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Review Paper

FACTS Technology: A Comprehensive Review on FACTS Optimal Placement and Application in Power System

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Abstract: The growing demand increases the maximum utilization of transmission and distribution lines which causes overloading, high losses, instability, contingency, and congestion. To enhance the performance of AC transmission and distribution systems FACTS devices are used. These devices assist in solving different issues of transmission lines such as instability, congestion, power flow, and power losses. Advancement in developed technology leads to the development of special application-based FACTS controllers. The main issues are concerned while placing the FACTS controller in the transmission and distribution lines to maximize the flow of power. Various methods like analytic method, arithmetic programming approaches, meta-heuristic optimization approaches, and hybrid approaches are being employed for the optimal location of FACTS controllers. This paper presents a review of various types of FACTS controllers available with both analytical and meta-heuristic optimization methods for the optimal placement of FACTS controllers. This paper also presents a review of various applications of FACTS devices such as stability improvement, power quality, and congestion management which are the main issues in smart power systems. Today's smart power systems comprise the smart grids with smart meters and ensure continuous high quality of power to the consumers.

Keywords: Congestion Management, FACTS Controllers, Optimal Size, Power Quality, Stability Improvement, Transmission Lines.

Nomenclature

CSA	Cuckoo Search Algorithm
DE	Differential Evolution
DSC	Distribution Static Compensator
EHV	Extra High Voltage
FACTS	Flexible AC Transmission System
GA	Genetic Algorithm
GSA	Gravitational Search Algorithm
GUPFC	Generalized Unified Power Flow Controller
IHSA	Improved Harmony Search Algorithm
IPFC	Interline Power Flow Controller
LOSF	Line Outage Sensitivity Factor
MOEPSO	Multi-Objective Evolutionary Particle Swarm Optimization
MOPSO	Multi-Objective Particle Swarm Optimization
POC	Power Oscillation Controller
PSO	Particle Swarm Optimization
PV	Photo Voltaic
RHFC	Rotary Hybrid Flow Controller
SSA	Salp Swarm Algorithm
SSSC	Static Synchronous Series Compensator
STATCOM	Static Synchronous Compensator
SVC	Static Var Compensator
TCPAR	Thyristor Controlled Phase Angle Regulator
TCSC	Thyristor Controlled Series Compensators
TCVR	Thyristor Controlled Voltage Regulator
TSC-TCR	Thyristor Switched Capacitor- Thyristor Controlled Reactor
TSSC	Thyristor-Switched Series Capacitor
TSSR	Thyristor Switched Series Compensator
UPFC	Unified Power Flow Controller

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1 Introduction

ELECTRICAL power network mainly comprises the transmission lines, generators, distribution lines, safety devices, and compensators. This complex network is prone to have faults and disturbances. Voltage failure occurs due to heavily loaded conditions, arise of fault, and reactive power shortage. So, power system expansion is required as the electricity demand is growing, and to preserve stability, consistency, and security of the electric power system, it is considered that FACTS are important devices [1]. They are used for the maximum flow of power to support the voltage so that the transmission line capacity increases and stability margins also increases. In [2] author uses tracing power flow method to show the impact of FACTS devices on both reactive and real power flow. Because of the compensating techniques and their fast activity, these FACTS devices are required to be made up of high accuracy so that good results are achieved. Otherwise, it gives the system insecurities due to that further gives rise to system failure or give rise to voltage fall [3]. The survey about FACTS controllers further shows positive results of applying these devices to power system and to improve the voltage stability under emergency conditions such as line outage as discussed by [4]. There is a certain desire to find solution to all the problems which can be achieved through FACTS devices. The rapid industrialization and growth of lifestyle have led to widening dependence on the electrical power system. The increase in demand has resulted in a few uncertainties. To overcome these uncertainties, changed technologies are implemented on transmission setups has been impelled to wield adjacent to their rationality limits. These limitations can be reduced by enhancing the control of the power system. In paper [5] the author presented a survey in order to find out which FACTS device is best for power system stability and which is providing optimum power. Today FACTS controllers have emerged as one of the best possible solutions for improving power system control techniques. In [6] frequency regulation is maintained by controlling the firing angle of thyristor. FACTS controllers are advanced static Power Electronic based equipment's such that they control the different transmission system parameters. These devices enhance the control ability and increase the voltage stabilization capability such that the interrelated parameters are controlled in a proper way. To transfer the maximum power with high quality to the users and to get better dynamic and transient behavior of the system FACTS devices are used. Another application of automatic generation control using FACTS devices is discussed by [7]. These devices are important at the transmission level, where load requirement has to be achieved. The compensators are employed in transmission lines in series as well as in parallel. Series compensation is primarily used for the maximum power transfer in the EHV lines. These series capacitors (compensators) are connected at different locations in the transmission lines. Thus, series compensation enhances the system's stability. TCSC which comprises a parallel LC circuit having fixed reactive capacitance, and a variable reactive inductance. Shunt compensation provides compensation in reactive power and thus improves voltage profile. In an embedded electrical network, STATCOM and SVC are used for the enhancement of the dynamic voltage stability in marine vessels [8]. Positive inductive reactance gives the consumption of reactive power and negative inductive reactance gives the generation of reactive power. The reactive power compensation is required to improve the voltage profile. One of the shunt controllers employed in parallel is STATCOM with the transmission line to control the reactive power. These day's combination type compensators are greatly employed such as series-shunt compensators which can regulate both reactive and active power in the transmission line. A UPFC is another example of the combination of series-shunt controllers. The benefits of the FACTS controller in the smart power system are shown in Fig. 1.

