or in quadrature with it.

- *Line impedance emulation mode*

The magnitude of the injected voltage vector, VS is maintained in accordance with the magnitude of the line current. The impedance is taken as reference input and generally is a complex quantities as combination of resistance and reactance. Special case of impedance compensation is resorted when the injected voltage is quadrature with the line current. This operating mode select the mode of matched series capacitive line compensation.

- *Automatic power flow control mode*

The input power plays major role to maintain the value of P and Q in transmission line although the system changes. The magnitude and phase angle of injected vector VS is controlled and it forces the line current vector that to maintain real and reactive power flow in the line. The series injected voltage generate automatically and closed loop control system action takes place. It will manage the suitable P and Q despite power system changes. In this situation the UPFC is used with transmission line as a high impedance power source or sink.

- *Stand-alone mode*

The UPFC offers shunt and series converters independently which can operate by disconnecting their common DC line and splitting the capacitor bank. In this case the shunt converter operates as like STATCOM and series converter as like SSSC. The reactive power domain is feasible when the two converters are standalone mode. In this case none of converter is capable to absorb or generate real power then reactive power domain is only possible. The injected voltage controls reactive voltage compensation in power system for power flow control.

8. UPFC MODEL:

The basic electrical model of UPFC is as shown in figure:

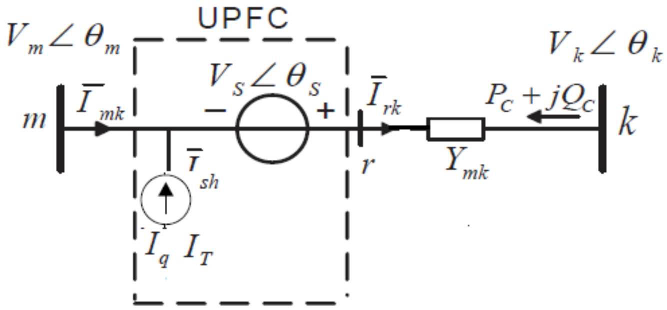


Fig.3.2 Electrical model of UPFC

The above fig. represents a lossless UPFC-embedded transmission line. The line connects node m and k as shown above. The output of the series voltage source ***Vs*** and ***θs*** are controllable magnitude and angle between the limits ***Vsmin≤***

Vs* ≤ *Vsmaxand ***0* ≤ *θs*≤ *2π*** respectively and the shunt branch is equivalent to an ideal current source***Ish***. The variable I sh of shunt current source also is controllable within ***Ish* ≤*Ish*$_N$,** ***Ish*$_N$** is current capacity limit of shunt converter. Ish is decomposed into two components: ***It*** and ***Iq***, which are respectively the real and imaginary controllable components of ideal shunt current source. ***It*,** in-phase components with respect to ***Vm***, is determined by active power of shunt converter exchanging with the system and the loss of UPFC. ***Iq*** is in quadrature components with respect to***Vm***, which provides independent shunt reactive compensation to maintain bus voltage level where the UPFC is installed [21, 22]. Assuming lossless converter values, the active power absorbed from the system by shunt converter is equal to that injected into transmission lines by series converter supplied to the shunt converter

$$\mathrm{V_m I_T} = \mathrm{Re}[\overline{V}_S \overline{I} * \mathrm{r_k}] \qquad (1)$$

This constraint equation shows that the overall active power exchange between the UPFC and the AC system become zero. So the active power ***Prk*** is equal to the ***Pmk*** on the transmission line.

$$P_{mk} = (V_m^{\,2} + V_s^{\,2})\, G_{mk} + 2V_mV_sG_{mk}\cos(\theta_s - \theta_m) - V_kV_s\,[G_{mk}\cos(\theta_s - \theta_k) + B_{mk}\sin(\theta_s - \theta_k)] - V_mV_k(G_{mk}\cos\theta_{mk} + B_{mk}\sin\theta_{mk}) \qquad (2)$$

$$Q_{mk} = -V_mI_q - V_m^{\,2}B_{mk} - V_mV_s[\sin(\theta_s - \theta_m) + B_{mk}\cos(\theta_s - \theta_m)] - V_mV_k(G_{mk}\sin\theta_{mk} - B_{mk}\cos\theta_{mk}) \qquad (3)$$

$$P_{km} = V_k^{\,2}G_{mk} - V_sV_k\,[G_{mk}\cos(\theta_s - \theta_k) - B_{mk}\sin(\theta_s - \theta_k)] - V_mV_k(G_{mk}\cos\theta_{mk} - B_{mk}\sin\theta_{mk}) \qquad (4)$$

$$Q_{mk} = -V_k^{\,2}G_{mk} + V_sV_k\,[G_{mk}\sin(\theta_s - \theta_k) - B_{mk}\cos(\theta_s - \theta_k)] + V_mV_k(G_{mk}\sin\theta_{mk} + B_{mk}\cos\theta_{mk}) \qquad (5)$$

However, the steady-state model of UPFC are classified into two main categories: decoupled model and coupled model.

