Editorial

S.N. Singh
Department of Electrical Engineering
Indian Institute of Technology Kanpur
Kanpur-208016, India
E-mail: snsingh@iitk.ac.in

Biographical notes: Dr. S.N. Singh received his MTech and PhD from the Indian Institute of Technology, Kanpur, India in 1989 and 1995, respectively. Presently, he is Associate Professor in the Department of Electrical Engineering, Indian Institute of Technology, Kanpur. Dr. Singh has received several awards, including Young Engineer Award 2000 of the Indian National Academy of Engineering, the Khosala Research Award, and the Young Engineer Award of the Central Board of Irrigation and Power, New Delhi (India). His research interests include power system restructuring, FACTS, power system optimisation and control, security analysis, power system planning, *etc*. He is a fellow of the IETE (India), a senior member of the IEEE, a member of IE (I), and a life member of the ISCEE (India).

1 Introduction

Power systems around the world have been forced to operate in their almost full capacities due to the environmental, right-of-way, and cost problems in both bundled and unbundled power systems. The amount of electric power that can be transmitted between two locations through a transmission network is limited by operating constraints. Power flows should not be allowed to increase to a level where a random event could cause the network to collapse because of angular instability, voltage instability, or cascaded outages. When such a limit is reached, the system is said to be congested. Patterns of generation resulting in heavy flows tend to incur greater losses and to threaten stability and security, ultimately making certain generation patterns economically undesirable. Hence, there is an interest in better utilisation of available power system capacities by installing new devices such as Flexible AC Transmission Systems (FACTS).

The electric utilities for transmitting and distributing power are entering into a period of change. Competition has been introduced in power systems around the world based on the premise that it will increase the efficiency of the electricity sector and reduce the cost of electrical energy consumption of the consumers. Electrical energy, however, is not a simple commodity, unlike other forms of energy; it cannot be stored easily in large quantities. Thus, continuity of supply has been a value that can be much higher than the cost of energy consumed. Overview of the technology of power system competition provides a solid basis upon which workable and durable solutions can be developed for the problems created by the introduction of electricity markets (Lie, 2001).

With open access to the transmission system by competing generators, the pattern of generations and flows can change drastically over a few hours. Under such circumstances, the operator needs more direct means of controlling the flows. Flexible

Copyright © 2006 Inderscience Enterprises Ltd.

AC transmission systems (Gyugyi, 1992; Hingorani, 1993) are the name given to the application of power electronics devices to the control of flows and other quantities in power system. Semiconductor technology enabled the manufacture of powerful thyristors and later of new elements such as the Gate Turn-Off thyristors (GTO) and Insulated Gate Bipolar Transistors (IGBT) (Hingorani, 1988). Development based on the semiconductor devices first established High Voltage DC transmission (HVDC) technology as an alternative to long-distance AC transmission. HVDC technology, in turn, has provided the basis for the development of FACTS equipment, which can solve problem in AC transmission (Hingorani and Gyugyi, 1998).

FACTS devices by controlling the power flows in the network without generation rescheduling or topological changes can improve the performance considerably. The insertion of such devices in electrical systems seems to be a promising strategy to decrease the transmission congestion (Singh and David, 2001) and to increase Available Transfer Capability (ATC) (Lie, 2001). Using controllable components such as Static Var Compensator (SVC), Static Compensator (STATCOM), Thyristor-Controlled Series Compensator (TCSC), Sub-Synchronous Series Compensator (SSSC), Thyristor-Controlled Phase Angle Regulator (TCPAR), and Unified Power Flow Controller (UPFC), line flows can be changed in such a way that thermal limits are not violated, losses minimised, stability margin increased, contractual requirement fulfilled, *etc*. without violating specified power dispatch. Increased interest in the use of these devices is due to two reasons: development in high-power electronics devices and increased loading of power systems combined with the deregulation of the power industry (Hingorani, 2000; Ooi *et al*., 1998).

