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A State-of-the-Art Review of Flexible AC Transmission System (FACTS) Controllers

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ABSTRACT

Transformations in the electrical sector and increasing consumer demand for electricity are exerting pressure on power networks. Networks must function nearer to their stability limits to do this. Network enhancements are not prioritized over more economical options. A state-of-the-art power electronics method known as FACTS enhances the controllability, stability, and power transfer capacity of alternating current (AC) transmission systems. This paper conducts a comprehensive investigation and evaluation of FACTS controllers.

Keywords: *Flexible AC Transmission System (FACTS); FACTS Controllers; Power Transmission;Power Flow Control.*

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1. INTRODUCTION

The global electrical supply sector is expanding. This remarkable transformation was driven by market forces, resource exhaustion, and energy requirements. Despite rapid advancement, environmental, land use, and legal challenges are obstructing the approval and building of further transmission lines and power plants. Numerous utility companies are hindered from expanding as a result of this.

One or more of the following steady-state and dynamic limitations may influence power transmission:

- Angular stability,
- Voltage magnitude,
- Thermal limits,
- Transient stability, and
- Dynamic stability.

These constraints provide the upper limit of electrical power that can be transmitted without causing harm to equipment or transmission cables. Enhancing power generation and transmission infrastructure may facilitate a constant rise in electricity flow.

FACTS Controllers

FACTS are defined as "alternating current transmission systems that utilize power electronic-based and other static controllers." This is done with the intention of enhancing controllability and increasing the capacity for power transfer. This particular definition was developed by the IEEE Working Group.

As a result of their skills, power electronics and static controllers are indispensable not only because of their lightning-fast response times but also because of their nearly unlimited operational capabilities. Using thyristors, GTOs, and IGBT capacitors makes it simpler to manufacture a wide range of FACTS Controllers and HVDC converters. This is because these components are used in the production process. This makes it simpler to create a large number of central processing units, similar to how it is easier to build a transistor. These controllers are responsible for dynamically regulating line voltage, reactive and active power flow, and line impedance, in addition to performing additional functions which are also included in their responsibilities. When they are outfitted with storage, they are able to generate and utilize both reactive and active power. This ability allows them to create power in both forms.

A look at Figure 1 reveals that there are three distinct types of FACTS Controllers. Every controller makes it simpler to quickly exercise control over the situation. There are three different approaches that can be utilized, and they are as follows: voltage injection in series with the line, current injection in a shunt configuration, and a mixture of using both of these approaches. These controllers have limitations that are intrinsic to them as a result of the traits, attributes, and requirements that they possess.

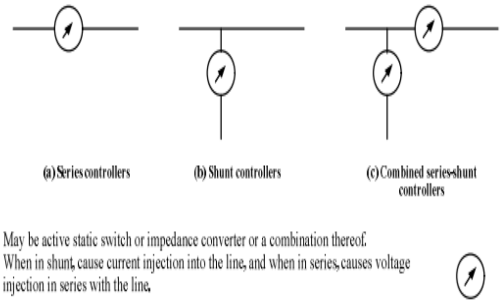

Figure1. Type of FACTS Controller

Objectives of FACTS controllers

The primary objectives of FACTS controllers are as follows:

- Power is disseminated by designated transmission lines.
- Transport lines must be loaded within their temperature criteria for safe operation.
- Emergency management must be improved to avert cascades.
- Oscillations that may impact security or line capacity are regulated.

To achieve objectives, advanced compensators and controllers must be engineered. Consequently, high-power electronics and real-time operational oversight are necessary. FACTS controllers can attain comprehensive system optimization control [1]. FACTS can surmount transmission capacity constraints. These limitations may arise from:

- Temporary, dynamic stability
- A subsynchronous oscillation
- Persistent system overvoltages and undervoltages
- Voltage Deterioration

Equilibrium conditions

- Erroneous Power Flow
- Excess Reactive Power Surplus Transfers
- Equilibrium Voltage
- Thermal Threshold

2. TYPES OF FACTS CONTROLLERS

(a) Static Synchronous Compensator (STATCOM)

As an illustration of a static synchronous generator, the Statcom, which is a static var compensator that is connected to a shunt, is an example. It is feasible for devices to generate capacitive or inductive currents that can be modified. At the same time as other systems are affected by the voltage that is generated by alternating current systems, STATCOM is not affected by this voltage. With regard to various other programs. An inquiry is now being conducted into the possibility of using STATCOM as a FACTS controller.