9. CONCLUSION

Research work is going on the FACTS controllers' potential to improve the system stability. Considering rapid electric power demand. The FACTS controller are used in power systems for its reliability and advanced technology. It improves the operational flexibility and controllability in power system with considering various power system limits. It gives most effective solution. The FACTS also used for better utilization of existing transmission resources. After review of research literatures about the FACTS devices, it can be said that these are most convenient device for solving the voltage stability problem in the power system. Author's survey articles of lead researchers for analysis of FACTS devices in present and past. The decision of the voltage improvement by FACTS controllers in complex power system networks are technically suitable and viable.

10. REFERENCES

1. Understanding Facts: Concepts And Technology Of Flexible Ac Transmission Systems Laszlo GyugyiNarain G. Hingorani), Publisher: Wiley, ISBN: 9788126530403, 8126530405, Edition: 2011
2. T. V. Cutsem and C. Vournas, Voltage Stability of Electric Power System, Kluwer Academic Publisher, 1998.
3. C. A. Canizares and Z. T. Faur, "Analysis of SVC and TCSC Controllers in Voltage Collapse," IEEE Trans. on Power Systems, Vol 14, No. 1, pp.1-8. Feb. 1999.
4. IEEE Guide for synchronous generator modeling practices in stability analyses, IEEE Standard 1110-1991.
5. Machowski J., Bialek J., Bumby J., Power system dynamics and stability, John Wiley & Sons, ISBN 0471 97174 X (PPC), 1997
6. Anderson P., Fouad A., Power system control and stability, Revised Printing, IEEE Press, ISBN 0-7803-1029-2, 1994
7. Anderson P. M., Analysis of faulted power systems, IEEE Press, ISBN 0-7803-1145-0, 1995
8. Grainger J., Power system analysis, McGraw-Hill, ISBN 0-07-061293-5, 1994
9. Kundur P., Power system stability and control, EPRI McGraw-Hill, ISBN 0-07-035958-X, 1994
10. Taylor C., Reactive power compensation and voltage stability: removing transmission limitations, Seminar Book, February 1997
11. Edris A., "FACTS technology development: an update," IEEE Power Engineering Review, vol. 20, no. 3, March 2000, pp. 4-9
12. Edris A.A., "Challenges and benefits in developing and applying FACTS technology in the USA," Proceedings of the IEEE Power Tech'99 Conference - BPT'99, Budapest, Hungary, August 1999, paper BPT99-376-44
13. Hingorani N., "Flexible AC transmission ," IEEE Spectrum, vol. 30, no. 4, April 1993, pp. 40-45
14. Hingorani N., "High power electronics and Flexible AC Transmission System," IEEE Power Engineering Review, July 1988, pp. 3-4
15. Hingorani N., "Power electronics in AC power transmission systems," Proceedings of the CIGRÉ Session - Panel 1, P1-00, Paris, France, 1996
16. Le Du A., Tontini G., Winfield M., "Which FACTS equipment for which need? Identification of the technology developments to meet the needs of Electricité de France (EDF), Ente per l'EnergiaElettrica (ENEL) and National Grid Company (NGC)," Proceedings of the CIGRÉ Joint Session 14/37/38 - Technology and benefits of Flexible AC Transmission Systems, 14/37/38-08, Paris, France, 1992
17. Sekine Y., Takahashi K., Hayashi T., "Application of power electronics technologies to the 21st century's bulk

power transmission in Japan," Electrical Power & Energy Systems, vol. 17, no. 3, June 1995, pp. 181-194

