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Flexible AC Transmission System by Static VAR Compensator (SVC)

[1]Prof. T.V. Deokar, [2]Kale Ganesh, [3]Jaybhay Shital, [4]Kalbhor Vijay
[1]Assistant Professor, Department of Electrical Engineering,
[2 3 4] Student, Department of Electrical Engineering, Savitribai Phule Pune University
S.B. Patil College of Engineering

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Abstract

The increasing demand for reliable and high-quality electrical power has led to the development of advanced techniques for controlling power flow in transmission networks. Flexible AC Transmission Systems (FACTS) are key technologies designed to enhance the controllability and stability of AC power systems. Among FACTS devices, the Static VAR Compensator (SVC) is widely used to regulate voltage, improve power factor, and maintain system stability under varying load conditions.

This project focuses on the design and implementation of a Static VAR Compensator for improving voltage stability and reactive power management in an AC transmission system. The SVC achieves rapid reactive power compensation using thyristor-controlled reactors (TCRs) and thyristor-switched capacitors (TSCs), allowing dynamic adjustment to changing system conditions. By maintaining voltage within desired limits, the SVC enhances the reliability, efficiency, and operational flexibility of the transmission network.

The project includes simulation and analysis of the SVC in different loading scenarios to demonstrate its effectiveness in reducing voltage fluctuations, improving power quality, and minimizing transmission losses. The implementation of SVC in a transmission system represents a cost-effective solution for modern power systems, enabling better control of power flow and contributing to the stability of the electrical grid.

INTRODUCTION

The modern power system faces increasing challenges due to the growing demand for electricity, the integration of renewable energy sources, and the need for maintaining power quality and system stability. Transmission networks must operate efficiently under varying load conditions, and voltage fluctuations, power losses, and instability can severely affect the reliability of power delivery.

Flexible AC Transmission Systems (FACTS) have emerged as an innovative solution to enhance the controllability, stability, and efficiency of AC power networks. Among these devices, the Static VAR Compensator (SVC) plays a critical role in regulating voltage, controlling reactive power, and maintaining the power factor of the transmission system. By providing fast and dynamic reactive power compensation, the SVC helps in mitigating voltage instability, reducing transmission losses, and improving overall system performance.

The SVC consists of thyristor-controlled reactors (TCRs) and thyristor-switched capacitors (TSCs), which work together to inject or absorb reactive power as required. This allows the transmission system to respond quickly to load changes, faults, or disturbances, thereby enhancing operational flexibility. The integration of SVC in power networks is particularly useful in urban areas, industrial zones, and regions with long-distance transmission lines where voltage regulation and stability are major concerns.

LITERATURE SURVEY

Several research studies and practical implementations have explored the use of Static VAR Compensators (SVCs) in improving the performance of AC transmission systems. These studies highlight the importance of SVC in voltage regulation, reactive power management, and stability enhancement.

[1] Hingorani and Gyugyi (1999) introduced the concept of Flexible AC Transmission Systems (FACTS) and emphasized the role of SVC in controlling voltage, reducing transmission losses, and improving system stability under varying load conditions. They demonstrated that SVC can provide rapid reactive power compensation, which is essential for maintaining a balanced power system.

[2] Kundur (1994) discussed power system stability and the importance of reactive power compensation in preventing voltage collapse. The study highlighted that SVC, as a shunt-connected FACTS device, can dynamically adjust reactive power to maintain voltage levels within permissible limits.

[3] J. Arrillaga et al. (2007) presented a detailed analysis of SVC models, including thyristor-controlled reactors (TCRs) and thyristor-switched capacitors (TSCs). Their research demonstrated that SVC could enhance voltage profile, minimize losses, and improve the transient and dynamic stability of transmission networks.

[4] Padiyar (2010) emphasized the practical applications of SVC in real-time power systems. The study discussed how SVC installations in high-voltage networks help mitigate voltage fluctuations, support heavy industrial loads, and stabilize long-distance transmission lines.

[5] Patel and Bhattacharya (2015) explored the implementation of SVC in simulation environments to study its response under various load and fault conditions. Their findings showed that SVC effectively reduces voltage sags and swells, improves power quality, and allows faster system recovery during disturbances.