(b) Static Var Compensator (SVC)

In the event that it is coupled in parallel, the SVC can either act as a generator or an absorber of static variable voltage, depending on the circumstances. It is possible to switch between capacitive and inductive current using the output in order to change the parameters of the electrical power system, such as the bus voltage. This is feasible because of the capacity of the output. The adaptability of the system is increased as a result of this. The FACTS controller SVC is responsible for a considerable amount of the work that is completed. The range of possible MVAR ratings is from sixty to six hundred.

(c) Thyristor Controlled Breaking Reactor (TCR)

For the goal of stabilizing power systems or minimizing power surges during generator operation in the presence of disturbances, shunt-connected thyristor-switched resistors (TCBRs) are deployed.

(d) Thyristor Controlled Series Capacitor (TCSC)

It is possible to manage a series capacitor bank by modulating the series capacitive reactance using a thyristor-controlled reactor. This allows for the management of the capacitor bank. In order for a capacitive reactance compensator (TCSC) to perform its intended purpose, it is essential to have this arrangement.

(e) Static Synchronous Series Compensator (SSSC))

In order to control the transmission of electric power without the requirement of an external energy supply, the static synchronous generator (SSSC) functions as a series compensator. This is done for the purpose of managing the frequency of the transmission. Whenever there is a change in the output voltage, it is essential to take note that the line current is ignored and phase-shifted by ninety degrees. Altering the reactive voltage drop in the transmission line is something that the SSSC is able to perform. The SSSC may make use of energy storage devices that are either energy-absorbing or transiently rated in order to enhance the dynamics of the power system. This is done in order to improve the system's overall performance. Additionally, these have the capability to instantly enhance or decrease the voltage drop that is brought about by the resistance that is located directly downstream.

(f) Interline Power Flow Controller (IPFC)

The IPFCs, which are connected to the AC terminals of the SSSC, make it feasible for power to be transferred in both directions. The means by which this objective is accomplished is by the connecting of two or more SSSCs through a shared DC link. The term "static synchronous series compensators" (SSSCs) refers to devices that are able to make independent changes to the flow of power in each line while simultaneously maintaining the distribution of reactive power flow [5, 8]. To completely remedy the real power shortages of the related SSSCs and to offer shunt reactive compensation, it is conceivable to insert a STATCOM into the shared DC connection of the IPFC. This would allow for the provision of shunt reactive compensation.

(g) Thyristor Switched Series Reactor (TSSR)

Through the utilization of a thyristor for the purpose of managing the series reactor, the TSSR is able to decrease the quantity of inductive reactance at its disposal. Consequently, this makes it easier to create a steady shift in inductive reactance .

(h) Unified Power Flow Controller (UPFC)

Additionally, the STATCOM and the Solid State Switching Controller are both components that are included in the Unified Power Flow Controller. When a conventional direct current (DC) link is utilized, it is possible to facilitate the transfer of power in both directions between the series output terminals of the SSSC and the shunt output terminals of the STATCOM. This is made possible by the fact that the power can be transferred in both directions. It is possible for the device to correct both actual and reactive series lines simultaneously, and it is able to do so without the requirement of a power source. The unidirectional power factor converter (UPFC) has the capability to make adjustments to the voltage, impedance, and angle of the transmission line either concurrently or independently. In addition to this, it is able to introduce angle-independent series voltage, which may be utilized to govern the flow of both active and reactive power in the line. This capability is a significant advantage. Through the utilization of unidirectional power factor correction (UPFC), it is possible to separately calibrate shunt reactive compensation. This is a possibility. The UPFC, which is the most adaptive FACTS controller for managing the voltage and flow of power over transmission lines, was developed by Gyugyi [9], who is responsible for its creation.

