Catalyzing Power Electrical Grid Resilience using Three Types of Facts Devices

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Abstract - In the contemporary landscape of power systems, enhancing stability and optimizing power flow are critical imperatives. This conference paper investigates the strategic integration of three diverse Flexible AC Transmission System (FACTS) devices - Static Var Compensator (SVC), Thyristor-Controlled Series Compensator (TCSC), and Unified Power Flow Controller (UPFC) - to fortify power flow dynamics within the standard IEEE 9-bus system. The study meticulously places these FACTS devices at various points, analyzing their combined impact on power system performance. Utilizing the Power System Analysis Toolbox (PSAT) in MATLAB, an exhaustive analysis was conducted, evaluating the outcomes in terms of augmented voltage stability, and reductions in both active and reactive power losses. The research dissects the intricate interplay among SVC, TCSC, and UPFC devices, offering valuable insights into their effectiveness in bolstering power system stability. Through systematic assessment of voltage profiles and simultaneous minimization of active and reactive power losses, this study significantly advances the field of power systems engineering. The comparative analysis presented herein not only enhances the current understanding but also lays a robust foundation for future innovations in FACTS device applications, steering power grids towards enhanced resilience and efficiency.

Keywords - Comparative Analysis, IEEE 9-Bus System, Power Flow, MATLAB, SVC, TCSC, UPF.

I. INTRODUCTION

As the demand for electricity continues to rise alongside the growth of distributed generation, particularly from renewable sources, it becomes imperative to address various associated challenges [1].

In the realm of contemporary power systems, ensuring stable and efficient power flow is fundamental for reliable electricity delivery. Various FACTS devices, such as Static VAR Compensator (SVC), Thyristor Controlled Series Capacitor (TCSC), Static Synchronous Compensator (STATCOM), Static Series Compensator (SSSC), Unified Power Flow Controllers (UPFCs), Thyristor Switched Capacitor (TSC), and Thyristor Controlled Reactor (TCR), have been explored to optimize the utilization of transmission line capacities[2-9].

Delving into the strategic integration of three distinct Flexible AC Transmission System (FACTS) devices - Static Var Compensator (SVC), Thyristor-Controlled Series Compensator (TCSC), and Unified Power Flow Controller (UPFC). The core objective of this study is to fortify power flow dynamics within the well-known IEEE 9-bus system, a standard benchmark in power systems analysis. By strategically placing these FACTS devices at diverse locations, our research meticulously examines their collective impact on power system performance metrics.

In a landscape where technological advancements are steering power systems toward unprecedented complexities, understanding the nuanced interactions among SVC, TCSC, and UPFC devices becomes imperative. Leveraging the Power System Analysis Toolbox (PSAT) in MATLAB, our study conducts a thorough analysis, focusing on the augmentation of voltage stability and the simultaneous reduction of active and reactive power losses. The comparative assessment of these devices offers deep insights into their efficacy, enabling us to discern the optimal configurations for enhanced power grid resilience.

This research not only contributes valuable knowledge to the domain of power systems engineering but also sets the stage for future innovations in FACTS device applications. By unveiling the intricacies of these devices and their roles in fortifying power systems, this study propels the industry toward more resilient, efficient, and adaptive electricity networks. Through this exploration, we aim to inspire further advancements, steering the trajectory of power systems research toward a sustainable and technologically advanced future.

II. FACTS DEVICES

A) Static VAR Compensator (SVC)

The Static Var Compensator (SVC) is a widely utilized reactive power compensator globally. Typically employed for continuous adjustment of reactive power within limited ranges, SVC plays a crucial role in voltage regulation and facilitates the system towards achieving a unity power factor [10].

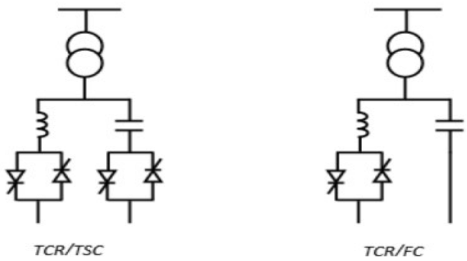

Fig. 1. Different configuration of SVC.

B) Thyristor Controlled Series Capacitor (TCSC)

A TCSC is composed of a capacitor bank in parallel with an inductor controlled by thyristors.

The total impedance seen by the line is a parallel combination of capacitance and the equivalent inductance which varies according to the firing angle of the thyristors. Several control modules can be aligned in series in the line to be compensated [11-12].

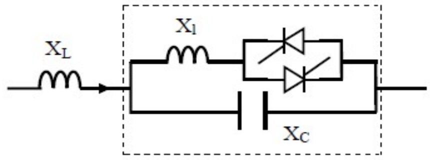

Fig. 2. Basic structure of TCSC.