2 Deregulated power system

The driving force behind the development of power systems is the growing demand for electrical energy. In developing countries, energy demand will be greater in the near future. As energy demands continue to grow, higher voltage levels are needed. Early on, AC transmission has been used for the transfer of power over long distances. Technical problems, such as voltage control and dynamic stability, do arise. General development in power system is superimposed by the trend towards deregulation, which is an opening up of power market and giving customers the opportunity to buy energy at more favourable price. When the producers and consumers of electrical energy desire to produce and consume an amount of power that would cause the transmission system to operate at or beyond one or more transfer limits, the system is said to be congested. Congestion is a term that has come to power systems for economics in conjunction with deregulation, although congestion was present in power systems before deregulation. In the pre-deregulation power systems, most energy sales were between adjacent utilities. The transaction would not go forward unless each utility agreed that it was their best interests for both economy and security.

In the deregulated power system, the challenge of congestion management (Verma *et al*., 2001) for the transmission system operator is to create a set of rules that ensure sufficient control over producers and consumers to maintain an acceptable level of power system security and reliability while maximising market efficiency. The rules must be transparent because there will be many aggressive entities seeking to exploit congestion to create market power. If a generator can successfully increase its profits by strategic bidding or by any means other than lowering its costs, it is said to have market power. The obvious example of market power is a nonregulated monopoly with zero elasticity demands, where the generator can ask whatever price it wants for electric energy. There are many possible causes among them. Unlimited market power is socially not tolerable.

Several emerging issues in competitive power market, such as enhancement of security and available transfer capability of the system, transmission pricing, *etc*., have been restricting the free and fair trade of electricity. FACTS devices can play a major role in these issues. Moreover, it is important to ascertain the location for placement of these devices because of their considerable costs.

Changing environment influences the optimisation of the transmission network since load flows existing today will be altered considerably. Ancillary functions – such as frequency control, load flow control, reactive power, voltage stability, and network security – are required for the smooth operation of the networks. Technological development in flexible AC transmission systems (Song and Johns, 1998) can develop the electricity markets by allowing the operation of the power system closer to its full economical potential.

3 FACTS controllers

The flexible AC transmission system is akin to high voltage DC and related thyristor developments, designed to overcome the limitations of the present mechanically controlled AC power transmission systems. By using reliable and high-speed power electronic controllers, the technology offers five opportunities for increased efficiency of utilities:

- Greater control of power so that it flows on the prescribed transmission routes
- Secure loading of transmission lines to levels nearer their thermal limits
- Greater ability to transfer power between controlled areas
- Prevention of cascading outages
- Damping of power system oscillation.

The driving force for new and more cost-effective FACTS equipment is the development of semiconductor devices. The most powerful are thyristors, which can have a blocking capability of more than 10 kV and carry current up to 4 kA. However, the GTO devices offer additional advantage for interrupting the current. These devices permit the use of forced commutated converters, which are advantageous in building FACTS equipment with more advanced characteristics. The IGBT devices are used for converters in the lower rating ranges, mainly to be used in medium- and low-voltage network. The advantage of these devices is that they allow switching frequencies in the higher range.

The GTOs and IGBTs are the more promising switching devices presently and potentially available within the near future. However, in the longer future (ten years or more), Metal Oxides (MOS) controlled thyristor (MCT) devices will be competitive to GTO and IGBT devices. A comparison of the various power switching devices is presented in Table 1.

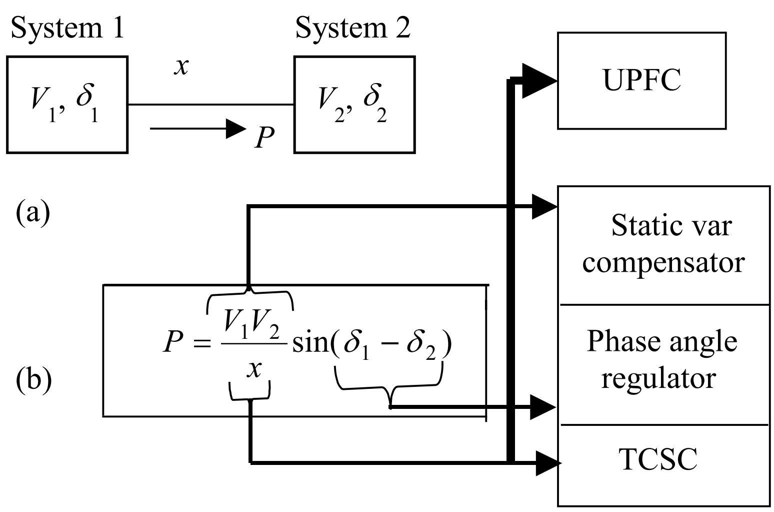
Table 1 Comparison of power semiconductor devices