(i) Generalized Unified Power Flow Controller (GUPFC)

GUPFC is able to effectively manage the transfer of active and reactive power across lines, in addition to managing the voltage of the bus. Also, it is possible to control the voltage of the bus. Three converters are required for a basic GUPFC design. Two of the converters must be linked in series, and the third converter must be connected in shunt between the two series converters. Because they are connected to the same bus, converters in a substation are connected to two transmission lines that share a common bus. This is because the converters all share the same bus. In addition to this, it has the capability of concurrently altering the active and reactive power flows of the two lines, in addition to adjust the voltage of the bus and all five parameters. The shunt converters and the series converters are connected to one another by a single DC connection. This is done in order to make the process of power transmission more efficient.

(j) Interphase power controller (IPC)

Both capacitive and inductive branches are provided by the IPC power controller, and these branches are coupled in series with one another. Each of these branches has the capacity to individually adjust the active and reactive power phases within each phase. Altering phase shifts and branch impedances can be accomplished through the use of switches that are either mechanical or electrical in nature. This allows for the achievement of the requisite amounts of active and reactive power. There is a situation in which the inductive and capacitive impedances are conjugate. In this scenario, every IPC terminal acts as a passive current source, and the voltage at the terminal opposite it is responsible for controlling the output of the terminal. Explanations of the IPC idea are provided in further detail in , and the realistic design criteria for linking the 120 kV networks of the 200 MW prototype are studied in. Both of these documents can be found on the internet. It has been proved by that the concept that was proposed by has been modified.

Table 1: Control attributes of Various controllers

FACTS controllers	Control attributes
STATCOM	Voltage control, VAR compensation, damping oscillations, voltage stability
SVC, TCR, TSC, TSR	Voltage control, VAR compensation, damping oscillations, transient and dynamic stability, voltage stability
TCBR	Damping oscillations, transient and dynamic stability
SSSC, TCSC, TSSC, TCSR, TSSR	Current control, damping oscillations, transient and dynamic stability, voltage stability, fault current limiting
TCPST	Active power control, damping oscillations, transient and dynamic stability, voltage stability
UPFC, GUPFC	Active and reactive power control, voltage control, VAR compensation, damping oscillations, transient and dynamic stability, voltage stability, fault current limiting
IPFC	Reactive power control, voltage control, damping oscillations, transient and dynamic stability, voltage stability

Table 2: The role of FACTS controllers in power system operation

Operating problem	Corrective action	FACTS controllers
Voltage limits: Low voltage at heavy load High voltage at low load High voltage following an outage Low voltage following an outage	Supply reactive power Absorb reactive power Absorb reactive power; prevent overload Supply reactive power; prevent overload	STATCOM, SVC STATCOM, SVC, TCR STATCOM, SVC, TCR STATCOM, SVC
Thermal limits: Transmission circuit overload Tripping of parallel circuits	Reduce overload Limit circuit loading	TCSC, SSSC, UPFC, IPC TCSC, SSSC, UPFC, IPC
Loop flows: Parallel line load sharing Post-fault power flow sharing Power flow direction reversal	Adjust series reactance Rearrange network or use thermal limit actions Adjust phase angle	IPC, SSSC, UPFC, TCSC IPC, SSSC, UPFC, TCSC IPC, SSSC, UPFC

Voltage, current, impedance, active power, and reactive power are interrelated; hence, each controller possesses distinct capacities to regulate voltage, power flow, stability, and other characteristics. A variety of control features of FACTS controllers are enumerated in table [4]. Table 2 illustrates the impact of FACTS controllers on electrical systems [19]. This table delineates the installation costs of HVDC and FACTS systems.

