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COMPARATIVE ANALYSIS OF DIFFERENT FACTS CONTROLLERS FOR POWER QUALITY IMPROVEMENT

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Abstract

The goal of this research is to compare several FACTS (Flexible AC Transmission Systems) controllers in order to enhance power quality in contemporary electrical networks. With the use of power electronics and static equipment, FACTS controllers provide more control over the parameters of AC transmission, including voltage, phase angle, and impedance. FACTS controllers are divided into kinds based on variable impedance and Voltage Source Converter (VSC), such as Unified Power Flow Controllers (UPFC), Thyristor Controlled Series Capacitors (TCSC), Static Synchronous Compensators (STATCOM), and Static VAR Compensators (SVC). Every sort of controller is essential for reducing power quality problems like harmonic distortion and voltage instability, which raises the overall efficiency and dependability of the system. In order to assess and contrast various controllers according to standards including voltage regulation, reactive power compensation, and dynamic response, the study makes use of simulation models and real-world case studies. The outcomes illustrate the distinct advantages and uses of every FACTS controller, offering significant perspectives to engineers and decision-makers in their choice of the best options for improving the power system.

Keywords: Facts Controllers, Power Quality, Synchronous Compensators (STATCOM), Unified Power Flow Controllers (UPFC), Static Var Compensators (Svc), Voltage Source Converter (VSC)

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1.INTRODUCTION

Due to the increasing use of renewable energy sources, the growth of sensitive electronic gadgets, and the rising demand for steady and dependable electricity, power quality has become an important component of modern power systems. For both industrial and residential customers, power systems stability and dependability are critical, so cutting-edge technology must be implemented to reduce power quality problems such voltage sags, swells, harmonics, and reactive power imbalances. Flexibility in AC Transmission Systems (FACTS) controller implementation is one of the best ways to improve power quality. FACTS controllers are cutting-edge devices that use power electronics to control a range of power system characteristics, enhancing the system's performance and stability.

One of the most popular FACTS controllers is the Static VAR Compensator (SVC), which is renowned for its quick and dependable reactive power compensation. SVC contributes to voltage stability and lowers voltage fluctuations by varying the amount of reactive power injected into or absorbed from the system. On the other hand, by dynamically regulating the reactance of transmission lines, the Thyristor Controlled Series Capacitor (TCSC) improves power transfer capability and system stability. This helps to manage power flow and mitigate sub synchronous resonance. A more sophisticated kind of FACTS controller, the Static Synchronous Compensator (STATCOM) provides better dynamic voltage regulation and harmonic reduction capabilities. STATCOM is more effective in conditions with large load variations than SVC because it uses power electronic converters to respond quickly to voltage changes, unlike SVC, which depends on passive components. The most advanced and flexible FACTS device is the Unified Power Flow Controller (UPFC), which can simultaneously manage phase angle, voltage, and impedance. Because of its multipurpose nature, UPFC is able to maximize power flow while enhancing the power system's overall stability and efficiency.

This study's goal is to compare these different FACTS controllers in order to assess how well they work to improve power quality in various operational scenarios. Through the application of metrics including harmonic distortion, reactive power compensation, and voltage regulation, this study attempts to offer a thorough grasp of the advantages and disadvantages of every controller. By helping power system engineers and decision-makers choose the best FACTS controllers for certain applications, the study's conclusions should improve the dependability and effectiveness of power systems. In this regard, the paper will go over the comparative analysis approach, including the real-world case studies and simulation models that were utilized. Thorough outcomes and conversations will emphasize the variations in performance between the controllers, offering valuable perspectives on their ideal uses. In the end, this study adds to the continuous attempts to meet improved power quality standards and emphasizes the significance of FACTS technology in contemporary power systems.

2. REVIEW OF LITREATURE

Abas et al. (2020) centered on using Dynamic Voltage Restorers (DVR) to enhance power quality. Their research, which was published in IEEE Access, examines the ways in which DVRs can improve the overall power quality of electrical networks by efficiently mitigating voltage swells and sags. Aspects including DVR operation principles, control schemes, and case studies illustrating the DVR's efficacy in real-world applications are probably included in the research.

Bajaj and Singh (2020) We out an extensive review of grid-integrated renewable Distributed Generation (DG) systems, which was published in the International Journal of Energy Research. Their research looks at the different power quality issues that arise when wind and solar energy are integrated into the grid. Modern mitigation methods are covered, including energy storage systems, power electronics-based solutions, and sophisticated management strategies, to maintain stable and dependable grid operation in the face of fluctuating renewable generation.

