Enhancing Transient Stability of a Two-Machine Power System under Fault Conditions Using Static VAR Compensator

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Abstract: This project explores advanced techniques to enhance transient stability in a two-machine power system by integrating a modern Power System Stabilizer (PSS) and a state-of-the-art Static VAR Compensator (SVC) to manage fault-induced disturbances. Leveraging cutting-edge control strategies, the PSS is designed to mitigate low-frequency oscillations caused by severe three-phase and various types of faults, while the SVC dynamically optimizes reactive power flow by injecting or absorbing reactive power in real time.

MATLAB Simulink simulations, combined with entropy-based stability analysis, quantify the system's response under various fault conditions. Entropy values, representing the degree of randomness in system oscillations, are used to evaluate the effectiveness of these solutions. Comparative analyses with and without PSS and SVC demonstrate their synergistic impact in improving damping performance and reducing instability. This study confirms that modern PSS and SVC technologies, combined with advanced fault-tolerant control algorithms, are critical for achieving robust transient stability in contemporary power systems.

Keyword: Transient Stability, Power System Stabilizer (PSS), Static VAR Compensator, Two-Machine System, Three-Phase Fault, Reactive Power Control, Oscillation Damping

1. INTRODUCTION

In modern power systems, maintaining stability under fault conditions is crucial to ensuring reliable and uninterrupted power supply. Transient stability, in particular, refers to the power system's ability to maintain synchronism when subjected to large disturbances, such as faults or sudden load changes. In the event of such disturbances, unregulated oscillations and loss of synchronism can lead to severe consequences, including system blackouts. For this reason, various control devices are employed to improve stability and mitigate the effects of these disturbances. The capacity of a power system to maintain an operating equilibrium under typical operating conditions and to return to a satisfactory state of balance following a disruption is known as power system stability. Over time, a variety of controllers and control techniques have been created and applied for this goal. In order to guarantee a dependable supply of energy to customers, stability is crucial, particularly when the system is exposed to significant, low-probability disruptions. A generator and the wider utility grid, or even the interconnected power systems of nearby utilities, may become out of sync as a result of specific disruptions. To overcome these obstacles and raise the general stability of the power system, numerous control strategies and tools have been created over time.

A commonly used device to enhance stability is the Power System Stabilizer (PSS), which improves damping of low-frequency oscillations in the system by adjusting generator excitation. However, in severe fault conditions, such as line-to-line-to-ground (LLG) faults, PSS alone may not be sufficient to maintain stability due to the significant reactive power imbalance and oscillatory behavior induced by such faults. The Static VAR Compensator (SVC) is an additional control device that can play a pivotal role in these scenarios. By injecting or absorbing reactive power, the SVC helps to stabilize voltage levels, thereby supporting the system during transient conditions. This research aims to underscore the complementary roles of PSS and SVC in addressing the challenges posed by LLG faults and other severe disturbances, demonstrating their combined effectiveness in achieving resilient and stable power system operation.

Power System Stabilizers (PSSs) are crucial in enhancing power system stability by mitigating low-frequency oscillations, which can occur due to generators lacking sufficient damping. These oscillations can be intra-area or inter-area, depending on the system's layout, operating conditions, and power flow dynamics. Multiple types of PSSs, such as the Multi-Band Power System Stabilizer, are used to manage these oscillations, enhancing system stability and dynamic performance. This multi-band approach ensures better response to various modes of disturbances. In severe fault conditions, PSSs alone may not provide sufficient stability. Flexible AC Transmission System (FACTS) devices like the Static VAR Compensator (SVC) are needed for additional support. SVCs improve voltage profiles and manage reactive power, reducing fluctuations and supporting the overall power system. They work in tandem with PSSs, providing additional control and mitigating voltage instability and synchronization.

This study explores the role of PSS and SVC in enhancing power system stability under fault conditions, focusing on scenarios where PSS alone may not be sufficient. Simulations and analysis demonstrate the complementary roles of PSS and SVC in maintaining reliability and stability, particularly during large disturbances or faults. The results provide insights into optimal use of both devices for power delivery.

