A Review on Enhancing Power System Transient Stability Using Static VAR Compensator-Based Intelligent Control

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***Abstract*—The system's aptitude to maintain synchronism following a significant signal disturbance is recognized as transient stability. The Rotor Angle Stability is understood as the capacity of an interconnected synchronous machine to maintain synchronization on the power supply. Transient stability is a part of the stability of the electrical machine rotor angle. The system's stability must be protected even when facing large disturbances or small signal variations to provide power to the consumer with high dependability. A specific system failure can cause a loss of synchronization between generators and the other parts of the utility system or between associated power systems of nearby utilities. Different controllers and control strategies have been developed and applied to improve power system stability. This article's review explores previous technical works, including various methods and analyses conducted since 2010, to compare different controllers and strategies, and identify emerging trends to enhance power system transient stability using the Static VAR Compensator (SVC).**

Keywords—Power System Stability; Transient Stability; FACTS Devices; SVC; Intelligent Controller.

I. INTRODUCTION

In the last few years, the stability problem of power systems has gained increasing attention due to the rapid growth in electricity and electronic demand. Nevertheless, the development and improvement of power production and distribution systems and the expansion in the number of sensitive and essential equipment in the energy system have been unable to cope with these rapidly growing burdens. Rapid changes in the system's load will result from variations in voltage and frequency. In addition, interruptions and short-term outages in transmission lines or generators always negatively affect the stability of networks. As a result of fluctuation and disruption that occur throughout the process, transient will experience problems with the quality and stability of the power system, therefore stability is a basic need for the current power system to ensure consistent, safe, and efficient operation. In modern power systems, growing power demand leads to overloading (beyond normal limits) of long transmission lines, exacerbating transient stability problems and becoming a significant limiting factor in power engineering [1]. The system's ability to retain a stable condition after a large disturbance, such as transmission line switching or fault, can be described as transient stability, there are multiple ways to enhance transient stability, including, **Fast-Exciters**: These rapidly adjust generator field excitation to counteract voltage drops during disturbances improving rotor stability, **Circuit Breakers** [2]: High-speed breakers isolate faults swiftly reducing fault duration and the risk of cascading failures, and reducing the system's **Transfer Reactance:** Lowering reactance improves power transfer capability making the system less sensitive to disturbances [3].

Currently, with the Flexible AC Transmission System (FACTS), the highly complex power system is stabilized; these systems can the network condition at the optimal speed of the networks and improve the transient, voltage, and steady-state stability [4]. FACTS systems are categorized into controller groups, including series, shunt, combined series-shunt, and series-series type. For regulating the system's parameters, the FACTS devices include a set of multiple controllers such as oscillation damping, phase angle, current level, voltage, and impedance at different frequencies [5]. Regarding applications, the SVC is the most common type of FACTS device. This device is renowned for improving power system characteristics such as voltage regulation, steady-state stability limitations, and system oscillation damping.

This research aims to provide a comparative analysis and a detailed overview of the study and implementation of the Static VAR Compensator (SVC) for maintaining transient stability in power systems. The structure is as follows for the paper: the second section discusses the stability of the power system; The third section uses the equal-area criterion to quickly and qualitatively determine whether it is stable; The fourth section explains the static VAR compensator model and principle; The fifth and sixth sections present a literature review and an overview of research on improving the transient stability of the power system, while the final section deals with the main conclusions of this work.

II. POWER SYSTEM STABILITY

In general, power system stability can be stated as the characteristic of a system that maintains an operating equilibrium state under regular operation and returns to an agreeable equilibrium state after a disruption. Depending on the operation mode and configuration, a power system has many sources of instability. Stability assessment focuses on the conduct of the power system when it is subject to a temporary disturbance [6]. Therefore, the stability issues of the power system are divided into three basic types:

1. **Steady-state stability** refers to a power system's ability to regain its previous/original state. The power moving out from the generator to the grid corresponds to the mechanical power achieved by the prime mover, ignoring losses.

2. **Dynamic stability**: It is the competence of a power system to remain stable under persistent minor disturbances. Dynamic instability is more likely to occur than steady-state stability. Minor disturbances are always happening on the grid (e.g. due to changes in speed and various loads), which are minor enough that the system does not lose synchronicity. However, they can cause the system to enter a natural oscillation state. Using a power system stabilizer (PSS) can significantly improve dynamic stability. For 5-10 sec, the dynamic system studies must be conducted, sometimes up to 30 sec.

