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# FACTS Controllers for Power Quality Improvement and Power System Stability

## Improving Power System Performance Using FACTS Devices

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## Abstract:

Flexible AC Transmission System (FACTS) controllers are modern power electronic devices used in electrical power systems to improve transmission efficiency, voltage stability, and power quality. In today's power systems, increasing electricity demand, renewable energy integration, and transmission congestion create many operational challenges. Conventional transmission systems are unable to provide flexible control during sudden load changes and disturbances. FACTS controllers solve these problems by controlling voltage, impedance, and phase angle of transmission lines. This paper explains the working principle, classification, applications, advantages, and limitations of FACTS devices. Major controllers such as Static VAR Compensator (SVC), Static Synchronous Compensator (STATCOM), Thyristor Controlled Series Capacitor (TCSC), Static Synchronous Series Compensator (SSSC), and Unified Power Flow Controller (UPFC) are discussed in detail. The role of FACTS controllers in smart grids, renewable energy systems, and power quality improvement is also explained. FACTS technology helps in reducing transmission losses, improving voltage profile, increasing power transfer capability, and enhancing system reliability. Although FACTS devices have high installation costs, their technical and economic benefits make them an important technology for future power systems and smart grids.

**Keywords:** FACTS Controllers Flexible, AC Transmission System, Power Quality, Voltage Stability, Reactive Power Compensation, Smart Grid, STATCOM, SVC, UPFC, Power Flow Control

### 1. Introduction

Electrical energy demand is increasing rapidly due to industrial growth, urbanization, and modern technology. Existing transmission systems face many problems such as voltage instability, transmission congestion, power losses, poor power quality, and limited transmission capacity. Constructing new transmission lines is expensive and requires large land areas. Therefore, modern power systems require flexible and efficient control methods.

Flexible AC Transmission System (FACTS) technology was introduced to improve the performance of AC transmission systems using power electronics. FACTS devices provide fast and dynamic control of power system parameters such as voltage, impedance, and phase angle. These controllers increase transmission capacity and improve system stability without building new transmission lines.

FACTS controllers are based on high-power semiconductor devices like thyristors and IGBTs. They are capable of controlling active and reactive power flow in transmission networks. The major advantages of FACTS controllers include:

- Improvement in voltage stability
- Better power quality
- Reduction in transmission losses
- Increased power transfer capability
- Fast system response
- Improved reliability

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Modern power systems with renewable energy sources such as solar and wind require advanced control techniques. FACTS controllers help in integrating renewable energy smoothly into the power grid.

## 2. Literature Survey

Many researchers have studied the applications and performance of FACTS controllers in electrical power systems.

Hingorani and Gyugyi introduced the concept of FACTS technology and explained its importance in flexible power transmission systems. Their work became the foundation for modern FACTS research. 

URC | IEEE Universal Resource Center

Research papers explain that FACTS devices improve voltage stability, power transfer capability, and congestion management in deregulated power systems. Third-generation FACTS devices such as UPFC and STATCOM provide better dynamic performance compared to older devices.

MDPI

Several studies compare different FACTS controllers such as SVC, STATCOM, TCSC, and UPFC. These studies show that UPFC provides the best overall control because it can control voltage, impedance, and phase angle simultaneously.

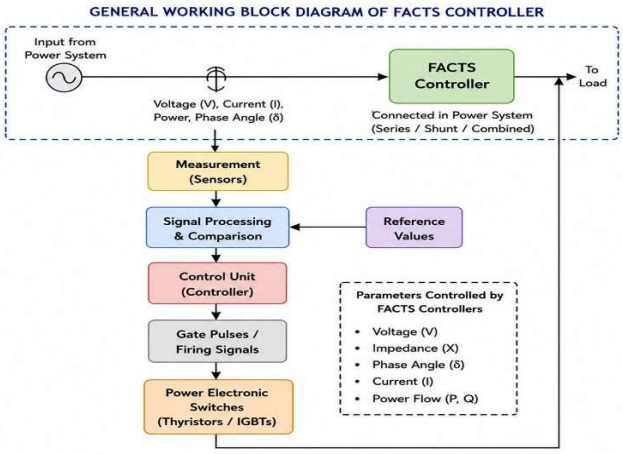
IJERT +1

Researchers also explain that FACTS devices are useful in renewable energy systems because they improve voltage regulation and reactive power compensation during variable generation conditions.

ScienceDirect +1

Modern optimization techniques such as genetic algorithms, particle swarm optimization, and artificial intelligence are now used for optimal placement and control of FACTS devices.

## 3.Working Principle




# Working Principle of FACTS Controllers

FACTS (Flexible AC Transmission System) controllers are advanced power electronic devices used in AC transmission systems to improve the performance, stability, and efficiency of electrical power networks. The main purpose of FACTS controllers is to control important transmission parameters such as voltage, current, impedance, phase angle, and reactive power. By controlling these parameters, FACTS devices help in improving power flow, reducing transmission losses, increasing transmission capacity, and maintaining system stability during disturbances and sudden load changes.

