A review on various application of several FACTS Controller

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Abstract **— Economic growth of the country is directly depicted with the development of electric power sector. As electricity demand continues to rise, there is an immediate need to increase the quality and reliability of today's highly complex power systems. Traditional power flows from power stations to the nearest big city are giving way to more complex patterns. Growth in the use of renewable sources also becomes a problem, as these generations are often located in remote regions where the power grid is traditionally weak. Construction of new transmission systems is not always the best option due to environmental crisis, land use, permit granting and cost considerations. In these aspects Flexible AC Transmission Systems (FACTS) technology with relatively low investment, compared to new transmission or generation facilities allows the industries to enhance power system performance, improve quality of supply and also provide an optimal utilization of the existing resources. This paper discuss about the various FACTS Controller used for different purposes.**

Index Terms **— Transmission systems, FACTS Controllers, TCPAR FACTS Controller, TCSC FACTS Controller, congestion management**

INTRODUCTION

The need for more efficient electricity systems management has given rise to innovative technologies in power generation and transmission. The combined cycle power station is a good example of a new development in power generation and Flexible AC Transmission Systems, generally known as FACTS, are controllers that improve transmission systems. Worldwide transmission systems are undergoing continuous changes and restructuring. They are becoming more heavily loaded and are being operated in ways not originally envisioned.

Transmission systems must be flexible to react to more diverse generation and load patterns. In addition, the economical utilization of transmission system assets is of vital importance to enable utilities in industrialized countries to remain competitive and to survive.

In developing countries, the optimized use of transmission systems investments is also important to support industry, create employment and utilize efficiently scarce economic resources. FACTS Controller is a technology that responds to these needs. It significantly alters the way transmission systems are developed and controlled together with improvements in asset utilization, system flexibility and system performance.

FACTS CONTROLLER

For better utilization of existing power systems, new power system equipment have been developed owing to rapid advancement in power electronics technology. According to IEEE, a system that incorporates power electronics devices for enhancing the controllability and increase power transfer capability is known as FACTS Controllers. As a result, more power reach to the consumer within shortest possible time.

According to K. E. Stahlkopf and M. R. Wilhelm **[1]**, the flow of power across the transmission line is identified by three major characteristics:

i. Voltages at both ends of the lines i.e. sending end and receiving end buses
ii. Reactance or the impedance of the line
iii. The phase angle difference between the sending end and receiving end buses

The FACTS Controllers regulate these parameters by using fast acting switches. Thus, FACTS Controllers have made it feasible to transfer the power in real time and thus, deliver almost instant response to disturbances occurring in the transmission system as explained by P. Etingov et. al. **[2].** N. G. Hingorani and L. Gyugyi **[3]** illustrate the different types of FACTS Controllers in Fig 1.

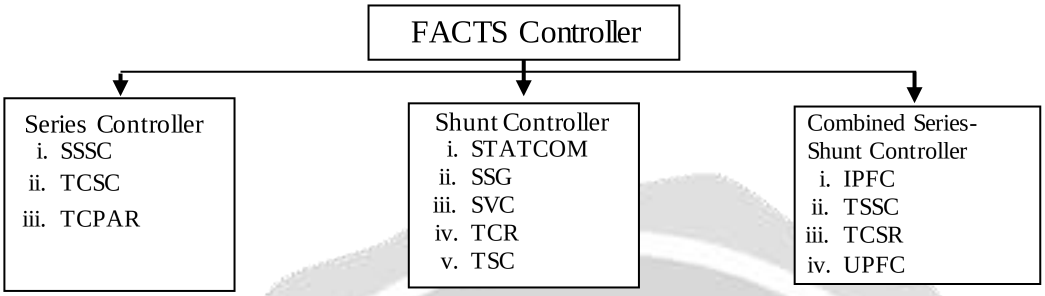

Fig 1: Flowchart showing the classification of FACTS Controllers

Brief descriptions of few FACTS Controllers, shown in Fig 1, are given below:

i. **Static Var Compensator (SVC):** This is a shunt device. It is basically a combination of Thyristor Controlled Reactor (TCR) and Thyristor Switched Capacitor (TSC) and/or fixed capacitor. The TCR consists of air-cored, glass fibre insulated, epoxy resin impregnated fixed reactor coil and the TSC is comprised of a capacitor bank. Both TCR and TSC are connected in series with bi-directional thyristor valve as explained by Illemsen, N. et. al. **[4]**.