3. **Transient state stability**: For a severe disruption, the change in angular difference may be so significant that the machine becomes out of sync. For a synchronous generator, the power angle of the machine is changed because of the immediate acceleration of the rotor shaft. The transient stability could indicate whether the load angle returns to a stable value after the disruption is eliminated. Transient stability is a fast event usually occurring within one second for a generator located adjacent to the source of the fault [7].

Power systems are exposed to various disturbances, minor and major. Minor disturbances, such as load changes happening constantly; the system has to be able to run satisfactorily, also be able to adapt to changing conditions, and withstand a major number of disruptions of a severe nature, such as transmission line short circuits or significant generator failures. A major failure may cause structural changes due to the disconnection of the faulty element. In the equilibrium theorem, a power system can be stable under a major natural perturbation and not stable under another physical perturbation. It is not economical and practicable to construct a power system that is stable under all fault conditions. The selection of design contingencies is based on their relatively high probability of happening.

Power system response to faults affects many devices. For example, the failure of an essential component, which is then isolated by a protective relay device, can lead to fluctuations in the bus voltage network, current, and machine rotor speed. Voltage fluctuations cause voltage regulation of the transmission network and generators; fluctuations in generator speed activate the speed regulator of the prime mover; voltage and frequency fluctuations have different effects on the system load depending on the characteristics [8].

III. THE EQUAL AREA CRITERION

By computing the machine's swing equation, the stability of a synchronous machine associated with an infinite bus bar after a significant disturbance can be determined, and from the results so obtained the variation of the machine power angle δ over time is plotted, called the swing curve Fig. 1. If the swing curve shows that the power angle δ of the synchronous machine increases indefinitely, the system is not stable. If not, the system is stable when a disruption including switching happens and the power angle δ of the engine reaches a maximum value and then decreases [9].

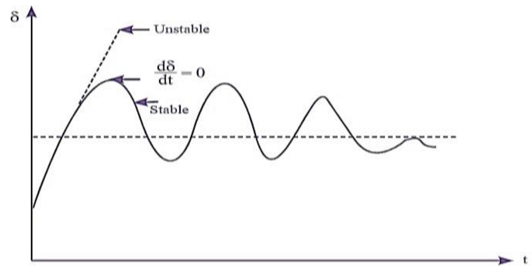

Fig. 1. Swing curve of synchronous machine

The equal area criterion is a simple graphical method that provides a quick qualitative assessment of whether stability is maintained. It is primarily applicable to single-machine infinite bus systems and does not consider the complexities of multi-machine interactions [10].

When synchronization loss occurs in a network system, the area must be isolated at a predetermined place to preserve the balance of the generation load and avoid power outages and damage to equipment. To ensure power system stability the Out-of-Step Trip feature separates stable and unstable power fluctuations and initiates system region isolation at specified network locations[11]. Using the equal-area criterion, the longest fault-clearing time can be calculated before the generator becomes out of synchronization [12].

The equal area criterion integrates energy obtained as the turbine generator accelerates within a fault. It contrasts that area (area A_1 in Fig. 2) with the area of deceleration during a fault (area A_2 in Fig. 2) when the generator outputs stored energy.

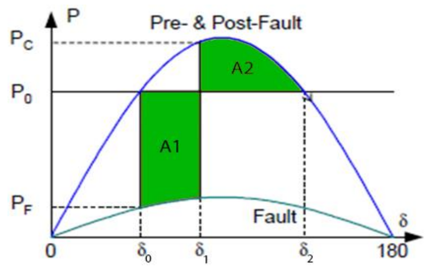

Fig. 2. (A_1) acceleration area and (A_2) deceleration area in the equal-area criterion

The entire amount of kinetic energy obtained during acceleration represents area A_1. Once the fault at angle δ_1 is cleared, the angle continues to rise and the kinetic energy acquired within the fault is propagated to the grid. The angle δ will reach its highest value when the area (A_1) is equal to the area (A_2) [13].

By the following formula, the areas A_1 and A_2 under the curve can be calculated:

- **Acceleration Area (A_1), as given in equation (1):**

During the fault, the electrical power $P_e = P_{maxD}\ sin\delta$, the power mismatch $(P_m - P_e)$ causes the rotor to accelerate.

$$A_1 = \int_{\delta_o}^{\delta_1} (P_0 - P_{maxD}\ sin\ \delta\ )d\delta \quad (1)$$

- **Deceleration Area (A_2), as given in equation (2):**

After the fault is cleared, $P_e = P_{maxP}\ sin\delta$, the power mismatch ($P_m - P_e$) causes the rotor to accelerate.

$$A_2 = \int_{\delta_1}^{\delta_2} (P_{maxP} sin\delta\ - P_0) d\delta \qquad (2)$$

Where, D is the fault period and P is the post fault.