2. MODELLING

Circuit Description:

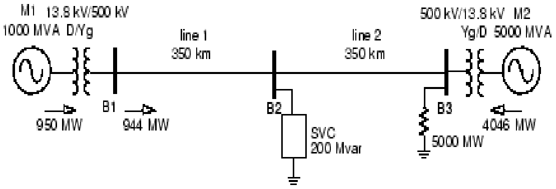

Fig 1: Improving the Transient Stability Using SVC and PSS – MAT Lab/Simulink – line diagram

A 1000 MW hydroelectric power plant (M1) is connected to a load center through a 500 kV, 700 km long transmission line. The load center, which represents the demand for electricity, is modelled with a 5000 MW resistive load, meaning it consumes power with minimal reactance, just resistance. This load is supplied by two generation sources: the remote 1000 MVA hydroelectric plant (M1) and a local power plant (M2) with a generating capacity of 5000 MVA. To analyze the system's operation, a load flow study was conducted, which simulates the power flow from the plants to the load center. The results of this study show that plant M1 is generating 950 MW of electricity, which is being transmitted via the 500 kV line to the load center. As a result of M1's generation, plant M2 compensates by producing 4046 MW to meet the remaining demand.

The transmission line itself is carrying 944 MW of power. This value is very close to the line's surge impedance loading (SIL), which is 977 MW. Surge impedance loading refers to the maximum amount of power a transmission line can carry without excessive voltage drops or instability under normal conditions. Since the line is operating near its SIL, it is functioning close to its optimal capacity, where any additional power load could lead to efficiency issues, voltage instability, or the risk of overloading the transmission line. Therefore, managing the power flow and maintaining stability is crucial in ensuring the continued efficient operation of this power system.

3. POWER SYSTEM STABILIZERS (PSS):

Power System Stabilizers (PSSs) are essential control devices used in power systems to enhance system stability, particularly during transient conditions caused by disturbances such as faults, load changes, or sudden fluctuations in generation. These disturbances can lead to low-frequency oscillations in the system, which, if not properly damped, can cause instability, system blackout, or damage to equipment.

PSSs are primarily designed to provide additional damping to these oscillations by modifying the excitation of the generator, thus improving the dynamic response of the system. These oscillations, typically in the frequency range of 0.2 Hz to 2.5 Hz, are caused by the interaction between generators in the system. If left unchecked, these oscillations can cause loss of synchronism between generators, leading to system instability. By effectively controlling the generator's excitation, the PSS helps mitigate the impact of these oscillations, ensuring that the power system remains stable and those generators continue to operate in synchronism with each other. PSSs are especially important in large interconnected grids, where multiple generators are operating in parallel and where disturbances can propagate across different regions.

The working principle of a Power System Stabilizer is based on modifying the generator's excitation system to provide a stabilizing effect during low-frequency oscillations. It achieves this by injecting a control signal into the generator's excitation system, which influences the generator's field voltage. The Power System Stabilizer (PSS) detects low-frequency oscillations in the power system caused by disturbances like load changes or power generation changes. It uses feedback signals to process these oscillations and determines the appropriate control action. The processed signal is fed to the generator's excitation system, which adjusts the generator's output power to counteract the oscillations. The excitation adjustment reduces the generator's mechanical power, providing additional damping to the oscillations. The PSS continuously monitors the system's operating conditions, making real-time adjustments to maintain stability.

Novelty:

1. *Entropy-Based Stability Analysis:* The project introduces the application of entropy, a novel quantitative metric, to evaluate the degree of randomness in system oscillations. Unlike traditional methods such as damping ratio or settling time, entropy provides a fresh, detailed perspective on transient stability.
2. *Advanced Control Strategies:* The use of state-of-the-art control mechanisms for both PSS and SVC ensures adaptability and precision in fault-tolerant operation, reflecting the latest technological advancements in power system stability enhancement.
3. *Comprehensive Fault Scenarios:* By evaluating the system under severe three-phase and line-to-line-to-ground (LLG) faults, the study ensures a robust and holistic understanding of the system's performance.

Contributions:

Integration Framework: The project provides a framework for integrating modern PSS and adaptive SVC technologies, showcasing their complementary functionality in enhancing transient stability.