[6] Kumar and Singh (2018) presented a comparative study of SVC and other FACTS devices. The research concluded that SVC is a cost-effective solution for reactive power control, providing faster response times and better voltage support compared to traditional methods such as capacitor banks or synchronous condensers.

[7] Recent studies have also focused on the integration of digital controllers and IoT-based monitoring for SVC systems, enabling remote supervision, automated control, and predictive maintenance, further enhancing the efficiency and reliability of power transmission systems.

In summary, the literature establishes that Static VAR Compensators are essential for modern transmission networks, offering dynamic voltage control, improved power quality, and enhanced stability. These studies provide a strong foundation for implementing and analyzing SVC in the current project to optimize the performance of an AC transmission system.

METHODOLOGY

The methodology for implementing a Static VAR Compensator (SVC) in a Flexible AC Transmission System involves the design, simulation, and analysis of reactive power compensation and voltage regulation. The system uses thyristor-controlled reactors (TCRs) and thyristor-switched capacitors (TSCs) to dynamically inject or absorb reactive power based on load conditions. The methodology is divided into the following key modules:

System Design and Modeling

• The transmission system is modeled using MATLAB/Simulink or a similar simulation platform to replicate a typical AC network with varying load conditions.
• The SVC is connected at strategic points in the transmission line as a shunt compensator to provide reactive power support.
• Key components of the SVC, including TCRs, TSCs, and control circuits, are modeled to simulate their dynamic response to voltage and reactive power variations.

Reactive Power Compensation

• The SVC continuously monitors the voltage and reactive power at the point of connection.
• When the system experiences voltage drops, the SVC injects reactive power via TSCs to maintain voltage levels within permissible limits.
• During overvoltage conditions, TCRs absorb reactive power to stabilize the system and prevent equipment damage.
• The control strategy ensures fast response and precise compensation, minimizing voltage fluctuations and improving power factor.

Control and Automation

• The SVC uses a closed-loop feedback control system to automatically adjust the firing angles of thyristors in TCRs and TSCs.
• Real-time monitoring of voltage, current, and reactive power enables dynamic adjustment of

compensation levels.
• IoT or SCADA integration can be implemented for remote monitoring and control, allowing operators to supervise the SVC performance from a central location.

Simulation and Analysis
• The system is tested under different scenarios, including load variations, fault conditions, and line disturbances, to evaluate the effectiveness of the SVC.
• Key parameters such as voltage stability, reactive power flow, and power losses are recorded and analyzed.
• Simulation results are used to optimize SVC design parameters, such as TCR and TSC ratings, to ensure efficient performance in real-world transmission systems.

Implementation and Validation
• The designed SVC system can be implemented in a laboratory setup or scaled to a real transmission line.
• Performance is validated by comparing simulated and actual voltage profiles, reactive power compensation, and stability improvements.
• The methodology ensures that the SVC enhances transmission system reliability, reduces voltage fluctuations, and supports efficient power flow.

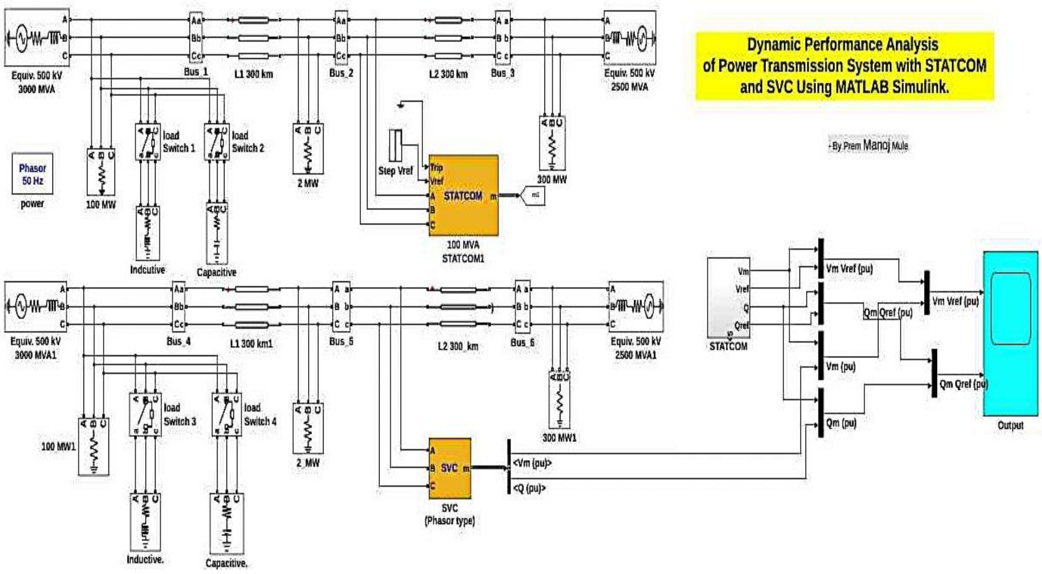
SVC Modules / Working Components
Thyristor-Controlled Reactor (TCR) Module
• Absorbs reactive power during overvoltage conditions to maintain system stability.
• Uses thyristors to control the current through the reactor, providing smooth and continuous reactive power adjustment.
• Helps reduce voltage fluctuations and improves transient stability in the transmission line.