If the area of (A_1) is smaller than (A_2), the system is stable. The system is unstable if (A_1) is larger than (A_2).

IV. STATIC VAR COMPENSATOR

The Static VAR Compensator (SVC) is a shunt element in the (FACTS) series that uses power electronics to manage the flow of power, regulate voltage, and enhance the transient stability of the power system [14]. The shunt susceptor (B) regulates the static reactive power compensator that adjusts the system's voltage by injecting or absorbing reactive power into the grid [15]. The SVC produces reactive power whenever the network voltage is low and absorbs reactive power if the network voltage is high [16]. Switching the capacitors and inductor banks will regulate the reactive power alteration [17]. Through the Thyristor Switched Capacitor (TSC) the capacitor bank is turned on-off, and the reactor is turned on-off through thyristor controlled reactor (TCR) [18].

The power system uses a static VAR compensator in two main places.

1. It is connected to large industrial sites to enhance the quality of power.
2. Placed in the power system to enhance and control transient voltage is a quick-acting device utilized to improve the transient stability in the transmission line of a high-voltage network. Improving the electrical grid's transient stability naturally increases the system's steady-state stability [19].

SVC comprises an n-thyristor Switched Capacitor (TSC) and at least one Thyristor Controlled Reactor (TCR). Typically, the SVC includes or may include a combination of the following, as depicted in Fig. 3.

1. The thyristor switched condensers.
2. Reactor with thyristor control; it might be either an iron or an air reactor.
3. Harmonic filter.
4. Automatic switch capacitors and reactors.

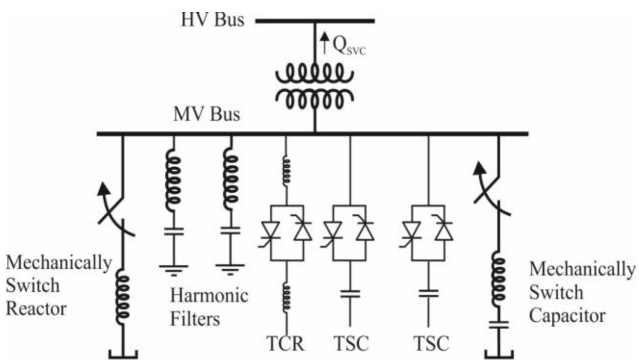

Fig. 3. The basic structure of SVC

V. LITERATURE REVIEW

In recent years, many researchers have proposed stability improvement technologies using SVC to eliminate electromechanical fluctuations in power systems.

In 2010, Jizhong Zhu et al. Explores the use of a coordinated Static VAr Compensator to improve reactive power (VAr) optimization, focusing on minimizing system losses and enhancing voltage profiles. The coordinated SVC controls internal, local, and remote devices simultaneously in two modes: voltage control and Q control. It is tested on a system with 568 buses and 920 branches, and the results show that it outperforms both general SVC models and systems without SVC in loss reduction and voltage improvement [20].

In 2011, Pravin Chapade et al. Evaluate the effectiveness of the Static VAR Compensator (SVC) for enhancing voltage control and reactive power management compared to fixed capacitor compensation, based on simulations using PSCAD/EMTDC. The study demonstrates that SVC offers superior dynamic control and improves transient stability, outperforming fixed capacitors. However, it also notes that fixed series capacitors can induce oscillations in the SVC control profile, a problem exacerbated by Thyristor-Switched Capacitors (TSCs). Key research gaps include the lack of empirical validation and the need for solutions to mitigate oscillations [21].

In 2012, Salam Keskes et al. Investigates the effectiveness of a Static VAR Compensator in enhancing the stability of a single-machine infinite-bus power system. It employs a systematic approach for modeling and simulating the system and uses Genetic Algorithm (GA) optimization to design robust SVC and power system stabilizer (PSS) controllers. The study demonstrates that integrating SVC significantly improves transient stability compared to systems with only PSS, particularly by enhancing generator power angle and terminal voltage. The GA optimization effectively identifies optimal controller parameters, ensuring rapid convergence and better overall system performance [22].

In 2013, Alok Kumar et al. Examined the role of Static VAR Compensators (SVC) in improving transient stability by regulating voltage and damping oscillations in power systems. It demonstrates SVC's effectiveness in stabilizing transmission lines during disturbances and enhancing system reliability. Financial benefits include increased transmission capacity and delayed infrastructure investments. While the paper highlights the advantages of SVC, it briefly mentions Unified Power Flow Controllers (UPFC) but overlooks potential challenges in implementing SVC on a large scale [23].