	Thyristor	*GTO*	*IGBT*	*SI * thyristor*	*MCT*	*MOSFET*
Maximum voltage rating (V)	8000	6000	1700	2500	3000	1000
Maximum current rating (A)	4000	6000	800	800	400	100
Voltage blocking	Sym./ asym.	Sym./ asym.	Asym.	Asym.	Sym./ asym	Asym.
Gating	Pulse	Current	Voltage	Current	Voltage	Voltage
Conduction drop (V)	1.2	2.5	3	4	1.2	Resistive
Switching frequency (kHz)	1	5	20	20	20	100
Development target maximum voltage rating (kV)	10	10	3.5	5	5	2
Development target maximum current rating (kA)	8	8	2	2	2	0.2

Notes: * SI: Static induction thyristor
MOSFET: MOS field effect transistor

The idea of FACTS controllers is explained in Figure 1, which shows schematic diagram of an AC interconnection between two systems. The active power (P) transmitted between the systems is defined by the given equation where V_1 and V_2 are the voltages at both ends of the transmission. x is the equivalent impedance of the transmission line and $\delta_1 - \delta_2$ is the phase angle difference between both systems. From the equation it is evident that the transmitted power is influenced by three parameters: voltage, impedance, and voltage angle difference. FACTS devices can influence one or more of these parameters as shown in the figure, and thereby control the power flow.

Figure 1 Representation of different controllers



The relative advantages of some of the FACTS controllers in AC systems, as shown in Table 2, have been realised or are still under development for application. They can be used for load flow control, voltage control, and stability improvement in transmission system as well as for additional special applications. The advantage of FACTS is that combining a variety of different equipment can create different new members of the FACTS family.

Table 2 Comparison of advantages of FACTS

Device name	*Load flow control*	*Voltage control*	*Transient stability*	*Oscillation damping*
SVC	*	***	*	**
TCSC	**	*	***	**
SSSC	***	**	***	**
UPFC	***	***	***	***

Note: * small
** medium
*** strong

As the first FACTS controller listed, SVC has already been in use for three decades with excellent operating experiences. The demand for SVC has increased continuously as systems become more heavily loaded and problems arose regarding voltage control. The second task for SVC is to damp out power system oscillations and to increase stability limit in long-distance transmission system. In the future, instead of SVC, the STATCOM alternative will be used more frequently for shunt-connected controllers.

4 Issues in the implementations of FACTS devices

The main issues include:

- The allowable phase shift between the voltages on the two sides of the series-connected devices (the phase shifter only allows a limited range of angles, whereas the HVDC link and the Matrix converter permit the full 360° control).
- The possibility of supplying only reactive power or both real and reactive power, either in the shunt or series configuration, through storage elements (real power is required for purposes of damping power system oscillations whereas modifying the X/R ratio of the transmission line and providing line voltage support under fault conditions).
- The speed of response, dependent on the switching frequency, the number of power converters associated in either series or parallel, and the passive reactive elements used.
- The harmonic distortion of the injected current in the shunt configuration, or the injected voltage in the series configuration.
- Losses and efficiency of the FACTS device, with efficiencies of 99% or better demanded (this has a direct impact on the capital and operating costs of the unit).

- Reliability, availability, and redundancy (this last feature is an implementation issue that depends upon the converter structure).
- Last but not least, the cost of these devices (which is still quite high; hence, proper locations are required to reduce the cost of these devices by optimising the size and number of locations).

Deregulation in the power industry and opening of the market for delivery of cheaper energy to the customers are creating additional requirements for economic and secure operation of the power systems. FACTS controllers offer major advantages in meeting these requirements. As a result of deregulation, however, operational problems arise, creatings additional requirements for load flow control and needs for ancillary services in the system.