ii. **Thyristor Controlled Series Compensator (TCSC):** TCSC FACTS Controller is the first generation FACTS Controller. It is connected in series with the transmission line. It can control the impedance of the line. Hence, this controller is used as a series compensator. It can be configured to control the flow of power, improve the transfer limits and transient stability. Variable impedance is also provided by TCSC FACTS Controller, which is essential for the compensation as illustrate by V. Mahajan **[5]**.

iii. **Static Compensator (STATCOM):** A STATCOM is an IGBT based voltage source converter, a coupling transformer and the controls. The converter is so designed that its output current leads the output voltage by 90^o and the converter voltage and the reactive output are controllable. If the voltage of converter is greater than voltage of the system, the device supplies reactive power to the system and therefore acts as capacitor. However, if voltage of converter is less than voltage of the system, the device absorbs reactive power i.e. acts as reactor.

iv. **Phase Shifter:** These are Phase Shifting Transformers (PST) in which phase shift is achieved by withdrawing a portion of line to ground voltage of one phase and fusing it in series with another phase. These shifters are applied to control the magnitude, direction and flow of power of the transmission line by varying phase. The line to ground voltage is obtained by using a regulating transformer and a portion of this voltage is injected by a series transformer. The angles of this shifter are regulated by On-Load Tap Changer (OLTC) and thus the series voltage is varied by varying the tap changer in steps. For changing the taps, fast acting switches are used so that phase angle may be varied.

v. **Unified Power Flow Controller (UPFC):** It is the first member of an emerging family of advanced FACTS Controllers. It comprises of two switching inverters in such a way that one inverter is connected in series with injecting transformer and infuse a series alternating voltage whose magnitude and phase angle both can be regulated. The second inverter is connected in parallel to the line through shunt transformer and supplies/absorbs the required reactive power at the common dc bus, which is backed by a capacitor bank. This inverter can either generate or absorb adjustable reactive power, thus allowing the line to have its own shunt reactive compensation. As an outcome, a UPFC may independently adjust both reactive and active power.

ORIGIN OF FACTS CONTROLLER

Step by step evolution of the FACTS Controller:

i. **Oil Embargo of 1947 & 1979:** Due to the huge rise in price of the oil, then actually putting an extra power plant become very costly. Because of this, some researchers thought of a solution where instead of putting extra power plant, power can be transmitted from one point to another.
ii. **Environmental movement:** Setting up a power plant will actually base on fossil fuel which causes a very big impact on environmental. Because of this environmental movement come into the picture and that forces to shut down many power plant.
iii. **Magnetic field concern:** If we have high voltage transmission line, so it will hazardous to the inhabitant, which will cause magnetic field.
iv. **Permit to build new transmission line:** Due to this magnetic field which concern health and environmental issue to build new transmission line. Permission from the higher and lower authority is required and due to healthy and environmental issue building a new transmission line is becoming costly day by day.
v. **HVDC & SVCs:** These give us the scope to revise the FACTS Controller itself and thereafter in 1998 investment are made on EPRI based FACTS Controller and parallel the researchers came out with rotary solution and with the advancement in power electronics it become easy to build FACTS Controller, which are used now-a-days.
vi. Increase in power transfer
vii. The need of power semiconductors

BENEFITS OF UTILIZING FACTS CONTROLLER

The benefits of utilizing FACTS Controller in electrical transmission systems can be summarized as follows:

i. **Better utilization of existing transmission system assets:** In many countries, increasing the energy transfer capacity and controlling the load flow of transmission lines are of vital importance, especially in deregulated markets, where the locations of generation and the bulk load centers can change rapidly. Frequently, adding new transmission lines to meet increasing electricity demand is limited by economical and environmental constraints. FACTS Controller helps to meet these requirements with the existing transmission systems.
ii. **Increased transmission system reliability and availability:** Transmission system reliability and availability is affected by many different factors. Although FACTS Controller cannot prevent faults; they can mitigate the effects of faults and make electricity supply more secure by reducing the number of line trips. For example, a major load rejection results in an over voltage of the line which can lead to a line trip. SVCs or STATCOMs counteract the over voltage and avoid line tripping.
iii. **Increased dynamic and transient grid stability:** Long transmission lines, interconnected grids, impacts of changing loads and line faults can create instabilities in transmission systems. These can lead to reduced line power flow, loop flows or even to line trips. FACTS Controllers stabilize transmission systems with resulting higher energy transfer capability and reduced risk of line trips.
iv. **Increased quality of supply for sensitive industries:** Modern industries depend upon high quality electricity supply including constant voltage, and frequency and no supply interruptions. Voltage dips, frequency variations or the loss of supply can lead to interruptions in manufacturing processes with high resulting economic losses. FACTS Controllers can help provide the required quality of supply.
v. **Environmental benefits:** FACTS Controllers are environment friendly. They contain no hazardous materials and produce no waste or pollutants. FACTS help distribute the electrical energy more economically through better utilization of existing installations thereby reducing the need for additional transmission lines.

FINANCIAL BENEFITS OF FACTS CONTROLLERS

There are three areas, where the financial benefits could be calculated relatively easily:

i. **Additional sales** due to increased transmission capability
ii. **Additional wheeling charges** due to increased transmission capability
iii. **Avoiding or delaying of investments** in new high voltage transmission lines or even new power generation

These are only rough calculations to indicate the possible direct economical benefits of FACTS Controllers. There are also indirect benefits of utilizing FACTS Controllers, which are more difficult to calculate. These include avoidance of industries outage costs due to interruption of production processes (e.g. paper industry, textile industry, production of semi-conductors/computer chips) or load shedding during peak load times.

INVESTMENT COSTS OF FACTS CONTROLLER

The investment costs of FACTS Controller can be broken down into two categories:

i. **The controller equipment costs:** Equipment costs depend not only upon the installation rating but also upon special requirements such as:
   a. Redundancy of the control and protection system or even main components such as reactors, capacitors or transformers
   b. Seismic conditions
   c. Ambient conditions (e.g. temperature, pollution)
   d. Communication with the substation control system or the regional or national control center.

ii. **The necessary infrastructure costs:** Infrastructure costs depend on the substation location, where the FACTS Controller should be installed. These costs include e.g.
   a. Land acquisition, if there is insufficient space in the existing substation
   b. Modifications in the existing substation, e.g. if new HV switchgear is required
   c. Construction of a building for the indoor equipment (control, protection, thyristor valves, auxiliaries etc.)
   d. Yard civil works (grading, drainage, foundations etc.)
   e. Connection of the existing communication

MAINTENANCE OF FACTS CONTROLLERS

Maintenance of FACTS Controller is minimal and similar to that required for shunt capacitors, reactors and transformers. It can be performed by normal substation personnel with no special procedures. The amount of maintenance ranges from 150 to 250 person-hours per year and depends upon the size of the installation and the local ambient (pollution) conditions.

OPERATION OF FACTS CONTROLLERS

FACTS Controllers are normally operated automatically. They can be located in unmanned substations. Changing of set points or operation modes can be done locally and remotely (e.g. from a substation control room, a regional control centre, or a national control centre).

STEPS FOR THE IDENTIFICATION OF FACTS PROJECTS

Following are the steps to be followed while projecting the location for FACTS Controllers:

i. The first step should always be to conduct a detailed system study to investigate the critical conditions of a grid or grids' connections. These conditions could include: risks of voltage problems or even voltage collapse, undesired power flows, as well as the potential for power swings or sub-synchronous resonances.
ii. For a stable grid, the optimized utilization of the transmission lines for e.g. increasing the energy transfer capability; could be investigated.
iii. If there is a potential for improving the transmission system, either through enhanced stability or energy transfer capability, the appropriate FACTS Controllers and its required rating can be determined.
iv. Based on this technical information, an economical study can be performed to compare costs of FACTS Controller or conventional solutions with the achievable benefits.

WORLDWIDE APPLICATIONS

The construction period for a FACTS Controller is typically 12 to 18 months from contract signing through commissioning. Installations with a high degree of complexity, comprehensive approval procedures, and time-consuming equipment tests may have longer construction periods.

The application of FACTS Controller along with various optimization methods is one of the leading developments in the existing electrical environment is explained by B.Chong et. al. **[6]**, R. Srinivasa Rao and V. Srinivasa Rao **[7]**. The role of FACTS Controller in mitigating congestion has been studied in the literature reviewed by J. Brosda et. al. **[8]** and Gupta

M et. al. **[9]**. The applications of various FACTS Controllers along with various optimization techniques used to manage congestion is outlined in Table 1.