Simulation-Based Validation: Through MATLAB Simulink, the study validates the effectiveness of the proposed solution, offering empirical evidence of improved damping and reactive power management under diverse fault conditions.

Entropy as a Stability Metric: By introducing entropy as a stability assessment tool, the research broadens the toolkit for analyzing transient stability, enabling more nuanced and quantitative evaluations of system performance.

Comparative Analysis: The research presents a detailed comparison of system performance with and without PSS and SVC, quantifying their individual and combined impact on transient stability.

Practical Application: The findings underscore the real-world applicability of modern PSS and SVC technologies in addressing fault-induced disturbances, offering insights for the design of more resilient power systems.

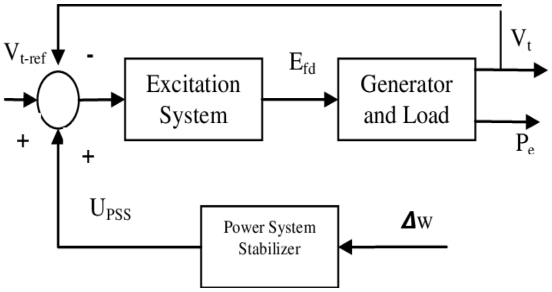

Fig 2: Block diagram of power system stabilizer

4. STATIC VAR COMPENSATOR

A Static VAR Compensator (SVC) is a crucial device in Flexible AC Transmission Systems (FACTS) that enhances voltage stability and regulates reactive power. It is ideal for critical locations, large load centers, and regions with fluctuating power generation, improving system controllability and stability.

While the latest methods incorporate advanced technologies like AI, hybrid systems, and wide-area coordination, this study's emphasis on entropy-based analysis, the synergy between modern PSS and SVC, and comprehensive fault scenario evaluation offers a unique and accessible contribution. It provides a solid foundation for further exploration and integration of these advanced methods into power systems. Benefits of using an SVC include voltage stabilization, improved system stability, increased power transfer capacity, quick response to disturbances, and flexibility, as they can operate over a wide range of voltages and be installed at various transmissions network points.

5. SIMULATION DIAGRAM

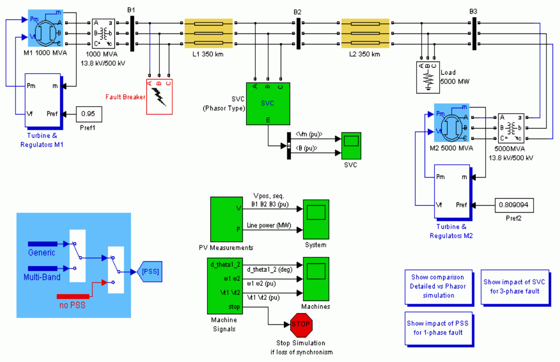

Fig 3: Simulink Diagram of PSS-SVC System

Three-Phase Fault — Impact of SVC — PSS in Service:

The process involves activating Power System Stabilizers (PSSs) to dampen low-frequency oscillations in the power system, which can be caused by disturbances like faults or load changes. The Fault Breaker block is reprogrammed to simulate a 3-phase-to-ground fault, allowing for an abnormal operating condition. The SVC injects reactive power into the transmission line when the voltage drops below the reference voltage (1.009 pu), restoring the voltage to the desired level and preventing voltage collapse or instability. The 1.009 pu reference voltage acts as a threshold, ensuring the SVC only activates when necessary. The results are carried out in the MATLAB/Simulink. It is knon that the SVC is at fixed Susceptance mode B_{ref}=0, in this mode, the SVC does not react to the voltage drop caused by the fault shown in the figure 4. As a result:

1. The voltage on the bus remains unregulated during and after the fault.
2. The machines experience severe oscillations and quickly lose synchronism after the fault is cleared.
3. This highlights the inability of a passive SVC (in fixed Susceptance mode) to support voltage stability under transient conditions.

The SVC is switched to voltage regulation mode with a reference voltage of 1.009 pu. In this mode, the SVC dynamically injects reactive power when the voltage drops below the set point or absorbs reactive power if the voltage exceeds the set point.