Today the biggest challenge of deregulated electric power market is that it is required to supply the contracted power to the customer from the supplier with the stability. The FACTS technology came because of the problems that were arisen in the year 1980 for the construction of transmission lines and to expand the network of import and export with the two main objectives:

- Increasing power transfer capability such that the demand of customer is fulfilled.
- Flow of power over designated routes which means that the selection of transmission lines can be done where power is to be sent.

The aim of this review paper is to present a survey on many types of existing FACTS controllers used in the smart power system. Here both analytical and

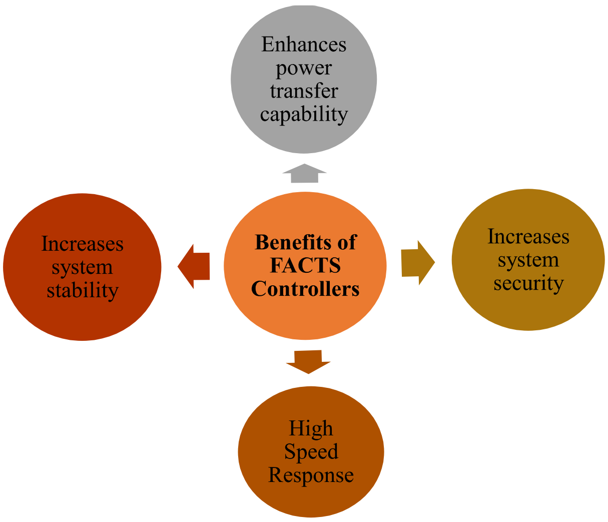

Fig. 1 Advantages of FACTS controllers.

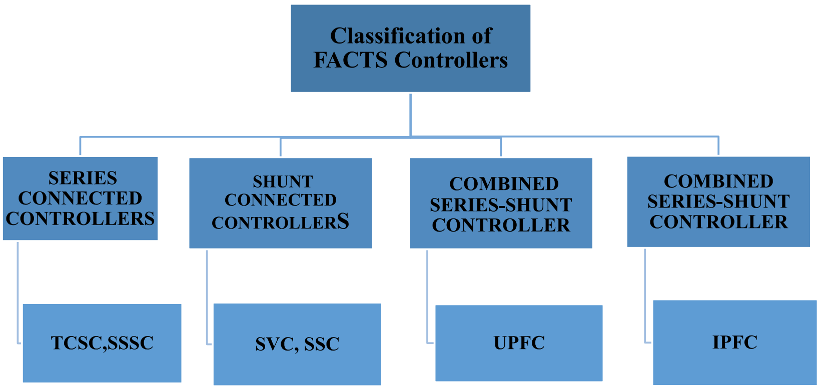

Fig. 2 Types of FACTS controller.