Benali et al. (2018) investigated low-voltage ride-through capabilities and power quality enhancement in hybrid wind-photovoltaic farms connected to the grid through the use of Dynamic Voltage Restorers (DVR). Their study, which was published in IEEE Access, looks into the ways in which DVRs might improve the integration of renewable energy sources and preserve grid stability. Analyses of control algorithms, system performance under various circumstances, and comparative evaluations of various mitigating strategies are probably included in the study.

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Chawda et al. (2020) did a thorough analysis that was published in IEEE Access, concentrating on distributed control algorithms for Flexible AC Transmission Systems (FACTS) to improve power quality in utility networks that integrate renewable energy. Many FACTS technologies, including Static Synchronous Compensators (STATCOM) and Static VAR Compensators (SVC), as well as their distributed control schemes, are probably covered in the paper. By dynamically altering grid parameters, the research investigates how these technologies can reduce voltage fluctuations, enhance grid stability, and enable a greater penetration of renewable energy sources.

Das et al. (2018) gave an overview of energy storage systems (ESS) in distribution networks that was published in Renewable and Sustainable Energy Reviews. Important topics covered in the review include best placement, size techniques, operational tactics, and how they affect improving power quality. Talks about various ESS technologies—like flywheels, batteries, and supercapacitors—as well as how they work with renewable energy sources to control intermittency and maintain grid stability are probably included.

3. FACTS

An alternating current transmission system that enhances controllability and power transfer capabilities is known as FACTS.

Based on the PE devices utilized for control, the FACTS controllers can be categorized as follows:

A) Different Impedance

B) Based on VSC

Power electronic-based FACTS controllers are capable of rapidly and constantly varying parameters like as phase angle, voltage, and impedance. As a result, they can improve the useable capacity of the current lines and regulate the reactive power flow pattern. FACTS devices are useful for reducing harmonics, increasing power factor, and enhancing power system efficiency. Table 1 compares a few popular FACTS controllers in comparison.

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Table 1: Common FACTS controllers

Sl. No	FACS Devices	Load Flow	Voltage Control	Transient Stability	Dynamic stability
1	SVC	Low	High	Low	Medium
2	STATCOM	Low	High	Medium	-do-
3	UPFC	High	High	Medium	-do-
4	TCSC	Medium	Low	High	-do-
5	SSSC	Low	High	Medium	-do-

4.1 SVC

Utility companies use Static Var Compensator systems in transmission lines for a variety of reasons.

Usually, the main goal is to quickly adjust voltage at the network's weak spots. Installation might take place at the line ends or in the middle of transmission connections. The location can be ascertained by measuring the voltage sensitivity ($\Delta Vi/\Delta Qj$) at the critical busses in relation to the reactive power injection. Static VAR compensators regulate the voltage of the electrical power system by shunting coupled static generators or absorbers whose outputs are altered.

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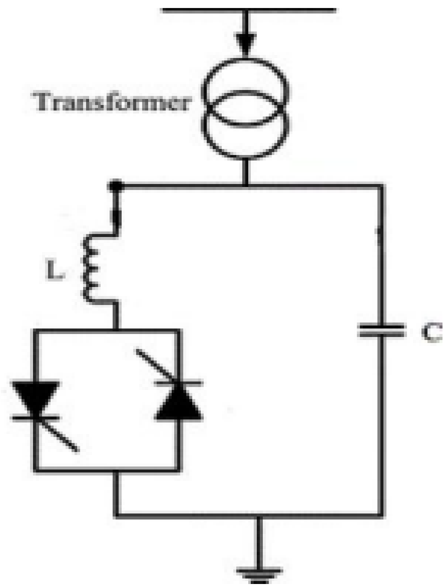

Figure 1: SVC building block

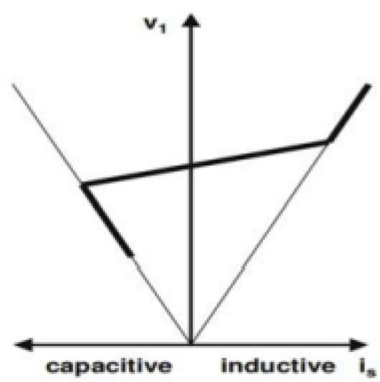

Figure 2: SVC voltage/current characteristics

The AC bus, whose voltage needs to be regulated, is directly connected to the coupling transformer that is connected to the SVC. Altering the anti-parallel thyristors' firing angle modifies the reactance of the functional TCR (Thyristor Controlled Reactor). In order to maintain a steady voltage at the bus to which the SVC is connected, the firing angle is controlled using a PI controller. In addition to improving power transfer, dynamic reactive control at the load bus can handle voltage instability or collapse brought on by unanticipated circumstances.