1. *Without Voltage Regulation (Fixed Susceptance Mode)**:*** The system experiences severe instability as the SVC does not respond dynamically to voltage disturbances.
2. *With Voltage Regulation Mode**:*** The SVC significantly enhances voltage stability by dynamically compensating for reactive power imbalances, preventing the machines from losing synchronism.

This comparison underscores the critical role of an SVC in voltage regulation mode for maintaining transient stability in power systems.

6. SIMULATION RESULTS FOR WITH OUT PSS AND WITH OUT SVC

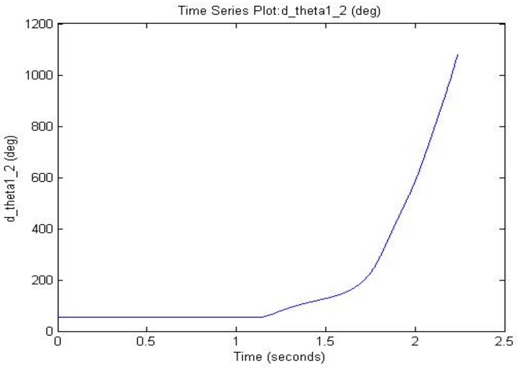

Fig 4: Rotor angle difference vs time

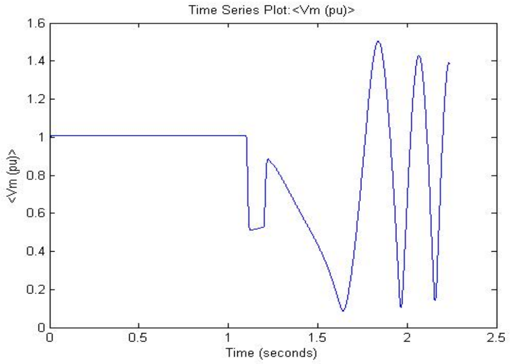

Fig 5: SVC measured voltage vs time

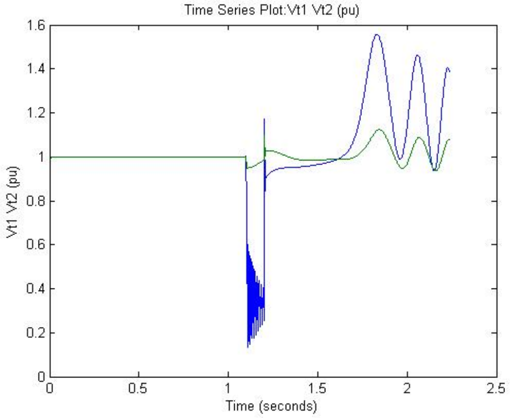

Fig 6: Terminal voltages vs time

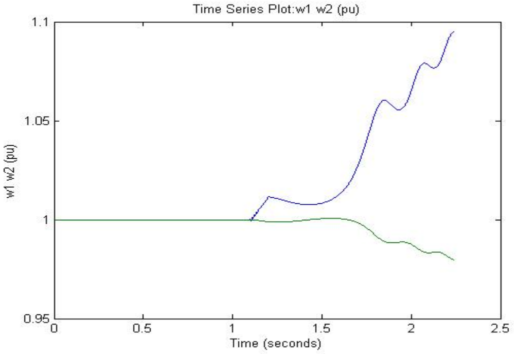

Fig 7: Machine speeds vs time

VII. SIMULATION RESULTS FOR WITH PSS and SVC

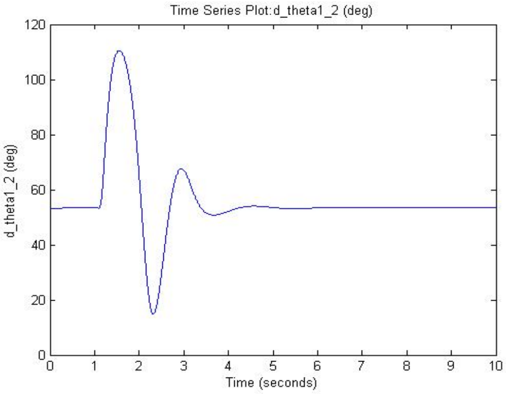

Fig 8: Rotor angle difference vs time

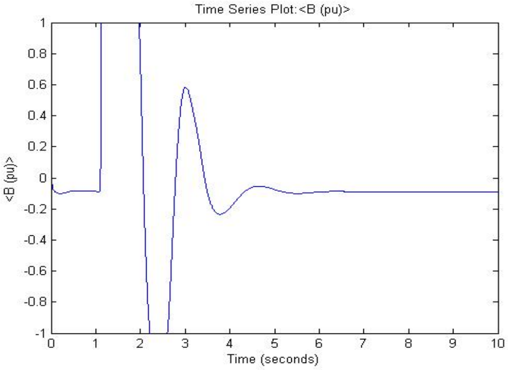

Fig 9: Susceptance vs time

Table 1: Entropy Analysis of SCV and PSS

S No	Bus Voltage	DetΘ	Line Power	SVCb
NO SVC & No PSS	-4.897e+11	-4.99e+11	-4.94e+11	-5.007e+11
With SVC & No PSS	-4.895e+11	-4.98e+11	-4.93e+11	-4.938e+11
NO SVC & With PSS	-4.90e+11	-4.99e+11	-4.94e+11	-5.005e+11
With SVC & With PSS	-4.95e+11	-4.97e+11	-4.96e+11	-4.981e+11

Comparison with Latest Methods:

Machine Learning-Based Stability Enhancements:

Comparison: Modern techniques increasingly incorporate machine learning (ML) and artificial intelligence (AI) for adaptive stability solutions. For instance, reinforcement learning and neural network controllers dynamically adjust parameters of PSS and SVC based on real-time grid conditions.

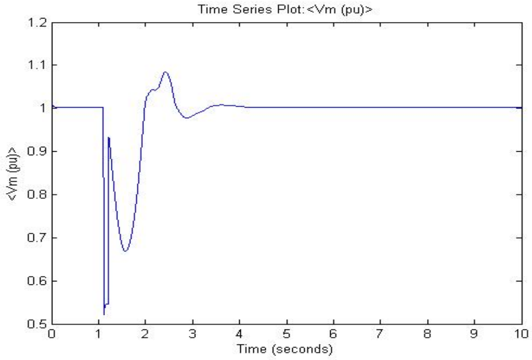

Fig 10: SVC measured voltage vs time

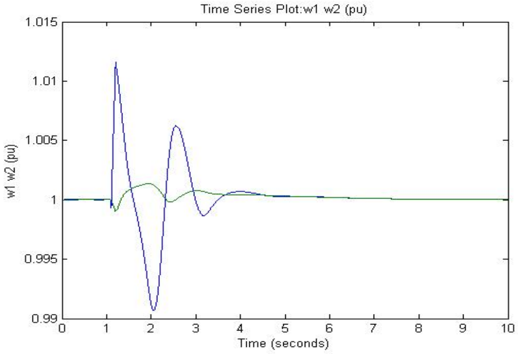

Fig 11: Machine speeds vs time

Advantage of This Work: While this study does not utilize ML/AI, it introduces entropy as a novel metric, offering a simpler yet effective method to analyze transient stability without the complexity of training and computational overhead associated with ML-based approaches.

Hybrid Compensation Systems (STATCOM + SVC):

Comparison: Recent research explores hybrid FACTS devices, such as STATCOM combined with SVC, offering faster response times and higher compensation capability compared to standalone SVCs.

Advantage of This Work: This research isolates the role of the SVC, providing a clear and focused analysis of its effectiveness in conjunction with a PSS. This simplification enables better understanding and optimization of each component's contribution to stability.

Renewable Energy Integration:

Comparison: Advanced methods explore the stability challenges posed by renewable energy sources, such as low inertia and fluctuating power. Adaptive control systems tuned for renewable-dominated grids are increasingly common.

Advantage of This Work: This research focuses on fundamental stability enhancements in traditional systems, offering insights that can later be extended to hybrid grids with renewable integration.