Thyristor-Switched Capacitor (TSC) Module
• Injects reactive power when the system voltage drops below the desired level.
• Thyristors switch capacitors on or off based on load requirements, providing dynamic voltage support.
• Ensures improved voltage profile and power factor in the AC transmission system.

Control and Monitoring Module
• Monitors real-time system voltage, current, and reactive power.
• Controls firing angles of thyristors in TCR and TSC to maintain optimal compensation.
• Integration with SCADA or IoT allows remote monitoring, control, and automated operation.

Simulation and Analysis Module
• Simulates system performance under load variations, faults, and disturbances.
• Analyzes key parameters such as voltage stability, reactive power flow, and system losses.
• Helps optimize SVC design for practical implementation in real transmission lines.

Integration with Transmission System
• Shunt connection to the transmission network ensures effective reactive power compensation.
• Enhances operational flexibility and supports long-distance power transfer.
• Reduces transmission losses and improves overall reliability and efficiency of the power system.



Voltage Regulation and Reactive Power Compensation

Dynamic Voltage Support

- The SVC monitors system voltage in real-time and adjusts reactive power injection to maintain the voltage within desired limits.
- During voltage sags, the SVC injects reactive power via TSCs to raise voltage levels.
- During overvoltage conditions, TCRs absorb reactive power to prevent system instability.

Power Factor Improvement

- By compensating reactive power, the SVC improves the overall power factor of the transmission system.
- Reduces losses in transmission lines and prevents overloading of transformers and generators.

Fast Response to Load Changes

- The SVC provides rapid compensation to sudden changes in load or network disturbances.
- Ensures continuous system stability and minimizes voltage fluctuations that can affect sensitive loads.

Automation and Control

- Thyristor firing angles are adjusted automatically by a closed-loop control system.
- Integration with SCADA or IoT platforms allows remote supervision, control, and performance monitoring.

System Efficiency and Reliability

- By maintaining stable voltage and reactive power balance, the SVC enhances the overall efficiency and reliability of the transmission network.
- Supports long-distance power transfer and heavy industrial loads without compromising system stability.

CONCLUSION

The implementation of a Static VAR Compensator (SVC) in a Flexible AC Transmission System demonstrates significant improvements in voltage stability, reactive power management, and overall power quality. By dynamically injecting or absorbing reactive power using thyristor-controlled reactors (TCRs) and thyristor-switched capacitors (TSCs), the SVC effectively mitigates voltage fluctuations, enhances system reliability, and supports efficient power transmission under varying load conditions.

Simulation and analysis of the SVC show that it provides fast response to load changes and disturbances, improves power factor, reduces transmission losses, and ensures the smooth operation of the electrical grid. The integration of automated control and monitoring systems further allows remote supervision and real-time optimization, making the SVC a practical and cost-effective solution for modern power networks.

Overall, the project confirms that SVC-based FACTS devices are essential for enhancing the efficiency, flexibility, and stability of AC transmission systems, contributing to reliable power delivery and supporting the growing demand for electricity in modern infrastructure.

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