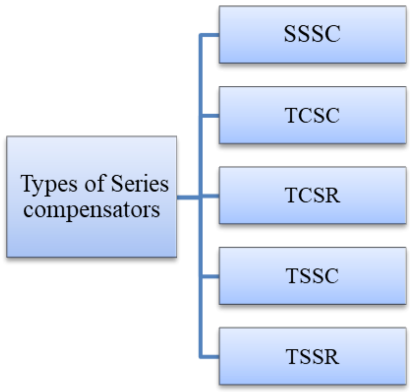

Fig. 3 Types of Series compensators.

meta-heuristic approaches are studied for identifying the optimal position of many types of FACTS controllers. This review paper is organized in seven sections. Introduction of FACTS devices presented in Section 1. Different types of FACTS controllers such as series, shunt, and combination types are discussed in Section 2. Surveys on the placement of FACTS devices are discussed in Section 3. Section 4 describes different applications of FACTS controllers in the power system. Section 5 includes a summary and the conclusion is presented in Section 6. The last section gives recommendations for future studies.

2 Types of FACTS Controller

FACTS concept was first given by Hingorani in [9]. These electronic-based devices are capable to control both reactive and active flow of power in the system and also, they can redistribute power in congested lines under heavily loaded conditions, thus improving the system stability. A survey on various types of FACTS controllers has been done in [10] for existing FACTS controllers in India. The first controller installed in India is TCSC. FACTS controllers improve the quality of power, improve impedance and thus give voltage stability. In [11], the author has discussed various FACTS controllers, their characteristics, and cost comparison of different controllers. FACTS controllers are classified as Series, Shunt, Series-Series controllers, and Series–Shunt controllers. Series controllers increase the capability of lines to transfer power.

2.1 Series Connected Controllers

These controllers are responsible for improving the power transfer capability. To decrease the total impedance of the line from sending end to receiving end, series compensation is effective. Thus, transient stability can be decreased through the damping of oscillations. Controlling the flow of current can be done using series controller.

Series controller could be in form of a variable capacitor, reactor, or varying power. An SSSC is a voltage source-based series compensator [12]. This controls the voltage drop in the line and transmittable power. Thus, it improves the maximum power transfer in the lines. The SSSC performance is analyzed by [13] at various locations like in the end of line, middle of line and at far-end during the occurrence of fault in distance relay. In [14] author has discussed about TSSR which is an inductive reactance compensator, which provides a stepwise control.

2.2 Shunt Connected Controllers

The shunt controllers in the transmission line can be in the form of varying source, impedance, or both. The shunt controllers provide varying current in the system. If the current with the voltage line is in phase quadrature, then it gives or consumes the varying reactive power. The placement of these shunt-connected controllers can be done in the middle of the transmission lines. STATCOM is one of the shunt controllers which regulate reactive power in lines. STATCOM which is installed in 5-bus power system is analyzed in detail in [15]. With installing STATCOM in the transmission line, the shunt controller is injecting the power in order to get the favorable amount of flow of power through the line as 0.43 P.U. and 0.154 P.U. respectively. The compensation techniques further show reduction in the loading of transmission lines. Also, a shunt compensator is added at bus 4 to improve voltage regulation. In these cases, all bus voltages are in the voltage limits. The application of two control strategies to enhance transmission stability using shunt-connected FACTS controllers is discussed in detail in [16]. A STATCOM shunt controller was taken and approached for the classical cascade controller which comprises of an inner vector-current controller and different outer-control loops. In [17] author discusses a power system network, which is simulated in MATLAB environment with three steps, with STATCOM only, without and STATCOM with using POC. The result will show that without STATCOM, the system parameters will become unstable during fault conditions. In [18] author proposed that if the system is operating at low voltage, then STATCOM will generate power and acts as capacitive. When the system voltage will operate under high

Fig. 4 Block diagram of series controller.

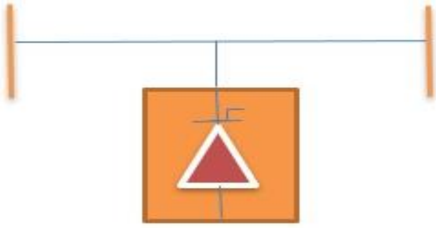

Fig. 6 Block diagram of Shunt compensators.