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4.2 STATCOM

A voltage-independent capacitive or inductive output current adjustment is possible with a shunt-connected Static Var Compensator (STATCOM). An abbreviated, one-line representation of STATCOM with VSC can be found in Figure 3.

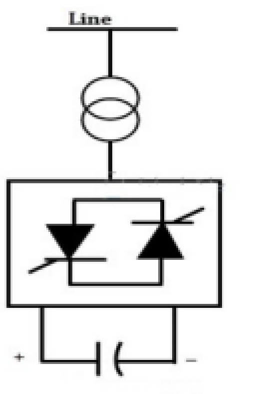

Figure 3: STATCOM structure

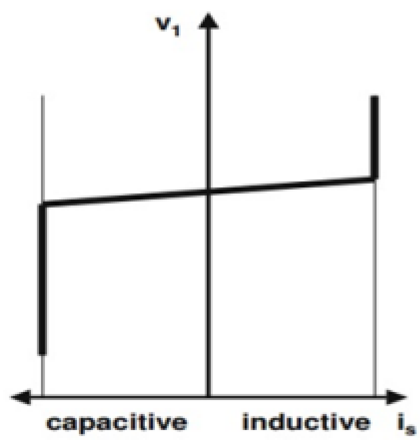

Figure 4: STATCOM properties of voltage and current

The transformer feeds the ac voltage into the line after the voltage source converters employ GTO to transform the dc voltage. If the voltage at the VSC is higher than the line voltage or the converter's output voltage, the converter will take in the source's trailing variables.

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Not only does STATCOM have smaller footprint and faster response times, it can also connect to real power sources like fuel cells, batteries, or SMES. Furthermore, STATCOM can maintain a constant reactive current even when operating with low voltage.

4.3 TCSC

A thyristor-controlled reactor switches a bank of series capacitors in the TCSC, a series compensated FACTS device, to provide a continuously variable series capacitive reactance. One line schematic of a TCSC controller is shown in Figure.5

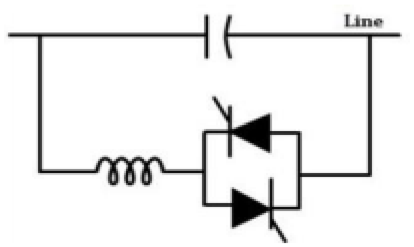

Figure 5: TCSC structure

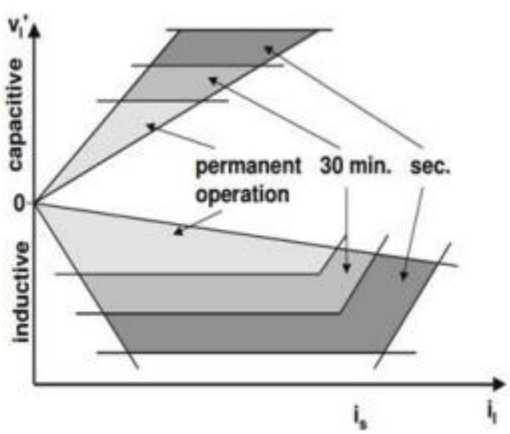

Figure 6: TCSC operational diagram

The thyristor that powers the TCSC lacks the capacity to turn off gates. In a TCSC, a series capacitor is linked across a variable thyristor-controlled reactor that becomes non-conducting at 180° of TCR firing angle, allowing the series capacitor to have its normal impedance. The capacitive reactance rises as the firing angle is lowered below 180°. At 90° firing angle, the reactor turns totally conducting and its whole impedance turns inductive.

5. Modeling

Two generators with variable voltage and speed are part of the IEEE 5-bus network, which is used to evaluate the capacity of FACTS equipment. Traveling wave theory is used to calculate the lengths of the seven tie lines that make up the network. The transmission cables are made to correspond with the frequency of the alternating current (AC) produced by the generators. The first bus is used as the swing bus, often referred to as the slack bus, and is coupled to three-phase RLC series loads.