7. CONCLUSION

The study concludes that integrating advanced Power System Stabilizers (PSS) and modern Static VAR Compensators (SVC) significantly enhances transient stability in two-machine power systems under various fault conditions. Simulations reveal that the PSS effectively dampens oscillations induced by three-phase and line-to-line-to-ground (LLG) faults, while the SVC dynamically manages reactive power flow to maintain voltage stability.

Entropy-based stability analysis confirms the complementary roles of PSS and SVC, demonstrating their ability to reduce instability and improve the system's response to disturbances. The findings underscore the importance of combining these technologies with modern control strategies to achieve robust fault tolerance and improved power system resilience. This approach provides a practical and scalable solution for transient stability challenges in increasingly complex and dynamic power grids.

FUTURE SCOPE:

Explore the integration of SVC with other Flexible AC Transmission System (FACTS) devices, such as STATCOM or UPFC, to provide a more comprehensive stability solution for modern power grids. Conduct cost-benefit analyses to evaluate the economic feasibility of deploying advanced PSS and SVC technologies in different power grid configurations. By addressing these aspects, future research can enhance the scalability, reliability, and sustainability of power systems, meeting the demands of modern grids and the integration of renewable energy sources.

REFERENCES

[1] Adware, R. H., & Chandrakar, V. (2022, January). Comprehensive analysis of statcom with svc for power quality improvement in multi machine power system. In *2022 2nd International Conference on Power Electronics & IoT Applications in Renewable Energy and its Control (PARC)* (pp. 1-5). IEEE.

[2] Suriya Devi, D. M., Shinisha, A., & Edward Wilson, S. (2021). Review on Power System Instability and Its Mitigation Techniques. *Advances in Automation, Signal Processing, Instrumentation, and Control: Select Proceedings of i-CASIC 2020*, 987-993.

[3] Meegahapola, L., Bu, S., & Gu, M. (2022). Rotor Angle Stability of Hybrid AC/DC Power Grids. In *Hybrid AC/DC Power Grids: Stability and Control Aspects* (pp. 89-129). Cham: Springer International Publishing.

[4] Rao, G. M. (2014). An Adaptive Neuro-Fuzzy Inference Distributed Power Flow Controller (DPFC) In Multi-Machine Power Systems. *International Journal of Power Electronics and Drive Systems*, *5*(2), 230.

[5] M.Klein, G.J.Rogers and P.Kundur, "A Fundamental Study of Inter-Area Oscillations", IEEE Trans, Power Systems Volume- 6, Number-3, August 1991.

[6] R. Mihalic, P. Zunko and D. Povh, 1996, "Improvement of Transient Stability using Unified Power Flow Controller," IEEE Transactions on Power Delivery, 11(1), pp. 485-491.

[7] Sundeep, S., & Rao, D. G. M. (2011). Modelling and analysis of custom power devices for improve power quality. *International Journal of Electrical and Computer Engineering*, *1*(1), 43-48.

[8] Igor Papic, Peter Zunko, 2002, "Mathematical Model and Steady State Operational Characteristics of a Unified Power Flow Controller,"Electro-technical Review, Slovenija, 69(5), pp. 285-290.

[9] Prechanon Kumkratug, 2009, "Application of UPFC to Increase Transient Stability of Inter-Area Power System," Journal of Computers, 4(4), pp. 283-287.

[10] Prechanon Kumkratug, Panthep Laohachai, 2007, "Direct Method of Transient Stability Assessment of a Power System with a SSSC," Journal of Computers, 2(8), pp. 7782.

[11] S.V. Ravi Kumar, S. Siva Nagaraju, 2007, "Transient Stability Improvement using UPFC and SVC," ARPN Journal of Engineering and Applied Sciences, 2(3), pp. 3845.

[12] Mingchen, G. U. *Stability analysis and enhancement of hybrid AC/DC power networks* (Doctoral dissertation, RMIT University).

[13] Rao, G. M., Kumar, V. A., & Ram, B. S. (2016, October). Design of a neural network based distributed power flow controller (DPFC) for power system stability. In *2016 International Conference on Signal Processing, Communication, Power and Embedded System (SCOPES)* (pp. 600-606). IEEE.