Table1: Congestion managed by using various FACTS Controllers

S.No.	Author	FACTS Controller	Approach	Remarks
1.	A.K, et. al. **[10]**	UPFC FACTS Controller	i. Pricing based method ii. Sensitivity based approach are used	Minimization of cost of rescheduling by using an Non-linear optimization Interior-point method
2.	A. Sharma et. al. [11]	TCSC FACTS Controller	LMP difference method	To minimize congestion rent
3.	S.K. Behera et. al.[12]	TCSC FACTS Controller	Grey Wolf Optimization technique	To manage congestion
4.	Rahmat Allah Hooshmand et. al. [13]	TCSC FACTS Controller	Hybrid method (Bacterial Foraging (BF) Algorithm + Nelder–Mead (NM) Method) (BF-NM))	To reduce the cost of i. Generation, ii. Emission, iii. TCSC FACTS Controller
5.	A. Mishra et. al. [14]	IPFC FACTS Controller	Disparity Line Utilization Factor (DLUF) by Multi-objective Differential Evolution	To mitigate transmission power congestion
6.	Akanksha Mishra, et. al. [15]	IPFC FACTS Controller	DLUF and Gravitational Search algorithm (GSA)	DLUF is used to find the best place for FACTS Controller while GSA is applied for fine-tuning of IPFC for managing congestion
7.	A. Kumar, et. al. [16]	TCPAR FACTS Controller	Mixed integer programming approach	For minimizing the cost of transmission congestion by finding out optimal location of TCPAR FACTS Controller
8.	S.N. Singh and A.K. David [17]	TCSC and TCPAR FACTS Controller	Sensitivity-based approach	Reduces the flows of heavily loaded lines, which at last improves load-ability and reduced cost of production
9.	S.A. Taher and M.K. Amooshahi [18]	UPFC FACTS Controller	Hybrid Immune Algorithm (HIA) (Immune Genetic Algorithm (IGA) + Immune Particle Swarm Algorithm (IPSO))	To minimize the production of cost of generation
10.	Seyed Abbas Taher et. al.[19]	UPFC FACTS Controller	Immune Algorithm (IA)	To minimized the overall cost
11.	M. Esmaili, et. al. [20]	Series FACTS Devices	Multi - objective optimization technique	To relieve congestion, optimization technique is used.
12.	R. Benabid, et. al. [21]	TCSC and SVC FACTS Controller	Non - Dominated Sorting Particle Swarm Optimization (NSPSO)	To maximize i. Load Voltage Deviation (LVD) ii. Static Voltage Stability Margin (SVSM) As a result reduces Real Power Losses (RPL)
13.	H. Besharat and S. A. Taher [22]	TCSC FACTS Controller	Sensitivity-based approach by Real Power Performance Index	Minimize the flows of heavily loaded lines, hence load-ability increases, reduces loss, improved stability, minimized cost of production and satisfied contractual obligations
14.	P. Acharjee [23]	UPFC FACTS Controller	Self-Adaptive Differential Evolutionary (SADE) algorithm	Under security measures, improve and manage flow of power
15.	M. Gitizadeh and M. Kalantar [24]	TCSC AND SVC FACTS Device	Sequential Quadratic Programming (SQP) problem	Minimize congestion in the transmission lines and improves distance of voltage collapse
16.	Sajad Rahimzadeh et. al.[25]	STATCOM and SSSC FACTS Device	Neural based optimization technique	The power losses in the converter were used to generate the necessary PQ-Phasor for power system steady state analysis
17.	Smt. Ushasurendra et. al.[26]	TCSC FACTS Controller	Line Utilization Factor along with Fuzzy logic based technique	Reduce Congestion

COMPARATIVE ANALYSIS OF VARIOUS TYPES OF FACTS CONTROLLER

M. H. Haque **[27]** has listed the basic and different types of FACTS Controller with various controllable parameters in Table 2. According to C.P. Gupta **[28]** to mitigate over-loading of the transmission line and enhance transfer capability, series controllers such as SSSC, TCSC, and TCPAR FACTS Controller can be employed. While shunt controllers like SVC and STATCOM FACTS Controller can be used to compensate the voltage in the transmission line by injecting reactive power, directly or indirectly, at low voltage buses within the system.