Every bus has a load flow monitoring block fitted to record the angles and voltage magnitudes. The FACTS controller theory calls for the use of connecting transformers as necessary. The Powergui block, which holds the model's state-space equations, is required for simulation in a Simulink model that uses Simpower Systems blocks. Discreteization is used in predetermined time steps to find the solution of the electrical system.

The conventional IEEE 5-bus method provides P.U. values for each line parameter, and traveling wave theory is used to compute each line's electrical length.

$$\beta l = \left(\frac{\pi}{180}\right)\theta$$

$$\left(\frac{2\pi f}{v_p}\right) l = \frac{\pi\theta}{180}$$

$$l = 13888.9\theta m$$

It is feasible to calculate and use physical length using the above equation. The standard 5-bus system datasheet is used to calculate the system's various parameters.

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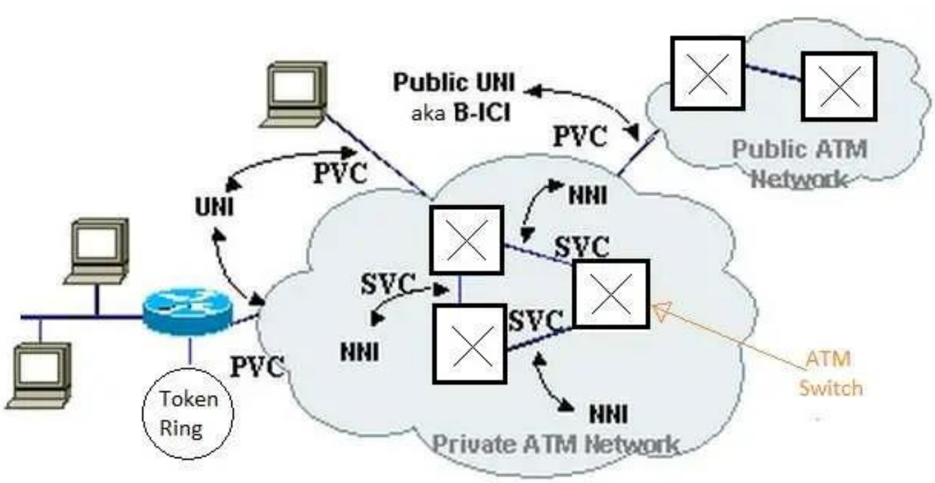
Table 2: IEEE 5-Bus System Line Data

From bus	To bus	Resistance	Reactance	Capacitance	Susceptance
1	2	0.02	0.06	0	0.06
1	3	0.08	0.24	0	0.05
2	3	0.06	0.18	0	0.04
2	4	0.06	0.18	0	0.04
2	5	0.04	0.12	0	0.04
3	4	0.01	0.03	0	0.02
4	5	0.08	0.24	0	0.05

The default values for voltage and power are 230 kV and 100 MVA, respectively. Since the transmission line is categorized as short, its capacitance is disregarded. Several FACTS devices are analyzed, modulated, and adjusted using a programmable voltage source prior to being integrated into the bus system. The 5-bus test system's power flow analysis is contrasted with and without the SVC, STATCOM, and TCSC FACTS controllers. The only factor being compared here is voltage magnitude. The power flow and bus voltage profile throughout the network have both improved in all four scenarios once FACTS controllers were installed.

5.1 SVC implementation:



SVC (Switched Virtual Circuit) vs PVC (Permanent Virtual Circuit)

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Figure 7: SVC implementation