C) Unified Power Flow Controllers (UPFC)

The Unified Power Flow Controller (UPFC) was developed for real-time control and dynamic compensation of AC transmission systems. It offers multifunctional flexibility to address various challenges encountered in the power delivery industry. The UPFC has the unique capability to simultaneously or individually control parameters such as voltage, phase angle, and impedance, which influence power flow within the power system network. This versatility is why it's called "unified." One of the key reasons for the widespread adoption of UPFC is its ability to manage power flow in both directions while maintaining well-regulated AC transmission line voltage. Essentially, the UPFC acts as a generally synchronous voltage source (SVS) that can exchange both active and reactive power with the transmission system. The basic configuration of a UPFC includes several main components, as depicted in Figure 1. [13-15].

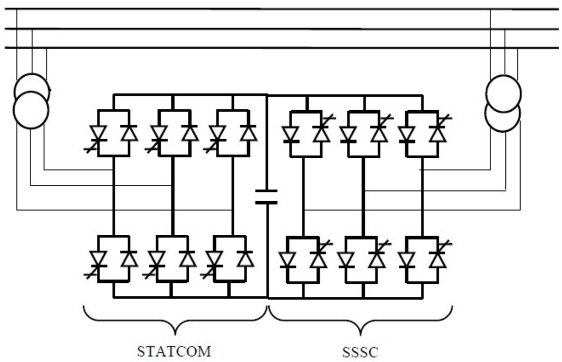

Fig. 3. UPFC structure.

III. PROBLEM FORMULATION

In our study, we focus on voltage stability as well as active and reactive power losses. Here, we present the relevant equations.

The voltage at bus $i + 1$ is calculated by using Kirchhoff's voltage law as :

$$V_{i+1}^{k} = V_i^k - J_i^k \times \left(R_i^k - JX_i^k\right) \tag{1}$$

V_{i+1}^{k} is the voltage at bus $i+1$ in the next iteration, while V_i^k is the voltage at bus i in the current iteration.J_i^k represents the injected current at bus i, and R_i^k and J_i^k represent the resistance and reactance at bus i, respectively.

The real and reactive power loss in the line section between buses i and i+1 is calculated by using the following equation :

$$P_{loss\ i,i+1} = \left(\frac{P_i^2+Q_i^2}{V_i^2}\right) R_i \tag{2}$$

$$Q_{loss\ i,i+1} = \left(\frac{P_i^2+Q_i^2}{V_i^2}\right) X_i \tag{3}$$

where Ri, Pi, Qi are resistance, active and reactive powers respectively from at bus i, Vi is voltage in the bus.

The total active and reactive power loss within the system can be readily determined by:

$$P_{T\ loss} = \sum_{i=1}^{n} P_{Loss}(i, i+1) \tag{4}$$

$$Q_{T\ loss} = \sum_{i=1}^{n} Q_{Loss}(i, i+1) \tag{5}$$

IV. TEST RESULTS AND DISCUSSIONS

In our comprehensive analysis, we meticulously examined the behavior of the IEEE 9-bus system across diverse scenarios. This network, consisting of 9 buses, 6 lines, 3 transformers, 3 generators, and 3 loads, mirrors a typical power grid configuration, as depicted in Fig. 4. Initially, the network was studied in its standard operating state, serving as our baseline. To simulate real-world challenges, a fault was introduced at bus number 7, a scenario frequently encountered in practical operations.

To mitigate the effects of this fault, we strategically deployed two distinct Flexible AC Transmission System (FACTS) devices in proximity to bus 7. These devices were precisely positioned to address the arising challenges and enhance the system's overall resilience.

The main objective of this analysis was to assess the influence of these interventions on the network's performance parameters. Specifically, the study centered on comparing the enhancements in voltage stability brought about by the deployment of SVC, TCSC, and UPFC devices. Furthermore, the inquiry delved into reducing both active and reactive power losses, crucial elements in guaranteeing effective power transmission.

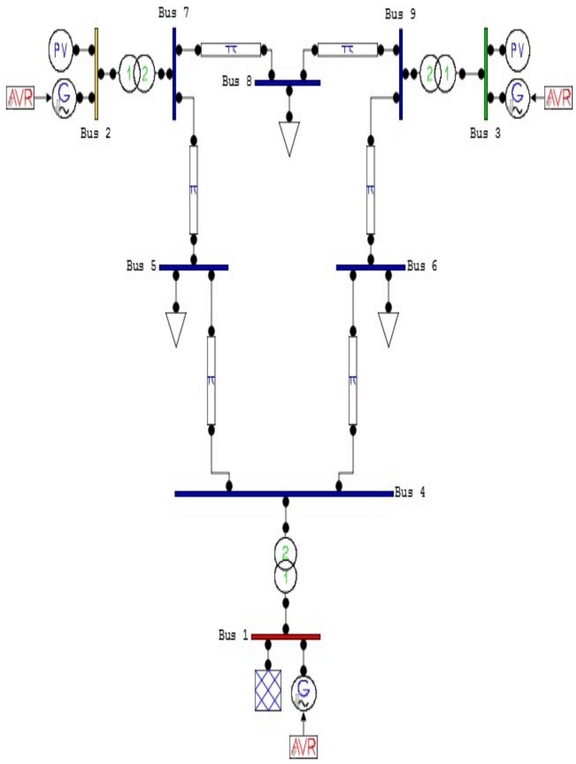

Fig. 4. IEEE 9-bus system.