In 2014, C. Udhayashankar et al. provided a comprehensive analysis of using Static VAR Compensators with fuzzy logic control to enhance transient stability in power systems. It highlights the advantages of combining traditional PI controllers with fuzzy logic to improve the non-linear performance of SVC, tested on a 2-machine, 3-bus system. The key advantage is the faster and more stable system response during disturbances, compared to conventional methods. However, the paper doesn't address potential challenges like the complexity of implementing fuzzy logic controllers or the additional computational demands for real-time applications [24].

In 2015, Fetissi Selwa et al. Discussed the use of SVC with fuzzy logic control to improve transient stability in power systems. The combination of fuzzy logic with traditional PI controllers enhances system performance by better handling non-linear conditions and providing quicker response during disturbances. The key advantage is the improved stability and quicker recovery times, demonstrated through simulations. However, the complexity and computational demands of integrating fuzzy logic control could pose challenges for real-time applications, which the article does not deeply explore. Overall, the paper highlights significant stability improvements but could benefit from discussing implementation difficulties [25].

In 2015, Aliyn Tukur et al. Present a simulation-based analysis of a Static Var Compensator (SVC) using Matlab/Simulink, demonstrating its role in improving power system stability by regulating voltage and controlling reactive power. A key strength is its clear illustration of SVC's response under different voltage conditions. However, the article falls short in exploring the limitations of SVC, such as its cost and implementation challenges. Including a comparative analysis with other reactive power compensation devices like STATCOMs or capacitor banks would have provided a more comprehensive evaluation. Furthermore, addressing real-world applications or practical constraints would have strengthened its relevance [26].

In 2015, C. Udhaya Shankar et al. compared the performance of Power System Stabilizers (PSS) and Static VAR Compensators for rotor angle stability in a 3-bus, 2-generator system. The study evaluates generic PSS, multi-band PSS, and SVC. It finds that while multi-band PSS performs better than generic PSS for single-phase faults, both fail during three-phase faults. The SVC, implemented with a PI controller, improves voltage and rotor angle stability, restoring system stability even under severe faults [27].

In 2016, Tariq Rahman et al. Examined the use of nontraditional generator measurements, such as rotor angle and field quantities, to improve generator monitoring and protection. A key advantage of the study is its practical implementation of real-time monitoring with synchronized data acquisition, offering deeper insights into the electromechanical relationship of generators. It highlights the potential for proactive condition monitoring, enabling more effective fault detection and enhanced understanding of machine performance during system events [28].

In 2017, Alsammak et al. Investigated transient stability enhancement in multi-machine power systems using modern energy storage systems, specifically the Static Var Compensator (SVC) and Solar Photovoltaic Generator (PVG). Its main advantage lies in demonstrating the effectiveness of these systems in maintaining synchronism during disturbances, highlighting their ability to regulate voltage through reactive power control. However, the article could benefit from a more extensive exploration of other stability improvement methods for a more comprehensive analysis [29].

In 2018, Mojeebalrhman M. A. Hassan et al. Focused on enhancing transient stability in power systems using a Static Var Compensator controlled by a Fuzzy Logic Controller (FLC) combined with a traditional PI controller. Simulations were conducted in MATLAB/Simulink to test the system's performance under single-line-to-ground and three-line-to-ground fault conditions. The results indicate that the FLC-based SVC outperforms the conventional PI controller in reducing oscillations and achieving faster system stabilization. While the article's strength lies in its practical approach and detailed comparison of control strategies, it could be further improved by including real-world case studies and discussing the implementation challenges in more detail [30].

In 2018, Shaswat Chirantan et al. Analyze transient stability in a two-machine long transmission system using a Power System Stabilizer (PSS) and a Static Var Compensator (SVC), simulated in MATLAB/Simulink. The study examines system performance under normal, single-line-to-ground, and three-phase-to-ground faults. It finds that while PSS alone can manage single-line faults, it struggles with more severe faults. Integrating SVC with PSS significantly enhances stability by providing reactive power support and damping oscillations. The article's strengths include detailed simulations and a practical approach. However, incorporating real-world case studies and comparing SVC with other methods would provide a more comprehensive analysis [31].