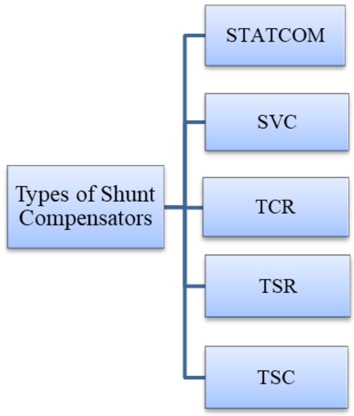

Fig. 5 Types of Shunt compensators.

Table 1 Objectives of Series and Shunt compensation.

Objectives	Series compensation	Shunt compensation
Voltage level improvement	Primary	Secondary
Power factor improvement	Secondary	Primary
Line losses	Secondary	Primary
Voltage fluctuations reduction	Primary	Not used till now

voltage then, STATCOM will absorb reactive power and acts as inductive. The controller of SVC used in order to study in improving the transient stability of the taken model. TCPST or TCPAR is regulated by thyristor switches to provide an instant change in phase angle which is basically a phase-shifting transformer.

Shunt controllers are employed to compensate reactive power in the transmission lines.

After the survey of different types of series and shunt controllers, their application as per different objectives is summarized in Table 1. From this table, it can be concluded that for power factor improvement and for line loss reduction shunt compensation is used. Series compensation is mostly used for voltage level improvement and for voltage fluctuation reduction in power systems.

2.3 Combined Series-Shunt Controllers

In the combination of series-shunt controllers, both types of series and shunt controllers are used. The main principle used in the series-shunt controller is to provide current in the lines through the series controller and voltage is controlled through the shunt controller. When the controllers are put together in the system, they exchange the real power between them. Series-Shunt controllers are regulating both real and reactive power and thus provide better performance of the system. UPFC is an example of the series-shunt controllers. The detail constructional features of UPFC are discussed in [19] that UPFC is a fusion of SSSC and STATCOM. In [20] author has discussed about UPFC that it can be used for power quality improvement by controlling both active and the reactive power. The UPFC application to control the flow of power in transmission line by controlling the impedance of transmission line, magnitude of voltage and phase angle with wind energy generation is discussed by [21] .These two devices are coupled through a DC link to provide the two-way power flow to impart reactive and real power compensation in series with line. A GUPFC device controls the smart power system parameters of line which includes power flows, bus voltage, real power, reactive power etc. which simply consist of three converters, two in series and one in parallel with the line. The shunt and series compensators are integrated and this combination is used effectively to change the system parameters such as to improve the power transfer capability proposed by [22].

2.4 Combined Series-Series Controllers

When the two or more series controllers are combined together, then this combination is formed. The main purpose of the series controller is to provide compensation in reactive power among lines but these controllers also control real power between the lines through power links. This capability of transfer of power makes the controller to balance both reactive and real power flow. The IPFC is a combined series-series controller. This converter is one of the voltage source converters and it controls the flow of power in multi-transmission line systems. They are generally placed on the transmission lines which are at high risk of danger.

3 Survey on Placement of FACTS Devices

Optimal placement of the controllers with soft computing techniques helps in minimizing the transmission losses and minimizing the cost of these controllers. Hence finding their location in the lines is another step toward getting a reliable system. In [23]

Table 2 A sample of technical contribution of FACTS devices.

FACTS controllers	Technical contribution	Paper No.
STATCOM	Stability, Voltage control, power flow control	[15-18], [76-78], [86]
UPFC	power quality improvement, use in single line system	[19-21], [79], [85]
SSSC	Transient and dynamic control, Stability	[12, 58], [61-63]
IPFC	Reactive power control , stability	[23, 26], [64-66]
TCSC	stability, current control	[24, 25], [46-48], [57, 61, 97, 98]
RHFC	contribution is similar to UPFC but cost effective	[74]

author has discussed about UPFC FACTS controller which is a series-shunt controller. In this paper, the author determined the best location for UPFC using the Simulated-Annealing algorithm with the IEEE 14-bus system. In [24] author has studied the optimal location and sizing of the TCSC and the SVC controllers in order to reduce the line losses and improvement in voltage stability by the use of the differential evolution algorithm. In [25] LOSF is used, which helps to detect the line which is best for optimal placement of TCSC. This PSO technique is used on the IEEE 14-bus and 57-bus systems.