Table 2: Comparative analysis of various types of FACTS Controller

S.No.	FACTS Controller	Controlled parameter	Its application
1.	STATCOM along with storage system	Reactive power	VAR compensation, Voltage control, Voltage stability, Damping oscillations, Transient and dynamic stability
2.	Static VAR compensator like TCR, SVC, TRS, TCS	Reactive power	Voltage control, VAR compensation, Transient and dynamic stability, Damping oscillations
3.	Static Synchronous Series Compensator (SSSC) FACTS Controller	Active power	Voltage stability, Damping oscillations, Current control, Transient and dynamic stability
4.	Thyristor Controlled Series Capacitor (TSSC, TCSC) FACTS Controller	Active power	Damping oscillations, Current control, Fault current limiting, Voltage stability, Transient and dynamic stability
5.	Thyristor Controlled Series Reactor (TCSR, TSSR) FACTS Controller	Active power	Current control, Voltage stability, Damping oscillations, Fault current limiting, Transient and dynamic stability, Congestion management
6.	Inter Line Power Flow Controller (IPFC) FACTS Controller	Reactive power and Active power	Reactive power control, Voltage control, Voltage stability, Damping oscillations, Transient and dynamic stability
7.	Unified Power Flow Controller (UPFC) FACTS Controller	Reactive power and Active power	VAR compensation, Damping oscillations, Voltage control, Active and reactive power control, Transient and dynamic stability, Congestion management

According to G. Glanzmann and G. Andersson **[29]** FACTS Controller plays a vital role in improving power transfer capability of existing transmission system and minimizing the congestion in the system. Ying Xiao et. at. **[30]** presents load-flow solution with implant FACTS Devices. Table 3 shows the installation of FACTS Controllers for various purposes in various countries as assessed and analysis by Surekha Manoja and Dr. Puttaswamy P.S **[31]**.

Table 3: List of practical application of several FACTS Controller in different countries

S.No.	Voltage level (kV)	Capacity (MVAR)	FACTS Controllers	Countries in year	Purpose
1.	115	80	SVCs	Thailand in 1986	Reduction in flicker, Voltage stabilization, Reactive power compensation, Improved power factor, Increased load bus voltage, Reduction of harmonics
2.	500	190	SVCs	Thailand in 1989	
3.	500	-20 to +80	SVCs	Japan	
4.	400	280	SVCs	India in 1992	
5.	132	45	SVCs	India in 1988	
6.	132	45	SVCs	India in 1988	
7.	132	45	SVCs	India in 1988	
8.	230	2 *165	TCSC	USA in 1992	To increase power transfer capability
9.	500	208	TCSC	USA in 1993	Controlling flow of power
10.	400	165	TCSC	Sweden in 1998	SSR mitigation
11.	400	118 controlled * 788 fixed	TCSC	India in 2004	Compensation, Damping of inter regional power oscillation
12.	500	55 controlled * 350 fixed	TCSC	China in 2002	Stability improvement, Low frequency oscillation mitigation
13.	500	150	TCSC	Brazil in 1999	To damp low frequency oscillations
14.	154	+80 to -80	STATCOM	Japan in 1991	Power system and voltage stabilization

15.	500	50	STATCOM	Japan in 1992	Dynamic reactive compensation
16.	400	0 to +225	STATCOM	UK in 2001	
17.	115	-41 to +133	STATCOM	USA in 2001	
18.	125	± 20	STATCOM	China in 1996	Reactive compensation, Improve system stability
19.	138	± 320	UPFC	USA in 1998	Dynamic voltage support
20.	154	80	UPFC	South Korea in 2003	

The use of several FACTS Controller to resolve steady-state operational challenges for the solution of various problems is discussed by K.R. Padiyar **[32]** in Table 4 given below:

Table 4: Applications of FACTS Controller to resolve steady-state operation for managing congestion