In 2019, Mahesh Singh et al. Analyze the performance of a Static VAR Compensator (SVC) supplementary controller in enhancing transient stability in a 4-generator, 6-bus power system. Using MATLAB/Simulink, the study examines the system's response under severe conditions, such as three-phase-to-ground faults. The results show that the Power System Stabilizer alone can dampen oscillations, it struggles to maintain synchronism during severe faults. However, the combined use of PSS and SVC significantly improves transient stability, effectively regulating bus voltages and rotor angles. The article's strengths lie in its detailed simulations and practical approach. However, the study could be improved by addressing implementation challenges, analyzing various fault conditions, and investigating the long-term effects of SVC on system stability for a more thorough evaluation [32].

In 2020, Mohammed A. Shraf Hossain Sadi et al. Proposes a fuzzy logic-controlled capacitive bridge-type fault current limiter (CBFCL) to enhance transient stability in power systems. Using MATLAB/Simulink, the study models the IEEE 39-bus power system with an integrated wind farm to assess the CBFCL's performance under various fault conditions. The CBFCL, optimized by a genetic algorithm, adapts in real-time to system changes. Results show that this approach significantly improves stability, outperforming traditional static controllers. The article's strengths lie in its innovative use of fuzzy logic control and detailed analysis. Real-world case studies and comparisons with other advanced control techniques could be explored for further improvement [33].

In 2020, R. Jegedeesh Kumar ME et al. Examined transient stability enhancement in a multi-machine 14-bus power system using a STATCOM (Static Synchronous Compensator). The researchers employed MATLAB/Simulink to model the system and simulate different fault conditions, with a focus on three-phase faults. The integration of STATCOM effectively improved the system's stability by regulating voltage and damping oscillations, helping maintain synchronism among generators. The study's strengths include its practical approach and detailed simulations using MATLAB/Simulink. However, it could be improved by incorporating real-world case studies, exploring other types of FACTS devices, and addressing the economic and technical challenges of implementing STATCOMs in larger power networks [34].

In 2021, Ahmed Z. Abass et al. analyzed a 340 MW solar combined cycle system in Basra, Iraq, using ETAP to address voltage instability. It identifies under-voltage issues and uses on-load tap changers (OLTC) and optimal capacitor placement (OCP) for reactive power compensation. These measures improve voltage stability and reduce power losses. The study emphasizes the need for advanced technology and planning to enhance Iraq’s energy infrastructure and suggests integrating more renewable energy sources for future expansion [35].

In 2021, Ahmed N et al. It investigated the enhancement of power quality using a fuzzy logic controller (FLC) based unified power flow controller (UPFC). The study uses MATLAB/SIMULINK to simulate a 100 MVA, 500 kV four-bus system with GTO-based converters. It compares the performance of FLC with a conventional PID controller, showing that FLC provides faster response, reduced total harmonic distortion (THD), improved power factor, and optimized power flow. The optimal DC capacitor value of 2.5 mF is identified for system stability. The paper’s strengths lie in its comprehensive analysis and effective use of FLC in power quality improvement. However, further research could include real-world validation and integration with renewable energy sources [36].

In 2023, Venu Yarlagadda et al. Performed a comparative analysis of STATCOM and SVC to assess their effects on power system stability and dynamic response. Using MATLAB for modeling and simulation, the study examined both weak and strong power systems through time and frequency responses, including root locus and Bode plots. Results showed that STATCOM has superior performance over SVC, with better stability, lower peak overshoot, and faster settling time. While the study offers detailed simulation insights, future work could involve real-time implementation and exploring their roles in more complex power systems [37].

In 2023, Suraj Ankush Dahat et al. Proposed a coordinated control of SVC (Static Var Compensator) and SSSC (Static Synchronous Series Compensator) to improve rotor angle stability in power systems. Using MATLAB/Simulink and real-time simulator (OPAL-RT), the study analyzed a two-area system connected by a weak tie line. The SVC maintained bus voltage, while the SSSC adjusted line impedance for series compensation. Results showed that the combined control of SVC and SSSC enhanced stability and allowed quicker recovery from faults compared to using a single device. The paper's strengths include detailed analysis and real-time validation, with future research suggested for other FACTS device combinations [38].

In 2024, Swapnil D. patil et al. developed a modified Static Var Compensator (SVC) combining Thyristor Binary Switched Capacitors (TBSC) and Reactors (TBSR) to enhance power system performance. The aim was to optimize reactive power compensation with near-zero switching harmonics, utilizing adaptive controllers like PID, Model Predictive Control (MPC), and Model Reference Adaptive Control (MRAC). Results demonstrated improved stability with faster response times, minimal overshoot, and effective harmonic elimination. Future work suggests exploring integration with other FACTS devices and further refinement of adaptive control techniques for broader applications [39].