A) Parallel Device (SVC)

We have three cases :

Case 1 : SVC At bus 7

Case 2 : SVC at bus 5

Case 3 : SVC at bus 8

Fig. 5 demonstrates the enhancements in voltage stability achieved by deploying the SVC at various positions.

Case 2 clearly displays the most substantial improvement in voltage.

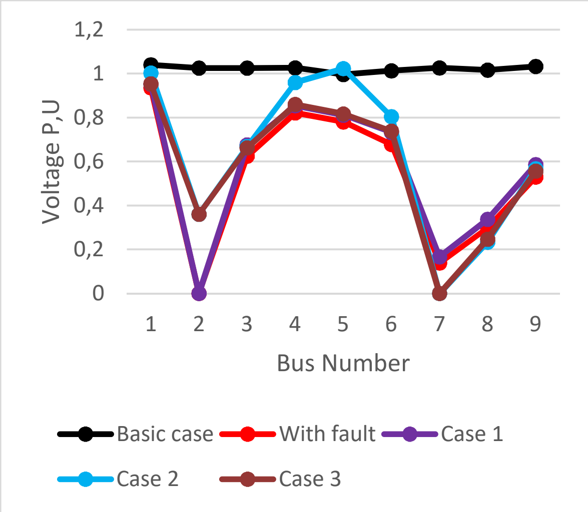

Fig. 5. Voltage improvement with SVC.

B) Serie Device (TCSC)

In its current configuration as a series device, the TCSC is positioned between the adjacent buses of the default location.

Case 1 : TCSC between bus 5 and 7

Case 2 : TCSC between bus 7 and 8

Case 3 : TCSC between bus 2 and 7

In Fig. 6, the influence of placing TCSC at different positions on voltage enhancement is illustrated.

Particularly, Case 2 emerges as remarkable, demonstrating the most significant enhancement in voltage stability compared to other scenarios.

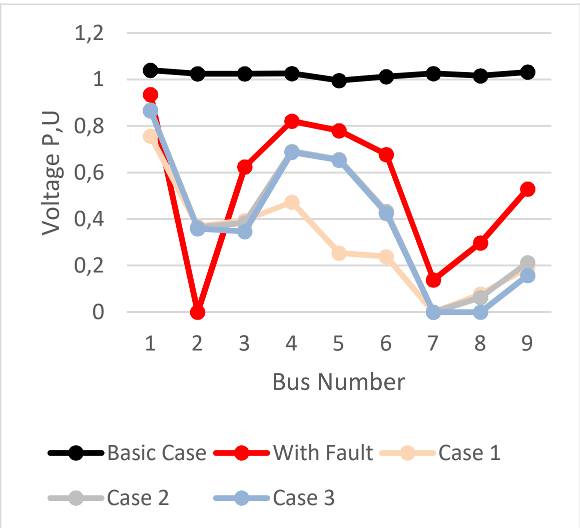

Fig. 6. Voltage improvement with TCSC.

C) Hybrid Device (UPFC)

As a hybrid device placed in series, UPFC is situated between two buses. The test involves two cases:

Case 1 : UPFC between bus 5 and 7

Case 2 : UPFC between bus 2 and 7

According to the obtained results at Fig. 7, There is convergence in the results between the two cases, but globally, it is evident that one case yields more significant voltage improvement across the total number of buses compared to the other case.

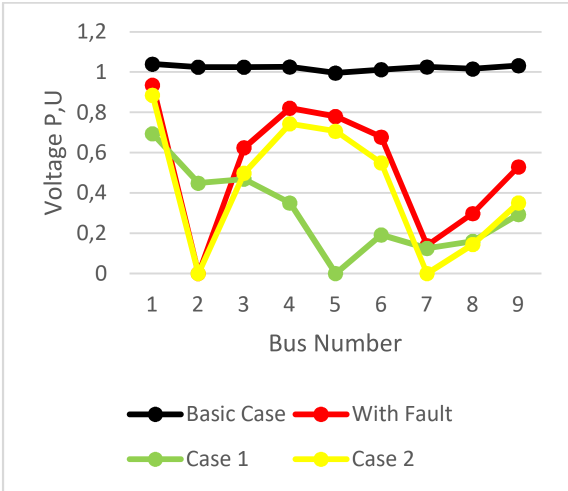

Fig. 7. Voltage improvement with UPFC.