18. Stahlkopf K., Budney W., Renz B., Cerdan J., Humphries M., "Stretching transmission capacity by technology deployment," IEEE Power Engineering Review, vol. 16, no. 11, November 1996, pp. 4-12
19. Stahlkopf K., Wilhelm M., "Tighter controls for busier systems," IEEE Spectrum, vol. 34, no. 4, April 1997, pp. 48-52
20. Zaborszky J., "On the road towards FACTS," Electrical Power & Energy Systems, vol. 17, no. 3, June 1995, pp. 165-172
21. N.G. Hingorani, L. Gyugyi, Understanding FACTS, Concepts and Technology of Flexible AC Transmission systems, IEEE Press 2000.
22. Bompard E., Carpaneto E., Chicco G., Napoli R.,"Analysis and modelling of thermostatically-controlled loads," Proceedings of the 8th Mediterranean Electrotechnical Conference MELECON'96, May 1996, Bari, Italy, pp. 730-734
23. L. Gyugyi, "Unified Power-Flow Control Concept for Flexible AC Transmission Systems," IEE Proceedings-C, vol. 139, no. 4, pp. 323–331, July 1992.
24. I. Papic, P. Zunko, and D. Povh, "Basic Control of Unified Power Flow Controller," IEEE Trans. on Power Systems, vol. 12, no. 4, pp. 1734–1739, Nov. 1997.
25. R. Mihalic, P. Zunko, and D. Povh, "Improvement of Transient Stability Using Unified Power Flow Controller," IEEE Trans. on Power Delivery, vol. 11, no. 1, pp. 485–491, Jan. 1996.
26. K. S. Smith, L. Ran, and J. Penman, "Dynamic Modeling of a Unifed Power Flow Controller," IEE Proc.-Gener. Transm. Distrib., vol. 144, no. 1, pp. 7–12, Jan. 1997.
27. M. Noroozian, L. Angquist, and M. Ghandhari, et al., "Improving Power System Dynamics by Series-connected FACTS devices," IEEE Trans. on Power Delivery, vol. 12, no. 4, pp. 1635–1641, Oct. 1997.
28. Bompard E., Carpaneto E., Chicco G., Napoli R., "Asynchronous motor models for voltage stability analysis," Proceedings of the International Seminar on Bulk Power System Voltage Phenomena - III, Voltage Stability, Security and Control, Davos, Switzerland, August 1994, pp. 489-499.
29. HSIAO, Y.T., CHIANG, H.D., LIU, C.C., and CHEN, Y.L.,"A computer package for optimal multi-objective VAR planning in large scale power systems", IEEE Trans. Power Syst., 1994, 9, (2),pp 668- 676
30. LEBOW, W.M., ROUHANI, R., NADIRA, R., USORO, P.B., MEHRA, R.K., SOBIESKI, D.W., PAL, M.K., and BHAVAR-AJU, M.P.,"A hierarchical approach to reactive ampere (VAR) optimization in system planning", IEEE Trans. , 1985, PALSLIM, (8), pp, 2051-2057
31. N. Kumar, and M.P. Dave, "Application of static var system auxiliary controllers to improve the transient performance of series compensated line transmission lines", Electric Power Systems Research, 34 (1995) 75- 83
32. E.V. Larsen, D.H. Baker, A.F. Imece, L. Gerin-Lajoie, and G. Scott, "Basic aspects of applying SVC's to series-compensated AC transmission lines", IEEE Trans. Power Delivery, 5 (3) (1990) 1466- 1473.
33. Dong JuLee ,EunWoongLeeI, Jong Han Lee 1, Jong Gyeum Kim2," Simulation of Static Synchronous Compensator (STATCOM)," Internal Report for ENEL and POLIMI, Sep 9, 2002.
34. E. Gholipour and S. Saadate, "Improving of transient stability of power systems using UPFC", IEEE Trans. on PD, Vol. 20, No. 2, pp. 1677- 1682, 2005.
35. R. Mihalic, P. Zunko, I. Papic and D. Povh, "Improvement of transient stability by insertion of FACTS devices", Proc. of the Power Tech, Sept. 5-8, 1993, pp. 521-525, Athens, Greece.
36. I. Papic, P. Zunko, D. Povh and W. Weinhold, "Basec control of unified power flow controller", IEEE Trans. on PS, Vol. 12, No. 4, pp 1734- 1739, 1997.
37. S. Limyingcharoen, U.D. Annakkage and N.C. Pahalawaththa, "Effects of unified power flow controllers on transient stability", IEEE Proc.– GTD, Vol. 145, No. 2, pp. 182-188, 1998.
38. P. Kumkratug and M.H. Haque, "Versatile model of a unified power flow controller in a simple power system", IEEE Proc.– GTD, Vol. 150, No. 2, pp. 155-161, 2003.
39. S. Robak, M. Januszewski and D.D. Rasolomampionona, "Power system stability enhancement using PSS and UPFC Lyapunov-based controllers: A comparative study", Proc. of the Bologna Power Tech Conference, June 23-26, 2003, Bologna, Italy.
40. Y. Morioka, M. Kato, Y. Mishima and Y. Nakachi, "Implementation of unified power flow controller and verification for transmission capability improvement", IEEE Trans. on PS, Vol. 14, No. 2, pp 575- 581, 1999.
41. K.Matsuno, I. Iyoda, and Y. Oue, "An Experience of FACTS Development 1980s and 1990s", IEEE PES Transmission and Distribution Conference and Exhibition 2002: Asia Pacific, 2(6- 10)(2002), pp. 1378 – 1381.
42. A.Edris, "FACTS Technology Development: an Update", IEEE Power Engineering Review, 20(3)(2000), pp. 4 – 9.
43. B. Schauder, M. Gernhardt, E. Stacey, T. Lemak, L. Gyugyi, T. W. Cease, and A. Edris, "Development of a ±100 MVAr Static Condenser for Voltage Control of Transmission Systems", IEEE Transactions on Power Delivery, 10(3)(1995), pp. 1486 – 1496.
44. C. Schauder, M. Gernhardt, E. Stacey, T. Lemak, L. Gyugyi, T. W. Cease, and A. Edris, "Operation of ±100