In 2024, Ibrahim et al. Presented a coordinated control using a Fractional Order Proportional-Integral-Derivative (FOPID) controller for both Power System Stabilizer (PSS) and Static VAR Compensator (SVC) to mitigate low-frequency oscillations. Using MATLAB/Simulink and the Moth Flame Optimization (MFO) algorithm, the study tested various scenarios on a Single-Machine Infinite Bus (SMIB) system. Results showed that the MFO-optimized FOPID-PSS and SVC controller outperformed other methods, enhancing stability, reducing overshoot, and speeding up settling time. The study's strengths include a detailed comparison of control strategies and advanced optimization techniques. Future work could explore real-time implementation in complex power systems [40].

In 2024, Ibram Y. Fawzy et al. explore the deployment of a Static Synchronous Compensator (STATCOM) with a Fuzzy Logic Controller (FLC) for enhancing power system performance under various fault conditions. It compares the effectiveness of the FLC against the traditional Proportional-Integral (PI) controller using MATLAB/Simulink simulations. Results demonstrate that STATCOM with FLC significantly reduces fault current and improves voltage stability better than the PI controller, especially under single-phase and three-phase faults. The study concludes that FLC offers superior performance for dynamic voltage regulation and system stability [41].

In 2024, Nnaemeka Sunday Ugwuanyi et al. introduced a simple method using STATCOM to enhance voltage and rotor angle stability in power systems. By employing Q-V sensitivity analysis and bus participation factors, they identified weak buses and optimally placed devices. Applied to Nigeria's 50-bus, 330 kV grid, their method improved rotor angle stability by 31%, ensured all voltages were within ±5% tolerance, and reduced the number of devices needed, making it cost-effective and efficient [42].

In 2024, Mandarapu Srikanth and Y.V. Pavan Kumar proposes a hybrid control scheme combining **state machine-based droop control (SMD)** and **internal model control (IMC)-based voltage and current (VA) controllers** to enhance the transient performance of microgrids. The hybrid controller addresses stability and response issues inherent in conventional droop and PI-based VA controllers. The SMD provides adaptive droop control, improving stability under inductive load variations, while IMC-based VA controllers enhance response by reducing startup delays and maintaining harmonic distortion below 5%. Simulation results show that the hybrid controller maintained stability even at a power factor of 0.47, outperforming conventional methods in handling severe load changes with reduced computational effort [43].

In 2024, Ziyad M.T. Salleh et al. conducted research to enhance power system transient stability using a Static VAR Compensator (SVC) controlled by a Fuzzy Logic Controller (FLC) instead of a conventional Proportional-Integral (PI) controller. MATLAB-Simulink simulations on a 2-generator, 3-bus system under six fault scenarios demonstrated that the FLC-based SVC outperformed the PI-based SVC by reducing maximum overshoot by 11.94%, settling time by 9.47%, and compensating 16.2% of the system's equivalent kinetic energy. The FLC's dual reliance on error and change of error enabled faster and more accurate responses, significantly improving system stability and fault recovery [44].

VI. Research Overview

Table I provides a summary of significant research efforts aimed at improving power system stability using Static VAR Compensators (SVC). These studies focus on various aspects such as transient stability, voltage control, and damping of oscillations. The table highlights the optimization techniques used by researchers, key performance parameters (e.g., voltage regulation, rotor angle stability), and offers insights into potential future research directions, such as expanding the application of SVC to more complex power systems or integrating with other control methods.

TABLE I. A Survey on the Conventional Techniques and Controller for Enhancing Power System Transient Stability by Different Types of FACTS Devices