Fig. 8 illustrates a comparison between the optimal locations for all devices.

It is evident that the SVC significantly improves the voltage profile correction at the default location, outperforming TCSC.

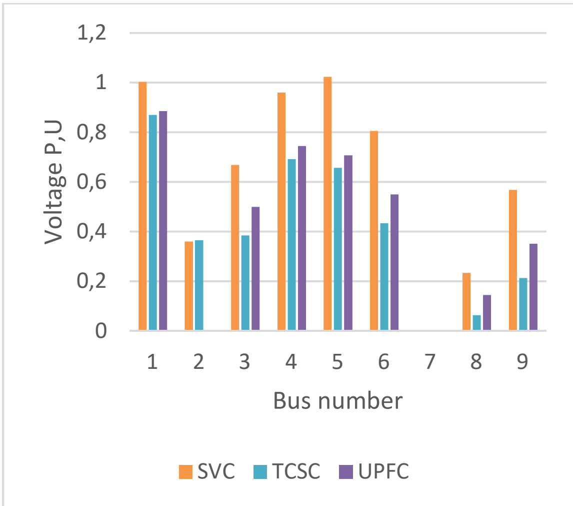

Fig. 8. Comparison results between SVC, TCSC and UPFC.

Fig. 9 and Fig. 10 presents the percentage reduction in active and reactive power losses achieved by all devices.

As previously mentioned, the SVC demonstrated superior voltage improvement as well as the most effective minimization of both active and reactive power losses.

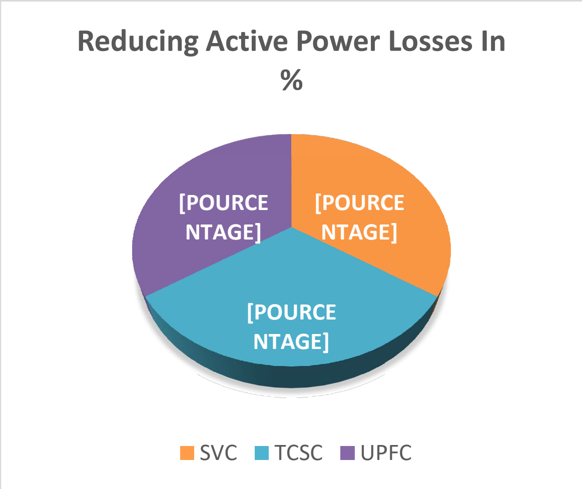

Fig. 9. Minimization rate of the active power losses for all device.

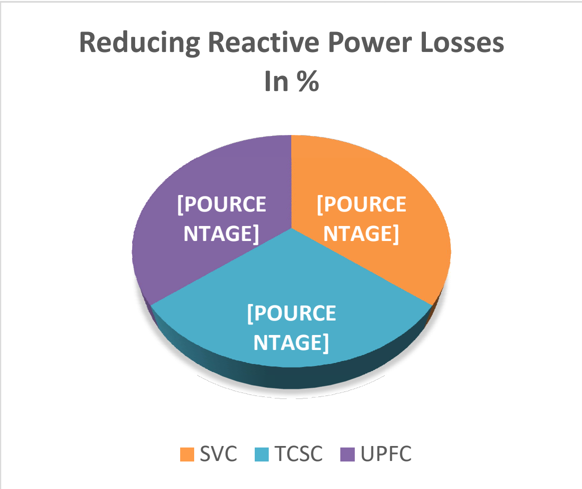

Fig. 10. Minimization rate of the reactive power losses for all device.

V. CONCLUSION

Culminating our study, the integration and strategic placement of Flexible AC Transmission System (FACTS) devices, including Static Var Compensator (SVC), Thyristor-Controlled Series Compensator (TCSC), and Unified Power Flow Controller (UPFC), within the IEEE 9-bus system has provided invaluable insights into fortifying power grid stability and efficiency.

Through meticulous analysis, our research demonstrated substantial enhancements in voltage stability alongside a remarkable reduction in both active and reactive power losses. Notably, our comparative analysis highlighted the superior performance of the Static Var Compensator (SVC), showcasing its proficiency in minimizing power losses and optimizing voltage stability. These findings underscore the pivotal role of advanced FACTS devices in advancing power systems, ensuring robust and reliable electricity transmission, and promoting energy efficiency. By addressing voltage instability and minimizing power losses, our study provides actionable strategies for power system engineers and policymakers alike.

The study not only contributes to the existing body of knowledge but also acts as a guiding beacon for future innovations. As we progress, these insights pave the path for a more resilient, sustainable, and technologically advanced future in the field of power systems engineering.

VI. REFERENCES

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