Congestion problems are elevated using artificial techniques by finding the proper location of STATCOM which is a shunt controller [26]. IPFC is applicable if one line is in a fault condition, then IPFC will be effective and provide power from other lines. In [27] author finds the optimal location of the IPFC controller in order to alleviate the congestion problem. In [28] STATCOM controller in PV solar farm is coordinated with power system stabilizers so that system oscillations can be improved. Thus, the transient and dynamic behavior of the system is improved. A GA-based approach was discussed in [29] to minimize the power plant generation cost and FACTS controller investment cost. Authors have used the GA approach to optimally place the multi-type FACTS controllers in the system. In [30], authors have taken the IEEE 30-bus system, in which they have discussed that after installing STATCOM at an optimal location, the congestion management can be improved which gives the reduction in operating cost of the system. In [31] authors have reduced generating cost in transmission system using FACTS controllers such that power system load ability is increased, and in this way annual saving can be done. In [32] author has developed a simulated model of TSC-TCR type SVC is taken with distribution transformer. Author [33] investigates the use of SVC and STATCOM operation on voltage fall. The results are carried out in a way to confirm that SVC and STATCOM could improve the voltage failure and fall during any contingency and acts as a fast-acting device to ensure the power system stability. The DE algorithm proposed in [34] minimizes the generator fuel cost by using FACTS devices. The controller UPFC is used by [35, 36] for congestion management in a connected power system network by selecting an optimal location. UPFC is also used by the authors of [37] to minimize the operating cost by selecting the optimal location. FACTS are also used in AC transmission network to improve stability and control the transferred power through the transmission line. In [38], the CSA algorithm is used with two controllers SVC and TCSC for controlling optimal reactive power dispatch through the transmission line. After deregulation burden on transmission lines was increased to reduce this burden on AC transmission lines FACTS devices are used. These devices are used to improve the voltage profile, balance the reactive demand and supply, and minimize the losses and generation cost. These improvements are only possible if FACTS controllers are located at optimal location [39].

3.1 Analytical Approach

Many authors [40-42] work to identify the optimal place of FACTS controllers in the deregulated power markets. In [43, 44] STATCOM and SSSC are optimally placed to remove the congestion. As the renewable energy resources are integrated into the power system network in [45] uses many FACTS devices in an optimal location to minimize the generation cost with wind power integration. FACTS devices were also incorporated at an appropriate place to reduce the cost with an optimal power flow program using TCSC in [46-48].To improve the system security sensitivity-based approach was used by [49] to allocate TCSC and UPFC. Similarly, in [50] to improve the system security line outage distribution-based sensitivity factor was used for the best placement of TCSC and SSSC. The sensitivity-based approach was used by [51] for UPFC and by [52] for TCSC optimal location. FACTS device's performance was also analyzed under contingency cases by [53, 54], both authors use TCSC such that to improve the power system network condition. The power flow-based sensitivity factor was also analyzed by [55, 56] for optimal placement of STATCOM.

3.2 Placement of FACTS devices Using Metaheuristic Techniques

Nowadays the most common method to know the optimal placement of FACTS controller is metaheuristic optimization techniques. These methods are stochastic and highly efficient with multi-objective and multi-constraints optimized algorithms. The PSO was used by [57] for the optimal placement of the FACTS controller which includes SVC, UPFC, and TCSC. For SSSC optimal location GA is used by [58]. Multi-objective function such as MOEPSO was used by [59] to know the optimal placement of SVC such that the losses in the IEEE 30-bus system are reduced. Another multi-objective function such as MOPSO is also used by [60] for optimal placement of DSTATCOM. In [61-63] PSO was used to know the optimal placement of SSSC, TCSC, and SVC, respectively. The binary PSO was also used by [63] to identify the optimal location of SVC. A new GSA algorithm is also used by [64-66] for sizing and optimal placement of IPFCs, SVC-TCSC, and STATCOM-SVC respectively. In [67] SVC is placed by using the hybrid Tabu search method to improve the total power transfer capability. For optimal placement of UPFC very rarely used algorithm Cat Swarm optimization was used by [68].