Ref. No.	Author	Year	Power system performance	FACTS device	Parameters for optimization	Techniques and Controller	Future work
[45]	Clauclio A.	2000	Voltage and angle stability	SVC, STATCOM, TCSC, UPFC	Transient stability parameters.	Power flow and stability models.	Study unbalanced system performance.
[46]	K. Hongesombut	2001	System stability	SVC	Fuzzy logic parameters.	Fuzzy logic control, MATLAB.	Optimize fuzzy logic controller.
[47]	A. C. M.Valle	2001	Power system stability	SVC	GA for PID tuning, RBF adaptability.	GA, RBF networks, MATLAB	Explore other adaptive methods like neural networks.
[48]	Jimmie J.	2002	Enhancing stability	SVC	Unity power factor, reactive power.	Model reference control, simulation.	Explore further contingency scenarios and practical applications.
[49]	Qun Gu	2003	improving transient stability	SVC	Fuzzy logic	simulation on a 2-area, 4-generator system.	Coordination with PSS, global input signals.
[50]	Samir A	2004	Enhanced transient stability	STATCOM	Nonlinear H∞ Control	state feedback, feedback linearization.	Extend robust control to multi-machine systems
[51]	M. H. Haque	2004	Enhanced first-swing stability and transient stability	SVC, STATCOM	Equal area criterion (EAC)	Proposed control strategy	Applying in the general multimachine systems.
[52]	Eskandar Gholipour	2005	Improved transient stability	UPFC	Active and reactive power modulation	Control strategy using local measurements and state variables	Further testing on larger systems and different contingencies
[53]	Tamer Abdelazim	2005	Enhanced transient stability	SVC	Fuzzy logic control	Adaptive fuzzy logic controller for SVC	Testing on more complex power systems
[54]	L. Cong	2005	Enhanced transient stability	SVC	Generator excitation, firing angle control	Coordinated control using feedback linearization and robust control theory	Evaluating multi-machine power systems under diverse operating conditions.
[55]	Yong Chang	2006	Improved damping of inter-area oscillations	SVC	Wide area signals, synthetic residue index	Supplementary controller based on wide area signals	Exploration of coordinated damping control using wide-area measurements.
[56]	S. M. Sadeghzadeh	2006	Improvement of transient stability	SSSC	Neuro-fuzzy control	Fuzzy logic control,	Exploration of the most suitable Neuro-Fuzzy configurations
[57]	M.H. Haque	2007	Improvement of first swing stability	SVC	Critical clearing time	Transient Energy Function	Further refinement of SVC control strategies to enhance FSS limit in larger systems
[58]	Jing Zhang	2007	Voltage stability enhancement	SVC	Nonlinear participation factors	Eigenvalue analysis	Application of nonlinear methods to improve the placement and effectiveness of SVC in stressed power systems
[59]	O.L. Bekri	2008	Improved voltage regulation and reactive power	SVC	Susceptance control	MATLAB/Simulations	Further simulation-based studies on the SVC's impact on system stability and real-time applications
[60]	Ibrahim Mansour	2009	Enhanced transient stability	SVC	Fuzzy logic control	MATLAB/Simulink	Further exploration of fuzzy controllers for other

							FACTS devices to enhance system stability
[61]	Dr. V.K. Chandrakar	2010	Damping of power system oscillations	SVC	Speed deviation, oscillations	eigenvalue analysis, MATLAB Simulink simulations	Investigation of coordinated tuning of SVC and POD for large-scale power systems with mechanical disturbances
[62]	A. Rajabi-Ghahnavieh	2010	Enhancing system reliability	Unified Power Flow Controller (UPFC)	Voltage, phase angle, power flow, and reactive power injections	Mixed-integer nonlinear optimization and sensitivity analysis	Applying methods for multiple UPFCs and expanding reliability metrics to larger systems
[63]	Ghazanfar Shahgholian	2011	Improved dynamic stability	SVC	Susceptance, firing angle, eigenvalue analysis	MATLAB Simulink simulations	Application of SVC-based POD controllers for improving system stability under various load conditions
[64]	N.A. Arzeha	2012	Enhanced transient stability	SVC	Voltage error, rotor angle difference	MATLAB/Simulink, 2-machine 3-bus system	Explore other fuzzy logic configurations and combinations with different control methods for large-scale power systems
[65]	Mohsen Darabian	2013	Improved transient stability	SVC	Power angle, rotor speed, adaptive learning rates	Wavelet Neural Network (WNN),	Further study of the intelligent control method applied to larger power systems with complex contingencies
[66]	Tarang Sharma	2014	Transient stability improvement	SVC	Voltage error, rotor angle difference, susceptance control	MATLAB/Simulink, 2-machine 3-bus	Study of neural network-based fuzzy logic controllers with TID to enhance transient stability
[67]	Md. Shafiullah	2014	Improved transient performance	SVC	Damping ratio, susceptance, eigenvalues	MATLAB/Simulink, SMIB model, GA for tuning	Study of GA-based controller for multi-machine systems with more complex disturbances
[68]	Pooja Rani	2015	Enhanced system stability	TCSC	Impedance, firing angle, rotor speed deviation	MATLAB/Simulink, multi-machine 4-bus system	Further exploration of TCSC with other controllers for larger systems under different fault conditions
[69]	Khoshnaw khalid Hama Saleh	2015	Transient stability improvement	SVC	Rotor angles, terminal voltages, active power	Power System Stabilizer (PSS) and SVC	Multiple SVCs, advanced controllers, larger systems.
[70]	Yogasree Manganuri,	2016	Voltage stability improvement	TCSC	Sensitivity index, stability index	IEEE-14 bus system, PSAT, MATLAB	Further research on integrating TCSC with other FACTS devices for enhanced voltage stability and loss minimization
[71]	M.M. ElAdany	2018	Transient stability improvement	TCSC	Critical clearing time (CCT)	Catastrophe theory (CT)	Further research into optimizing the placement of TCSC in larger systems and comparison with other FACTS devices
[72]	Alok Kumar Mohanty	2019	Improvement of system stability, dynamic control, and enhanced power flow	SVC, TCSC, STATCOM, UPFC, and SSSC	Reactive power management, Voltage stability, Power angle and impedance control	Fuzzy Logic and other advanced strategies for optimal device performance	Developing advanced control algorithms for FACTS
[73]	Shiba Ranjan Paital	2020	Transient stability enhancement	SVC	Peak overshoot, settling time, speed deviation, voltage deviation	Fractional order PID, Bat algorithm, BFO, PSO	Further exploration of FOFPID controllers for other system configurations, and comparison with alternative optimization techniques
[74]	Wiwin A. Oktaviani	2020	Voltage stability analysis	UPFC	Load and dynamic stability margins	Continuous Power Flow (CPF) and Time Domain Analysis	Recommendations include further integrating renewable energy sources and optimizing controller settings for better efficiency.
[75]	Yousif Al Mashhadany	2022	Power system stability analysis	SVC, STATCOM, TCSC, UPFC, and IPFC	Voltage regulation, reactive power control, and dynamic system	Fuzzy Logic, Genetic Algorithms, and VSC-based control techniques	Using advanced semiconductor technologies, deeper inter-area stability solutions