Table 3: Cost Comparison of HVDC and FACTS

Throughput MW	HVDC 2 Terminal	FACTS
200 MW	$ 40-50 M	$ 5-10 M
500 MW	$ 75-100 M	$ 20-20 M
1000 MW	$ 120-170 M	$ 20-30 M
2000 MW	$ 200-300 M	$ 30-50 M

3. BENEFITS OF FACTS CONTROLLERS

FACTS controllers can assist transmission owners and their systems in the following manners:

- Cost variables are prioritized over other metrics due to the substantial expenses associated with the development of the transmission plant. FACTS technology frequently represents the most economical solution for mitigating transmission overload challenges [20].
- Environmental implications: New transmission pathways are required to satisfy global energy demand. This necessitates authorization to transmit electrical energy along a designated route.
- Power flow control is employed to fulfill contractual obligations, adhere to utility requirements, enhance power distribution efficiency, mitigate emergencies, or achieve a combination of these objectives. Minimize power dissipation and enhance voltage stability to augment system efficiency.
- Enhance the lines' capacity to attain their ideal temperature, considering both short-term and long-term variations.
- To enhance system security, elevate the transient stability threshold, mitigate cascading blackouts, regulate short-circuit currents and overloads, and diminish electromechanical oscillations in power systems and machinery.
- Forge secure connections with adjacent utilities and sites to reduce the dependency on backup power sources for both entities.
- Increase sitting alternatives for young individuals.
- Reactive power must be diminished to enhance active power for line transmission.
- Enhance loop continuity.
- Augment the utilization of the most cost-effective electricity supply.
- Voltage changes require attention.

4. CONCLUSION

This study evaluated the control characteristics and advantages of various FACTS controllers. FACTS controllers can enhance transmission capacity, dynamic performance, stability, and quality in contemporary power systems. Their primary responsibilities include reactive power compensation, voltage regulation, and power flow management. Conventional apparatus such as phase-shifting transformers equipped with mechanical on-load tap changers or switched compensation can execute control actions more rapidly than FACTS controllers. FACTS controllers possess programmable power electronics. The operations of transmission networks will become increasingly integrated following the deregulation of energy markets. FACTS controllers provide a viable solution to the complex technical challenge of creating electric power networks that optimize transmission capacity while reducing costs.

REFERENCES

[1] S. N. Singh, Flexible AC Transmission Systems (FACTS) controllers: an overview, International Journal of Energy Technology and Policy 2006; 4(3- 4):236-254.

[2] L. Gyugyi, Dynamic compensation of AC transmission lines by solid-state synchronous voltage sources, IEEE Transactions on Power Delivery 1994; 9(2):904-911.

[3] L. Gyugyi, N. G. Hingorani, P. R. Nannery, N. Tai, Advanced. Static Var Compensator Using Gate Turn-Off Thyristors for Utility. Applications, CIGRE Paper 1990; 23-203.

[4] K. R. Padiyar, A. M. Kulkarni, Flexible AC transmission systems: A status review, Sadhana-Academy Proceedings In Engineering Sciences 1997; 22(6):781-796.

[5] N. G. Hingorani, L. Gyugyi, Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems, IEEE, New York, 2000.

[6] Rubaai, A. R. Ofoli, D. Cobbinah, M. D. Kankam, Two-layer supervisory controller-based thyristor-controlled braking resistor for transient stability crisis, IEEE Transactions on Industry Applications 2005; 41(6):1539-1547.

[7] L. Gyugyi, C. D. Schauder, K. K. Sen, Static synchronous series compensator: a solid-state approach to the series compensation of transmission line, IEEE Transactions on Power Delivery 1997; 12(1):406-417.

[8] L. Gyugyi, K. K. Sen, C. D. Schauder, The interline power flow controller concept: a new approach to power flow management in transmission systems, IEEE Transactions on Power Delivery 1999; 14(3), 1115-1123.

[9] L. Gyugyi, Unified power-flow control concept for flexible AC transmission systems, IEE Proceedings Conf. Generation, Transmission and Distribution 1992; 139(4):323-331.

[10] X.-P. Zhang, E. Handschin, M. Yao, Modeling of the generalized unified power flow controller (GUPFC) in a nonlinear interior point OPF, IEEE Transactions on Power Systems 2001; 16(3):367-373.