MVAR TVA STATCON", IEEE Trans. PWRD, 12(4)(1997), pp. 1805–1811.

45. D.Schauder, E. Stacey, M. Lund, L. Gyugyi, L. Kovalsky, A. Keri, A. S. Mehraban, and A. Edris, "AEP UPFC Project: Installation, Commissioning and Operation of the ±160 MVA STATCOM (Phase I)", IEEE Transactions on Power Delivery, 13(4)(1998), pp. 1530 – 1535.
46. B. Fardanesh, A. Edris, B. Shperling, E. Uzunovic, S. Zelingher, L. Gyugyi, L. Kovalsky, S. Macdonald, and C. Schauder, "NYPA Convertible Static Compensator Validation of Controls and Steady State Characteristics", CIGRE 14-103, France, August 2002.
47. G. Reed, J. Paserba, T. Croasdailc, et al., "The VELCO STATCDM Based Transmission System Project", IEEE Power Engineering Society Winter Meeting, 28 January - 1 February Val. 3(2001), pp. 1109–1114.
48. Q. Yu, P. Li, W. Liu, and X. Xie, "Overview of STATCOM Technologies", Proceedings of the 2004 IEEE International Conference on Electric Utility Deregulation, Restructuring and Power Technologies, DRPT 2004, 5–8 April 2004, Vol. 2, pp. 647 – 652.
49. J. Paserba, "Recent Power Electronics/FACTS Installations to Improve Power System Dynamic Performance", Proceedings of the 2007 IEEE Power Engineering Society General Meeting, 24-28 June 2007, pp. 1 –4.
50. S. Limyingcharoen, U. D. Annakkage, and N. C. Pahalawaththa, "Effects of unified powerflow controllers on transient stability," IEE Proc.-Gener. Transm. Distrib., vol. 145, no. 2, pp. 182–188, March 1998.
51. A. S. Mehraban and A. J. F. Keri, et al., "Application of the World's First UPFC on the AEP System," in EPRI-the Future of Power delivery Conference, Washington, DC, 1996.
52. M. P. Bottino, B. Delfino, and G. B. Denegri, "FACTS for More Effective Networks: Unified Power Flow Controller Using PSCAD/EMTDC Code," in EPRI-the Future of Power delivery Conference, Washington, DC, 1996.
53. www.bhel.com
54. www.ptcindia.com
55. suppliers.jimtrade.com/100/99343/34277.html
56. P.Kundur, Power System Stability and Control: McGraw-Hill Inc., 1994, pp. 813–816.
57. N. Mohan, T. M. Undeland, andW. P. Robbins, Power Electronics: Converters, Applications and Design, Second ed: JohnWiley& Sons, 1995.
58. EPRI Report, "Extended transient-midterm stability program (ETMSP),", EPRI TR-102 004-V2R1, 1994.
59. P. Anderson and A. A. Fouad, Power system control and stability: IEEE Press, 1994.
60. D. J. Hanson, C. Hotwill, B. D. Gemmell, and D. R. Monkhouse, "A STATCOM-Based Relocatable SVC Project in the UK for National Grid", IEEE Power Engineering Society Winter Meeting, 27-31 January 2002, vol. 1, pp. 532 –537.
61. G. Reed, J. Paserba, T. Croasdailc, et al., "SDG&E Talega STATCOM Project-System Analysis, Design and Configuration", IEEE/PES Transmission and Distribution Conference and Exhibition, Asia Pacific., 6–10 October 2002, Vol. 2, pp. 1393 –1398.