S.No.	Technical Problem	Possible Solution	FACTS Controller
1.	**Voltage Limit:**		
a)	Dip in voltage at heavy load	Provide reactive power	STATCOM, SVC
b)	Dip in voltage, followed by an outage	Provide reactive power, Reduces over-load	
c)	Rise in voltage at low load	Absorb reactive power	STATCOM, SVC, TCR
d)	Rise in voltage, followed by an outage	Absorb reactive power, Reduces over-load	
2.	**Thermal Limits:**		
a)	Parallel circuit tripping	Restrict the amount of load on the network	SSSC, TCSC, UPFC, IPC, PS
b)	Over-loading of transmission system	Minimize over-load	
3.	**Loop flows:**		
a)	Load sharing on parallel lines	Series reactance may be adjusted	IPC, SSSC, UPFC, TCSC, PS
b)	Reversal the flow of power in opposite direction	Phase angle may be adjusted	
c)	Sharing power flow after occurrence of fault	Reconfigure network or take some thermal limit operations	

The benefits associated with FACTS Controller can be utilized for the efficient operation all three types of electricity markets. Table 5 shows the application of several FACTS Controller used for many purposes including managing congestion.

Table 5: Application of several FACTS Controller for many purposes including congestion management

S.No.	Authors	Various FACTS Controller	Their application
1.	Hingorani, et. al. **[3]**	Several types of FACTS Controller like TCSC, TCR, SVC, STATCOM, TCSR, SSSC etc. are described	Working and its application
2.	Mohammed Zellagui et. al. [33]	TCSC, TCSR and GCSC FACTS Controllers	Effects of MHO distance relay on the impedance of a transmission line
3.	Enrique Acha, et. al. [34]	Classification of various FACTS Controller like UPFC, TCR, IPFC, TSSC etc.	Application of various controller with diverse applications as well as their modeling and simulation
4.	Mohammed Zellagui et. al. [35]	TCSR FACTS Controller	Reduces congestion
5.	Jitender Kumar et. al. [36]	Discuss various FACTS Device	Impact and application of those FACTS Controllers in mitigating congestion
6.	N.I. Yusoff et. al. [37], Anusha Pillay et. al. [38], & Foad H. Gandoman et. al. [39]	Managing congestion in the transmission system	Reviewing various approaches and techniques helps in managing congestion
7.	A.K. et. al. [40]	Use UPFC FACTS Controller	In mitigating congestion
8.	K.R.S. Reddy et. al. [41]	Various FACTS Devices	Reducing congestion
9.	A. Siddique, et. al. [42]	A detailed study on FACTS Devices	To enhance the stability and flow of power in power system
10.	A. Siddique, et. al. [43]	UPFC and MB-PSS controller	Improves the quality of power and transient stability margin in coordination
11.	Aditya Chorghade et. al. [44]	SSSC, STATCOM, IPFC, UPFC FACTS Controller	Reactive power compensation and power flow control