					damping through FACTS		
[76]	M.R. Djalal	2023	Transient stability enhancement	SVC	Voltage, speed deviation, damping ratio	MATLAB/Simulink simulation, eigenvalue analysis	Apply MOA to larger power systems for improved stability
[77]	Suraj Ankush Dahat,	2023	Enhanced damping and voltage stability during disturbances.	SVC, SSSC	Injected voltage (Vr) by SSSC - Susceptance (Bc) by SVC	Coordinated control of SVC and SSSC	Integration of hybrid SVC/SSSC with other FACTS
[78]	Feaka M. Khater	2024	Improving power system performance	STATCOM	Adjusted for voltage regulation and reactive power	PI and Fuzzy logic controller	Exploring **SSSC** and **UPFC** at different points can enhance system stability and performance further.
[79]	Mehdi Shafiee	2024	Improved transient stability	SSSC	Overshoot, settling time, damping ratio	Fuzzy logic, EOA, MATLAB/Simulink	Apply the approach to larger systems with additional FACTS devices
[80]	Ban H. Alajrash	2024	Improving power quality, voltage stability	SVC, TCSC, UPFC, STATCOM, and DPFC,	Optimization parameters include voltage levels, power flow, and reactive power compensation,	Genetic Algorithms (GA), Particle Swarm Optimization (PSO), and Fuzzy Logic	Improving FACTS placement techniques, integrating AI, enhancing renewable compatibility, and addressing power quality issues cost-effectively

VII. CONCLUSIONS

This review comprehensively addresses the topic of transient stability in power systems, focusing on enhancement techniques through FACTS devices, particularly Static VAR Compensators (SVC). The findings confirm that SVC is an effective tool for maintaining transient stability by regulating reactive power output and ensuring voltage stability, especially during disturbances. SVC's ability to provide rapid reactive power support significantly improves the damping of rotor angle oscillations, aiding the system's recovery to stability post-fault clearance.

The review of prior research highlights key advantages of SVC, including its fast response time, cost-effectiveness, and reliable performance in transient stability enhancement. However, several studies employed advanced methods such as fuzzy logic controllers and genetic algorithms, further optimizing SVC performance by improving system response under complex fault conditions. For future work, researchers could explore the integration of hybrid controllers, such as combining SVC with STATCOM or implementing more sophisticated optimization techniques like neural networks and machine learning algorithms to enhance control accuracy and system resilience. Additionally, real-world case studies and practical implementations would provide a more robust validation of these techniques, ensuring wider applicability in modern power systems.

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