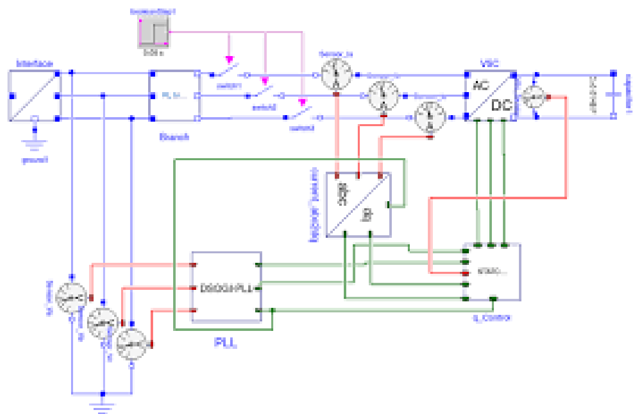

Figure 8: STATCOM implementation

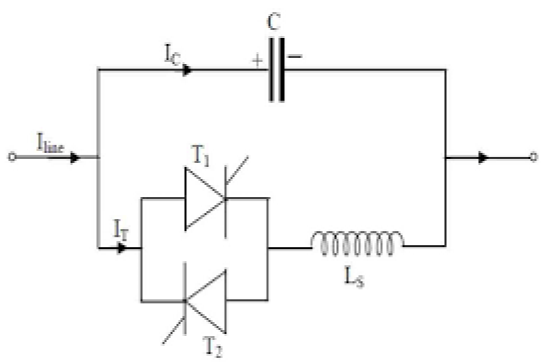

Figure 9: Implementation of TCSC

6. Output

By contrast, a bus system that makes use of STATCOM produces output that is noticeably better than what the SVC can produce. STATCOM is more controllable than the SVC because it makes use of contemporary power semiconductor switches (Fig. 11).

Power flow is improved via the TCSC, a series-connected FACTS controller. Figure 12 displays an almost 250% increase in power flow from the scope's output. The voltage profile is mostly controlled by shunt compensators, and voltage magnitudes are compared using a 5-bus test system. Bus voltage profiles and overall network power flow are enhanced by the integration of FACTS

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devices. The bus voltage profile is shown in Figure 16 both before and after the integration of FACTS devices, with an upper limit of 0.9 to 1.1 pu for voltage.

This enhancement is necessary to achieve voltage stability. The graphic unequivocally demonstrates that the voltage magnitude of the system is lower in the absence of FACTS devices than it is in their presence. As a result, the low-voltage system's overall voltage profile has improved since the FACTS devices were installed. Because there is a generator at bus 1, the voltage magnitude of buses 1 and 2 did not change, indicating that they are photovoltaic buses. In comparison to the SVC model in the test system, STATCOM has shown a greater ability to improve the voltage profile by bringing the entire voltage profile closer to 1.0 pu.