12.	W. Aslam, et. al. [45]	TCSC and SSSC FACTS Controller	Done contingency analysis to improve power transfer capability
13.	Waseem Aslam, et. al. [46]	Series FACTS Controller like TCSC	To improve the transient stability margin
14.	A. Siddique, et. al. [47]	Series FACT Devices like TCSC and SSSC along with POD controller	To improve transient stability by reducing peak over-shooting and clearing time of inter area oscillations
15.	Xing K, and Kusic G. [48]	Thyristor Controlled Phase Shifter (TCPS) FACTS Controller	Helps in reducing active power losses and hence, enhance the stability of the system
16.	U. Okeke, and , R. G. Zaher [49]	Various FACTS Controller	To enhance the power transfer capability of transmission line
17.	R. Grunbaum, et. al. [50]	Application of several FACTS Devices	To improves flexibility and efficiency of power transmission and distribution system
18.	Siddiqui A.S., and Deb, T.[51]	STATCOM, TCSC and UPFC FACTS Controller	Mitigating congestion in the line
19.	S.S. Reddy, et. al. [52]	TCSC and SVC FACTS Devices	Enhance the stability of the voltage and thus reducing the losses in the line to minimize congestion
20.	V.P. Rajderkar, et. al. [53]	TCSC and SSSC FACTS Device	To mitigate congestion problem, a comparative assessment was conducted
21.	Rajalakshmi L., et. al. [54]	Series FACTS Devices	Increase the transmission capability of lines and reduces total reactive power losses
22.	Pooja P. Kulkarni et. al.[55]	TCSC FACTS Controller	Reduces power losses thereby managing congestion
23.	M. I. Alomoush [56]	Installed UPFC FACTS Controller	To reduce the out-of-merit costs and LMPs
24.	Seyed Abbas Taher and Hadi Besharat [57]	TCSC FACTS Controller	Install in bilateral dispatch system to minimize the congestion and ensure the security of the system
25.	A. Kumar, et. al. [58]	TCPAR FACTS Controller	Transmission congestion distribution factors to recognize the congestion clusters
26.	Y. Shi, et. al. [59]	TCSC and TCPAR FACTS Controller	Minimizing the transmission congestion cost after placing it effectively in the system
27.	B. Chong, et. al. [60]	UPFC FACTS Controller	The controller's optimal rating at over-loaded lines in the bilateral market
28.	References [61-64]	PSO based technique to identifying most appropriate size, number & optimal location of UPFC FACTS Controller	Improving the security and mitigating congestion in the line
29.	Syed Osama Shah, et. al. [65]	SVC, STATCOM and UPFC FACTS Controller	Comparison has been made between three different techniques by analyzing system i.e. power factor and reactive power support, system losses
30.	F. Nepsha, et. al. [66]	SVC, STATCOM, D-STATCOM, DVR, UPQC	Comparative characteristics of the use of FACTS Controller in coal mines
31.	Singh A., et. al. [67]	TCSC FACTS Controller using PSO technique	Detail analysis under N-1 contingency analysis
32.	Pooja Rani T, et. al. [68]	Various FACTS Controller	Investigate several computational algorithms for calculating ATC of a load variation and line outages on a continuous basis
33.	K. Gita and A. Kumar [69]	Incorporating STATCOM along with Overall Performance Index (OPI) value	OPI value is use to rank most severe line in the system
34.	B. Vijay Kumar, et. al.[70]	UPFC FACTS Controller	Modified Salp Swarm Optimization Algorithm (MSSA) and Moth-Flame Optimization (MFO) Algorithm is used for finding optimal place and capacity of UPFC to boost the dynamic stability
35.	T. Nireekshana, et. al. [71]	TCSC FACTS Controller	Congestion management by dominant real flow of power in the lines by employing algorithmic (LUF + PSO)

36.	Kalaimani, P., et. al. [72]	TCSC FACTS Controller	To maximize the flow of active power and reactive power in the transmission lines
37.	B. Chatuanramtharnghaka, et. al. [73]	Multi-objective based Particle Swarm Optimization	To mitigate the congestion and to minimize the cost of operation of the transmission system
38.	A. Singh et. al. [74]	TCSC FACTS Controller	Minimizing the congestion
39.	Gupta M. et. al. [75-77]	TCSR, TCPAR FACTS Controller	Used for managing congestion and phase shifting

By applied FACTS Controllers, higher loading of the line can be attained without disrupting the operating limits of the system. Congestion depends upon the system constraints which eventually limit the capacity of transmission, and hence, contracted flows explained by an author Singh K et. al. **[78]**. FACTS Controllers can be utilize to control both steady-state power flow and dynamic stability without rescheduling generators or other equipment which are used to enhance the performance of the power system is assessed by F.D. Galiana et. al. **[79]**.
Uses of several FACTS Controllers like STATCOM and SVC for controlling voltage and reactive power of the line have been considered by Gupta et. al. **[80]**, Rao et. al. **[81]**, Liu JY et. al. **[82]**.
Congestion is a very important issue for concern as due to congestion, market price increases and it hinders the free trade of power supply. FACTS Controllers like TCSC, UPFC, TCPAR, TCR etc. can be used to mitigate congestion is discuss by K.S. Verma et. al. **[83]**. MT Khan and AS Siddiqui **[84]** explain that by using an optimization method in the locating devices, TCSC is employed to minimize congestion with the least amount of installation cost. The issues like congestion can be resolved by applying the sensitivity analysis technique to locate the best position for TCSC, and it is stated that the recommended technique has successfully applied to mitigated congestion. FACTS Controller can help in adjusting the flow of power quickly, and hence, enhance the power transfer capability limit of the transmission line.
A Comparative study of traditional control techniques with FACTS Controllers are shown in Tables 6,7 and 8 along with their advantage to control voltage, to control flow of power and to improve stability respectively. Tables demonstrate the replacement of traditional approaches with FACTS Controllers. As a power system engineer, one must consider the optimal operation of power system and must continue to work smoothly regardless of any circumstances. Although traditional approaches can achieve the same result, yet FACTS Controller plays an essential role in fixing the power system problems more quickly.
Following are some of the advantages of FACTS Controller for steady state voltage regulation and control for the power system over other traditional methods:

i. Reduction in transformer tap change operations and shunt capacitor switching
ii. Better voltage profiles for customers
iii. System better prepared to withstand outages