A novel and unique heuristic optimization Brain storm optimization algorithm [69] was used for improvement of voltage profile to control overload and loss issues in transmission line outage conditions. This algorithm is implemented on the IEEE 57-bus system by using optimal placement of FACTS controller TCSC and SVC. Another novel algorithm known as IHSA was used by [70] to identify the best location of SSSC. A new hybrid algorithm JAYA blended moth flame optimization technique is proposed by [71] for optimal location and transmission loss reduction in power systems by adding TCSC and SVC.

The proposed method is implemented on IEEE 14-bus and 30-bus systems. The optimal reactive power dispatch through the AC transmission line is a complex problem. However, the solution based on modifying the SSA algorithm is suggested by [72] for optimal location and size of SSSC to resolve the reactive power issues. This algorithm is used in the IEEE 30-bus and 57-bus systems. RHFC which is a newly added controller in the FACTS family is discussed briefly in [73] and a comparison is done with other FACTS controllers. The optimal location of RHFC controller is done using GAMS software [74].

4 Applications of FACTS Devices

4.1 Stability Improvement Using FACTS Devices

Supplier's aim is to provide electricity to their customers in a stable manner without any disturbances. The stable supply must have a pure sinusoidal voltage waveform with constant magnitude, frequency and balance between phase angles for three-phase operations. However, a normal stable operation is not always possible due to variation in voltage magnitude and angle under heavy reactive load condition. Sometimes under fault condition, under contingency cases system become unstable. Development of semiconductor switches-based FACTS devices helps in controlling voltage magnitude and angle under heavy reactive load condition [75]. STATCOM is mostly used for stability analysis [76-78]. Another device used for stability analysis is UPFC to control the flow of power through transmission lines [79]. In [80, 81] optimal location of the FACTS devices is analyzed for stability improvement.

4.2 Power Quality Improvement

The power quality can be defined as the system where voltage remains pure sinusoidal continuously with constant magnitude, phase angle, and frequency. Some of the power quality requirements are [82]:

- Voltage must be stable in the range,
- Frequency must be stable in the range,
- Phase angle must be balanced,
- No electromagnetic and telephonic interference effect.

There are many causes of the power quality problems [83]. Some of them are discussed here.

- Voltage sag in which the voltage decreases less than 10% from the nominal voltage level.
- Short interruption of power supply for a few milliseconds.
- Long interruption of power supply for more than 1or 2 seconds.
- Increase in voltage spikes from nominal voltage to thousands of voltages for a few milliseconds.
- Change in frequency for milliseconds.
- Harmonic distortion in which waveform of current and voltage become non-sinusoidal.

The author of [84] has discussed the three types of FACTS devices SVC, STATCOM, UPFC for power quality improvement. UPFC is able to control three parameters voltage at bus, the reactance of transmission line, and phase angle for power quality improvement [85]. In [86], authors compare the performance of STATCOM and SVC to improve the quality of power. The author suggests that STATCOM has more ability to produce capacitive reactive power under fault condition. The STATCOM is the most suitable device for power quality improvement [83] and many other applications of this device are stated in [87].

Power swing impedance characteristics performance in distance protection schemes are improved by using FACTS devices in [88]. Working of STATCOM for power quality improvement is shown in Fig. 7.

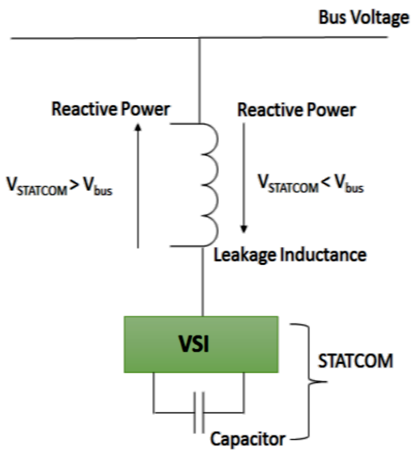

Fig. 7 Working of STATCOM [83].

Fig. 8 Congestion management methods.

Table 3 Summary of control techniques and its outcomes.