The working principle of FACTS controllers is based on fast electronic control using semiconductor devices such as thyristors and IGBTs. In an AC power system, the amount of real and reactive power transferred through transmission lines mainly depends on voltage magnitude, line impedance, and

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phase angle difference between sending and receiving ends. FACTS controllers continuously monitor these parameters and adjust them according to system requirements.

The operation of FACTS controllers "begins with sensing the electrical parameters of the power system. Sensors such as Current Transformers (CTs) and Potential Transformers (PTs) continuously measure voltage, current, power factor, frequency, phase angle, and reactive power in the transmission network. These measured signals are sent to a control unit for further processing.

After receiving the measured signals, the control unit compares the actual system values with the desired reference values. If any difference or error is detected, the controller immediately generates appropriate control signals called firing pulses or gate pulses. These signals are used to control the switching operation of power electronic devices such as thyristors or IGBTs.

The power electronic switches operate at very high speed and control the flow of reactive power, voltage, impedance, or phase angle in the transmission line. Depending on system requirements, the FACTS controller may inject reactive power into the system, absorb excess reactive power, or modify line impedance to improve power transfer capability. This entire control process takes place automatically within milliseconds, making FACTS devices highly effective for dynamic system control.

Different types of FACTS controllers perform different functions in the transmission system. Shunt-connected devices such as SVC and STATCOM mainly provide voltage regulation and reactive power compensation. Series-connected devices such as TCSC and SSSC control transmission line impedance and power flow. Combined controllers such as UPFC can simultaneously control voltage, impedance, and phase angle, making them the most powerful FACTS devices.

The use of FACTS controllers greatly improves the overall performance of electrical power systems. They help in maintaining voltage stability during heavy load conditions, reducing transmission losses, improving power quality, minimizing voltage sag and swell, and increasing transmission line capacity. FACTS devices also support renewable energy integration and smart grid applications by providing fast and flexible control of the power system.

In simple words, FACTS controllers act like intelligent electronic control systems for transmission networks. They continuously monitor the condition of the power system, identify problems, and quickly take corrective action to maintain stable and reliable operation of the electrical grid.

## 4. Applications of FACTS Controller

FACTS controllers are widely used in modern electrical power systems.

### 5.1 Voltage Stability Improvement

FACTS devices maintain stable voltage during sudden load changes and disturbances.

### 5.2 Reactive Power Compensation

They provide or absorb reactive power according to system requirements.

### 5.3 Power Quality Improvement

FACTS controllers reduce:

- Voltage sag
- Voltage swell
- Flicker
- Harmonics

### 5.4 Renewable Energy Integration

FACTS devices help in connecting:

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- Solar power plants
- Wind farms
- Hybrid renewable systems

### 5.5 Congestion Management

They control power flow and reduce overloading of transmission lines.

### 5.6 Smart Grid Applications

FACTS controllers improve:

- Grid automation
- Real-time monitoring
- Energy efficiency

## 5.Methodology

The methodology of this research paper is based on studying and analyzing different FACTS controllers and their applications in electrical power systems.

The following steps are included in the methodology:

### Step 1: Study of Power System Problems

The major power system problems studied are:

- Voltage instability
- Reactive power imbalance
- Shunt Controllers
- Transmission congestion
- Power losses
- Harmonics
- Voltage sag and swell

### Step 2: Study of FACTS Controllers

Different FACTS controllers are analyzed based on:

- Working principle
- Control method
- Installation type
- Performance
- Applications

### Step 3: Classification of FACTS Devices

FACTS controllers are classified into:

**A. Shunt Controllers**
- SVC
- STATCOM

**B. Series Controllers**
- TCSC
- SSSC

**C. Combined Series-Shunt Controller**
- UPFC

**D. Combined Series-Series Controller**
- IPFC

## 6. Results and Discussion

The study shows that FACTS controllers significantly improve power system performance.

Observed Improvements

| Parameter | Without FACTS | With FACTS |
|---|---|---|
| **Voltage Stability** | Low | High |
| **Power Transfer Capability** | Limited | Increased |
| **Transmission Losses** | High | Reduced |
| **Reactive Power Control** | Poor | Excellent |
| **System Reliability** | Moderate | Improved |

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FACTS devices improve both steady-state and transient stability of transmission systems. UPFC provides the best overall performance among all FACTS devices because it can simultaneously control multiple transmission parameters. STATCOM performs better than SVC during low-voltage conditions due to its fast response.

IJERT +2

The research also shows that FACTS controllers are highly useful in renewable energy systems and future smart grids. However, high installation cost and complex control systems remain major challenges

## 7.Conclusion

FACTS controllers are important technologies for modern electrical power systems. They improve voltage stability, power quality, transmission efficiency, and system reliability. Different FACTS devices such as SVC, STATCOM, TCSC, SSSC, and UPFC provide flexible and fast control of transmission system parameters.

Among all FACTS controllers, UPFC provides the best overall performance because it controls voltage, impedance, and phase angle simultaneously. STATCOM and SVC are effective for reactive power compensation and voltage regulation. TCSC and SSSC improve transmission line performance and power flow control.

FACTS technology is highly suitable for smart grids and renewable energy integration. Although the initial installation cost is high, the long-term benefits such as reduced losses, improved reliability, and increased transmission capacity make FACTS controllers an important solution for future power systems.

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