Table 6: Comparative study of traditional methods with different FACTS Controllers to control voltage

S.No.	Traditional Methods	FACTS Controllers
1.	Synchronous condenser	STATCOM
2.	Electric generators	SVC
3.	Shunt capacitors/ reactor	BESS (Battery Energy Storage Systems)
4.	Transform tap changer	SMES (Superconducting Magnetic Energy Storage)

Following are some of the advantages of FACTS Controller for steady state control of flow of power in transmission line with other traditional methods:

i. Higher contract flow by reducing unscheduled line flow
ii. Control over-loads to allow higher system flow
iii. In winters, force the flow of current in order to avoid ice accumulation over the lines
iv. Increase the flow of current in order to control over voltage

Table 7: Comparative study of traditional methods with FACTS Controllers to control power flow

S.No.	Traditional Methods	FACTS Controllers
1.	Transmission line switching	TCPST
2.	Generator schedules	TCSC
3.	HVDC transmission	SSSC

4.	Conventional phase angle regulator	UPFC
5.	Inter-phase power controller	IPFC

Following are some of the advantages of FACTS Controller of transient and dynamic stability enhancement in transmission line over other traditional methods:

i. Allow increased steady state loading
ii. Minimizing the requirement of load shedding or other special protective measures
iii. Minimizing the risk of system failure due to multiple contingency incidents
iv. Empower system functioning over a large range loading profiles while avoiding power and voltage fluctuation
v. Minimizing the requirement of special protection systems

Table 8: Comparative study of traditional methods with FACTS Controllers to improve stability

S.No.	Traditional Methods	FACTS Controllers
1.	Independent pole tripping	IPFC
2.	Special protection system	SVC, STATCOM, TCSC, UPFC
3.	Excitation	TCPST
4.	Braking resistor	TCBR (Thyristor Controlled Braking Resistor)

SCOPE & DEVELOPMENTS IN FACTS CONTROLLER

Future developments will include the combination of existing devices, e.g. combining a STATCOM with a TSC (Thyristor Switched Capacitor) to extend the operational range. In addition, more sophisticated control systems will improve the operation of FACTS Controller.

Improvements in semiconductor technology (e.g. higher current carrying capability, higher blocking voltages) could reduce the costs of FACTS Controllers and extend their operation ranges. Finally, developments in superconductor technology open the door to new Controllers like SCCL (Super Conducting Current Limiter) and SMES (Super Conducting Magnetic Energy Storage).

There is a vision for a high voltage transmission system around the world to generate electrical energy economically and environmentally friendly and provide electrical energy where it's needed. FACTS are the key to make this vision live.

DESIGN, IMPLEMENTATION, OPERATION AND TRAINING NEEDS OF FACTS CONTROLLERS

System studies are very important for the implementation of FACTS Controllers to determine the requirements for the relevant installation. Experienced network planning engineers have to evaluate the system including future developments. Right Controllers of right size at right place having right cost. Reliable operation of FACTS Controllers requires regular maintenance in addition to using equipment of the highest quality standards. Maintenance requirements are minimal but important.

Just like everything has got its own advantage and disadvantage even FACTS has issues that have limited its application. These are as follows:

i. For many application, the costs of FACTS Controller is higher than other traditional approaches
ii. Size of power semiconductors, which is basic unit for construction in FACTS Controller, must be increased
iii. Higher cost of power semiconductors
iv. Transient over-load capability is not as high as that of generators or other transmission equipment
v. Long term stability, dependability, performance, reliability and life of equipment are uncertain
vi. Technology is improving and continues to be explored

CONCLUSION

Optimal use of FACTS Controllers depends upon well-trained operators. Since most utility operators are unfamiliar with FACTS Controllers (compared with for example switched reactors or capacitors), training on the operation of FACTS Controllers is therefore very important, which helps to learn that what is important for the operators to know is are the appropriate settings of FACTS Controllers, especially the speed of response to changing phase angle and voltage conditions as well as operating modes.

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