FACTS devices used in studies	Control techniques	Outcomes after finding optimal location for controllers	Paper No.
UPFC	Simulated-Annealing algorithm	Congestion management	[23]
TCSC, SVC	Differential evolution algorithm	Reduces line losses, voltage stability improved	[24]
TCSC	Particle Swarm optimization	Reduction in congestion and control flow of power in lines.	[25]
STATCOM , IPFC	Real Genetic algorithm	Improved voltage security	[26]
IPFC	Gravitational Search algorithm	Congestion is managed	[27]
TCSC ,TCPS	Differential evolution	Generation fuel cost is minimised	[34]
SVC ,TCSC	CSA	Control of reactive power	[38]
TCSC	Optimal power flow	Control power flow	[46-48]
TCSC, UPFC	Sensitivity-based approach	System security is improved	[49], [51-52]
SVC,UPFC,TCSC	PSO	Minimizes operating cost	[57]
SSSC	Genetic algorithm	congestion management	[58]
SVC	MOEPSO	Reduces transmission losses	[59]
DSTATCOM	MOPSO	Decreases active power losses	[60]
SSSC,TCSC,SVC	Particle Swarm optimization	Improves voltage profile	[61-63]
IPFC,SVC,TCSC	New GSA algorithm	congestion management	[64-66]
SVC	Hybrid Tabu search and simulated annealing method	Increases the total transfer capability	[67]
UPFC	Cat Swarm Optimization	voltage stability improved	[68]
TCSC , SVC	Brain Storm Optimization Algorithm	voltage profile improvement	[69]
SSSC	Improved harmony search algorithm	operating cost minimization	[70]
TCSC ,SVC	Jaya Blended Moth Flame optimization	Minimization of transmission losses	[71]
SSSC	Modified SALP Swarm Algorithm	Enhances voltage stability	[72]
RHFC	General Algebraic modelling system	Optimizes fuel cost, power losses reduce	[74]

4.3 Congestion Management Using FACTS Devices

Congestion is managed by many methods as shown in Fig. 8. The most applicable methods are technical methods, market and non-market-based methods [89]. The technical method uses FACTS devices to manage the congestion. To remove the congestion FACTS controller, help in controlling the transmission line impedance, bus voltage magnitude and angle to enhance the line flow and improve the system reliability and security. After implementing these devices transmission line loading limits can be increased without violating any constraints. Congestion violates transmission limit constraints and reduces contracted power flow through transmission lines [90].

After deregulation, as the generator competition increases, congestion in transmission line increases and creates problems for system operator [91]. The optimal placement with size of the FACTS controllers TCSC and SSSC are determined by observing voltage magnitude and reactive power changes in a congested environment [92]. Under loading condition FACTS devices' optimal size and location is determined by voltage magnitude and required reactive power of load

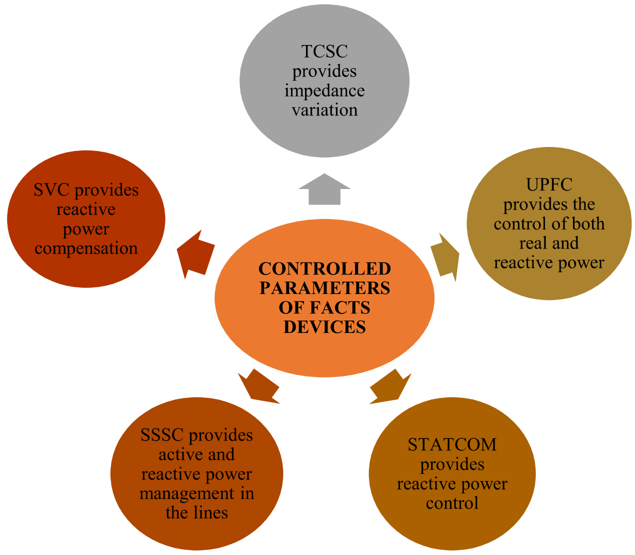

Fig. 9 FACTS controlled parameters.