The ancillary function required for smooth operation of the networks, such as congestion management, increasing available transfer capability, frequency control, optimal-load-flow control, reactive power and voltage stability, as well as security are being assumed by the operators. New installations are needed, *e.g.*, FACTS equipment in the system or additional purchases of ancillary services from the power plants or other transmission companies. These additional requirements for power system can be effectively met by using FACTS equipments. Due to excessive cost of these devices, it is important to choose best sitting and sizing of these apparatus in power system (Verma *et al*., 2002).

5 Summary and conclusion

FACTS controllers have the ability to control the power flow in the network by which the static and dynamic performance of the system can be improved significantly. These devices can play a major role in both regulated and deregulated power systems. However, these devices were used mainly for improving the dynamic performances in vertically integrated power systems. Due to present trends in power system restructuring, which is proving the competition in the electric supply industry, the role of these devices is to improve not only the dynamic performance but also the static performances such as congestion management, enhancement of power transfer capability, improving the system security, *etc*.

Most of the FACTS controllers, except SVC and TCSC, are in the development stage. Some of the tested FACTS controllers are ready for commercial application. The cost of these controllers is still quite high and therefore their optimal locations in the system must be ascertained. Moreover, research and development towards cheap and reliable high power rating power electronic devices are also needed to reduce the overall cost of the controllers. Some adverse effects during the system disturbances and maloperation of FACTS controllers must be suitably mitigated. It is sure that FACTS controllers have a bright future in the deregulated environment.

However, once a sufficiently large number of these fast compensators and controllers are deployed over the system, the coordination and overall control to provide maximum system benefits and prevent undesirable interactions with different system configurations and objectives, under normal and contingency conditions, present a different technological challenge. This cha1lenge is to develop appropriate system optimisation control strategies, communication links, and security protocols.

Acknowledgements

Being a Guest Editor of the special issue on 'Present and future of flexible AC transmission systems controllers in power systems' of the *International Journal of Energy Technology and Policy*, I would like to thank all the authors for their contributions and all the reviewers for reviewing the papers in this special issue. I also gratefully acknowledge the assistance provided by Professor SC Srivastava, IIT Kanpur (India); Dr. Mohammed Dorgham, Editor-in-Chief of IJETP; and Janet Marr, Editorial Manager of IJETP.

References

Gyugyi, L. (1992) 'A unified power flow control concept for flexible AC transmission systems', *IEE Proceedings Part-C*, Vol. 139, No. 4, pp.323–333.

Hingorani, N.G. (1988) 'Power electronics in electric utilities: role of power electronics in future power systems', *Proceedings of the IEEE*, Vol. 76, No. 4.

Hingorani, N.G. (1993) 'Flexible AC transmission', *IEEE Spectrum*, Vol. 30, pp.40–45.

Hingorani, N.G. (2000) 'Role of FACTS in a deregulated market', *IEEE Power Engineering Society Summer Meeting*, Vol. 3, pp.1463–1467.

Hingorani, N.G. and Gyugyi, L. (1998) *Understanding FACTS*, The Institution of Electrical and Electronics Engineers Press.

Lie, L.L. (2001) *Power System Restructuring and Deregulation*, UK: John Wiley & Sons.

Ooi, B.T., Joos, G., Galiana, F.D., Mcgillis, D. and Marceau, R. (1998) 'FACTS controllers and the deregulated electric utility environment', *IEEE Canadian Conference on Electrical and Computer Engineering*, Vol. 2, pp.597–600.

Singh, S.N. and David, A.K. (2001) 'Optimal location of FACTS devices for congestion management', *Electric Power Systems Research*, Vol. 58, No. 2, pp.71–79.

Song, Y.H. and Johns, T.A. (1998) *Flexible AC Transmission System*, IEE press.

Verma, K.S., Singh, S.N. and Gupta, H.O. (2001) 'Optimal location of UPFC for congestion management', *Electric Power Systems Research*, Vol. 58, No. 2, pp.89–96.

Verma, K.S., Singh, S.N. and Gupta, H.O. (2002) 'Role of FACTS devices in open power market: an overview and key issues', *International Conference on Computer Applications in Electrical Engineering (CERA01)*, University of Roorkee, India, pp.122–132.