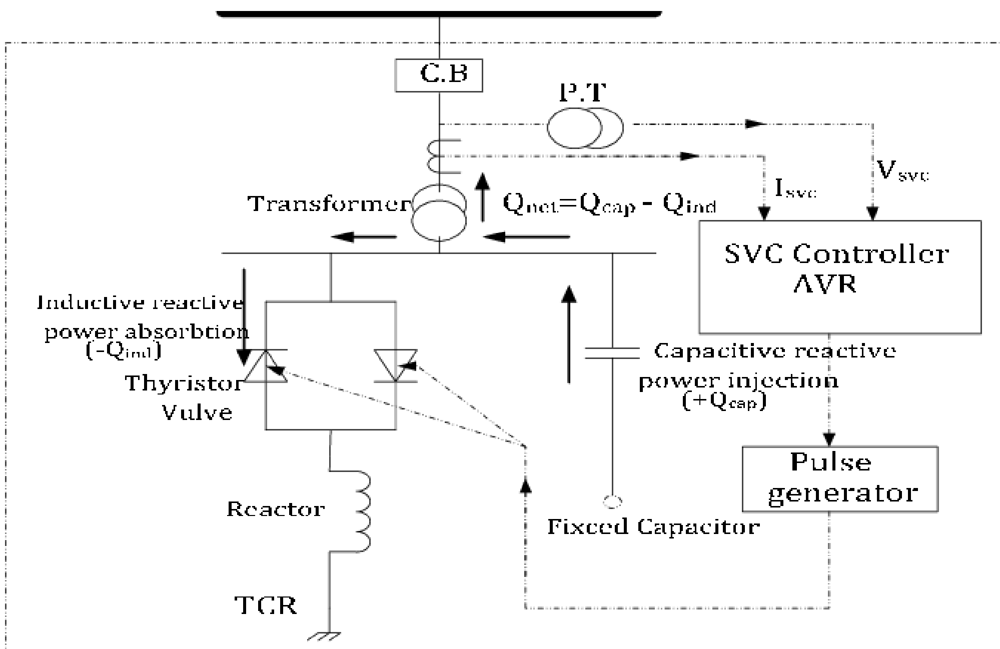

Figure 10: SVC Control

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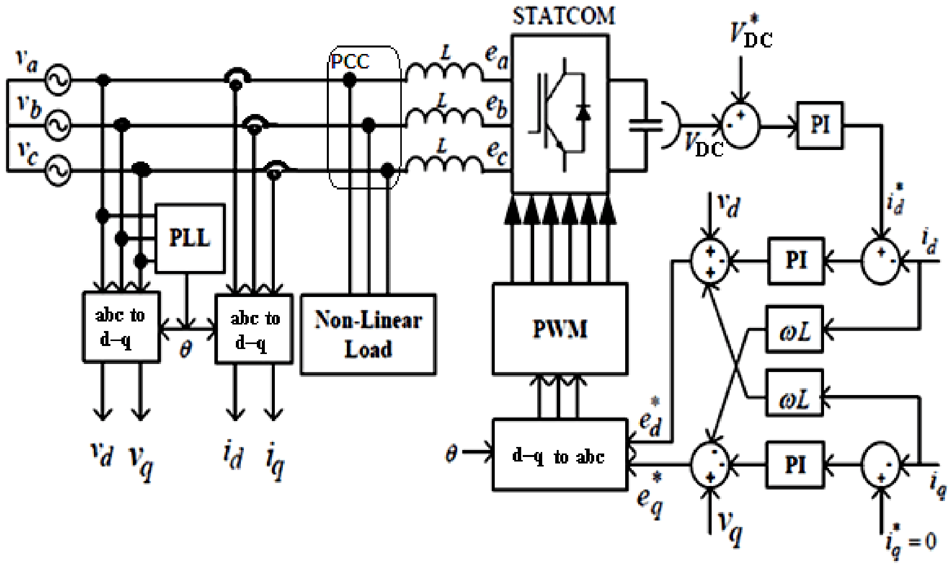

Figure 11: STATCOM Control

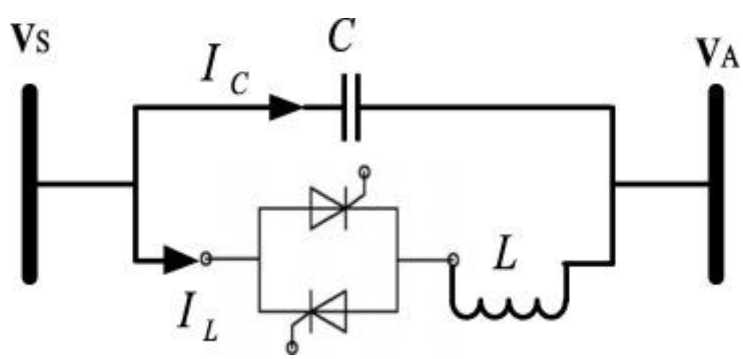

Figure 12: TCSC Power Flow Control

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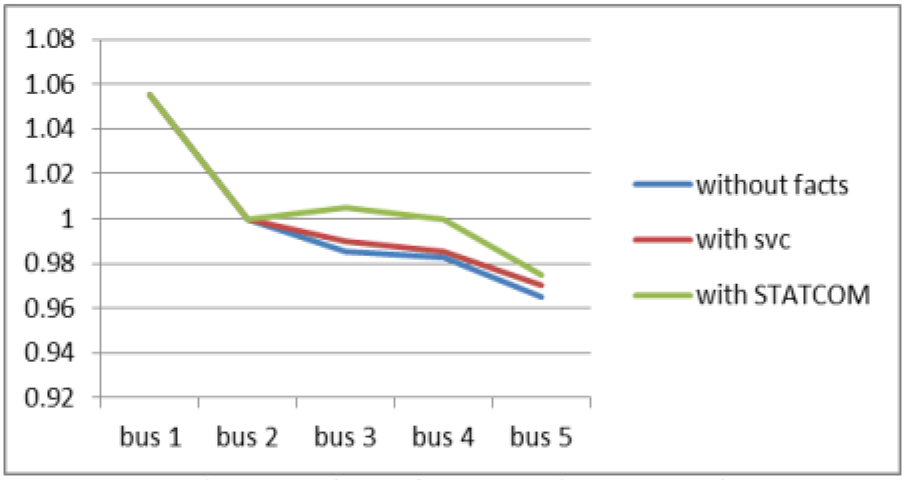

Figure 13: FACTS implementation in an IEEE 5-bus system

6. CONCLUSION

This study emphasizes how important it is to improve power quality by utilizing different FACTS controllers, such as SVC, TCSC, STATCOM, and UPFC. A thorough comparison research reveals that SVCs perform exceptionally well in reactive power compensation and fast voltage control, both of which are essential for preserving voltage stability. Through the optimization of power flow, reduction of resonance, and adjustment of series capacitive reactance, TCSCs improve power transfer capacities. Because of their capabilities for dynamic voltage management and harmonic abatement, STATCOMs provide stability under varying loads. Because UPFCs can manage voltage, impedance, and phase angle in multiple ways, they greatly enhance grid stability and make it easier to integrate renewable energy sources.

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