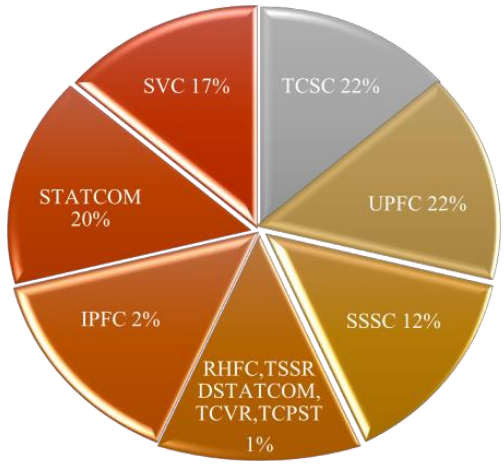

Fig. 10 Percentage of FACTS controllers used in this survey.

buses. TCSC and SSSC are used in the IEEE 14-bus system to know the optimal location by analyzing voltage magnitude and required reactive power of load buses. Under a congested environment, optimal placement of FACTS controllers is discussed by [93-96]. TCSC is used by [97, 98] for congestion management. The UPFC is introduced by [94-99] for congestion relieving and minimizing generation cost.

5 Summary

This review paper presents the general idea about the types of FACTS controllers and their applications are studied and presented in Table 2. Also, various optimization techniques are reviewed and their outcomes are summarized in Table 3. Total 99 research articles are reviewed to analyze the FACTS optimal location and application in the power system in which 12 types of controllers are studied. Out of total research articles, 6 are the review articles, 14 research articles are reviewed to summarize different types of FACTS controllers, and 16 research articles are reviewed for controlling and optimizing FACTS controllers. To analyze the placement of FACTS devices 36 research articles are reviewed considering both analytical approach and meta-heuristic techniques.

As per the literature review, various parameters of the power system can be controlled by different FACTS devices as shown in Fig. 9. To control reactive and real power with bus voltage UPFC and IPFC is the most appropriate FACTS controller. However, for compensation of reactive power SVC and STATCOM is the most used device. To vary the impedance of transmission line, TCSC is the most suitable controller and SSSC controller provides active power control. Most researcher has used recent metaheuristic optimization approaches to know the optimal placement and optimal size of FACTS controller.

6 Conclusion

In this article, a review of FACTS controllers for finding the best location and different applications in power systems are illustrated in detail. To obtain the best location both analytical and meta-heuristic approaches are reviewed in detail. The FACTS controllers used to resolve issues related to power systems such as stability, power quality, and congestion management are also discussed in detail. Different variables of power system such as power factor, voltage magnitude and phase angle, and active and reactive power flow through transmission lines are controlled through different FACTS controllers which are summarized in this paper. From this survey, it is observed that the three most used devices are TCSC, UPFC, and STATCOM.

7 Future Work

According to the survey done in [100], the numerous benefits of FACTS devices have led the FACTS market to reach USD 1.5 billion by 2025 from USD 1.2 billion in 2020. There is rising demand for STATCOM controller for voltage control and TCSC for power transfer. Some of the established players of FACTS market are ABB (Hitachi), General Electric Company (US), Siemens, and Mitsubishi Electric Corporation (Japan).

- ➢ The integration of FACTS devices with distributed energy sources such as solar, wind, and hydro in transmission networks provides the system stability, constant power supply but the uncertain behavior of these sources creates complexities. Some other sources electric vehicles can be integrated (vehicle to grid technologies). Thus, it has been also observed that FACTS controllers are less explored in the smart distribution network.
- ➢ There is a requirement to know the optimal size of

these Distributed Generation sources which can be integrated with FACTS devices to alleviate the congestion problems.

- The challenging part of FACTS controllers is their high initial cost. More advanced algorithms are required to be searched. Most of the work involves the reduction of generation cost of these devices but reduction in consumer cost is not taken into account. There is a need for advanced algorithms which reduces both generation and consumer cost.
- There is very less research work in which comparison of all FACTS controllers is done by taking the same objective function. More work is required in this area to provide a clear comparison for the same objective function.

Intellectual Property

The authors confirm that they have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property.

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R. Gandotra: Conceptualization, Methodology, Software, Formal analysis, Writing - Original draft. **K. Pal:** Supervision.

Declaration of Competing Interest

The authors hereby confirm that the submitted manuscript is an original work and has not been published so far, is not under consideration for publication by any other journal and will not be submitted to any other journal until the decision will be made by this journal. All authors have approved the manuscript and agree with its submission to “Iranian Journal of Electrical and Electronic Engineering”.

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