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A Review on SVC control for power system stability with and without auxiliary controller

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Article Info	ABSTRACT
	Since the beginning of the last century, power system stability has been recognized as a vital problem in securing system operation. Power system instability has caused many major blackouts. This paper reviewed the previous technical works consisting of various methods of optimization in controlling power system stability. The techniques presented were compared to optimize the control variables for optimization of power system stability. Power system stability enhancement has been investigated widely in literature using different ways. This paper is focusing on SVC performance for enhancing power system stability either through SVC controlled itself or SVC controlled externally by other controllers. Static VAR compensators (SVCs) are used primarily in power system for voltage control as either an end in itself or a means of achieving other objectives, such as system stabilization. The analysis on performance of the previous work such as advantages and findings of a robust method approach in each technique was included in this paper.

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1.   INTRODUCTION

Power system is the ability of an electrical power system to provide initial operating conditions to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact. Power system stability can be divided into three categories; rotor angle stability, frequency stability and voltage stability. Power system has operated under much more stressed conditions from the past two decades. There are number of factors responsible for this; the use of new technologies, continuing growth in interconnections, bulk power transmission over long transmission lines, increased electricity consumption in heavy load areas, environmental pressures on transmission expansion, new loading patterns due to the opening up of the electricity market, large penetration of wind generators and local coordinated controls in systems and growing use of induction machine.

This review paper aimed to study and investigate the previous technical works consisting of various methods of optimization in controlling power system stability. Furthermore, there were some discussions on the advantages of previous research methods.

2.   RELATED WORKS ON POWER SYSTEM STUDIES

D. Murali [1] investigated the improvement of transient stability of a two-area power system using Unified Power Flow Controller (UPFC) which is an effective Flexible AC Transmission System (FACTS) device capable of controlling the active and reactive power flows in a transmission line by appropriately control its series and shunt parameters. The performance of UPFC is compared with other FACTS devices such as Static Synchronous Series Compensator (SSSC), Thyristor Controlled Series Capacitor (TCSC) and Static Var Compensator (SVC) respectively.

Habibur Rahman [2-5] proposed external controller for Static Var Controller (SVC) for the improvements of voltage stability and damping effect of an on-line power system. The authors present the Proportional Differential (PD) and Proportional Integral (PI) controllers [2], Proportional Integral Differential (PID) controller [3, 4] and newly designed Power System Controller (PSC) [5]. PD and PI controllers parameters have been optimized by Ziegler-Nichols closed loop tuning method whereas PID controller parameters has been optimized by proposed Triple Integral Differential (TID) and Ziegler-Nichols closed loop tuning method respectively. The proposed PSC consists of two controllers namely PID and POD controller.

A study on the effect of SVC on voltage stability using cascade Proportional Integral Differential (PID) controller is discussed by Pranoy Sinha Roy [6]. The cascade PID controller parameters have been selected using Tyreus-Luyben setting method for primary loop controller and modified Ziegler-Nichols method for secondary loop controller. Cascade controller is mainly used to achieve fast rejection of disturbance before it propagates to the other parts of the plant. Imran Azim [7] also presented PID controller for SVC. With Cohen-Coon open loop tuning rule, the augmented PID-SVC is able to improve the voltage stability and damping effect of online power system.

Habibur Rahman [8] presented a new simple method of transient stability and voltage level improvement of a large scale power system for different types of faults during transient conditions to improve the stability of multi-machine large scale power system. This paper contributes to the improvement of transient stability of multi-machines power system using Power System Stabilizer (PSS). This work is to improve voltage stability and damped out oscillation using power system stabilizer and SVC with and without PI controller.

M. H. Haque proposed a modification transient energy function method [9] to determine the first-swing stability limit of a power system in the presence of SVC. The unstable equilibrium point at which the critical energy is to be evaluated is determined by considering that the SVC operates at its full capacitive rating. The technique is tested on both single and multi-machine systems. The results are then compared with the corresponding actual values found through repetitive time-domain simulations of system dynamic equations.

Fuzzy logic control SVC for power system stability was discussed [10-17]. Takashi Hiyama [10] presented a Fuzzy Logic (FL) control scheme with variable gain for SVC to enhance power system stability. Variable gain is proposed to terminate the switching control of the SVC soon after reaching quasi steady-state to avoid excessive and unnecessary control action from SVC. Qun Gu [11] presented a simple approach to achieve damping of phase angle oscillations and to improve transient stability of an interconnected power system network using fuzzy logic. The output of the fuzzy logic controller is fed to an existing SVC. The fuzzy controller for achieving stability has been demonstrated on a four-generation, two-area system using simulation studies.

Fuzzy logic based SVC stabilizer was proposed by Kitti Porang [12]. This controller is used to generate a supplementary control signal to voltage regulator of SVC in order to improve damping of the inter-area mode oscillation in power system. The base system is symmetrical and consists of two identical areas connected through a relatively weak tie line where the SVC is located. The supplementary signal is calculated using fuzzy membership function in order to determine the quantity of reactive power supplied or absorbed by SVC. The effectiveness and feasibility of a fuzzy logic based supplementary controller for SVC are demonstrated by single machine infinite (SMIB) system and multi machine system [13].

Some authors [14] presented an application of fuzzy control to determine the control signal of SVC for the improvement of power system stability. The device improves the damping of electromechanical oscillations and also increases power transfer in transmission systems. Input signals for the fuzzy logic are chosen as accelerated power and generator speed deviation. The proposed control method is demonstrated by single machine infinite bus system. In terms of damping low frequency power oscillations, J. Lu presented an approach to design a fuzzy logic based adaptive SVC damping controller [15-16]. A fuzzy signal tuner is introduced to achieve the adaptiveness of the controller.

A novel concept called the bus power oscillation energy function was introduced [17]. According to this concept, a fuzzy logic adaptive SVC control scheme is developed. The adaptive approach overcomes the

drawback of fuzzy logic control schemes with constant gain factor. The effect of the adaptive control techniques is demonstrated on the 10-generator New England systems.

Youjie Ma presented an in-depth analysis of two kinds of nonlinear controllers [18]. Direct Feedback Linearization (DFL) is employed to design a nonlinear SVC controller. A new signal modulation synthetical nonlinear SVC controller is developed to improve a nonlinear SVC voltage controller. The synthetical nonliear controller is able to produce additional damping torque as well as maintain the voltage at SVC location.

The model of SVC is controlled externally by an Auxiliary Controller for damping power system oscillations as presented by Poonam Singhal [19]. Different auxiliary controller structures have been designed and controller's parameters have been optimized using Ziegler-Nichols close loop tuning method. Comparison has been carried out without, with SVC and with SVC Auxiliary controllers under three phase fault contingencies.

A modified particle swarm optimization (MPSO) algorithm is utilized to determine the optimum design of PID controller parameters that improve the stability of SMIB system with SVC [20]. The performance of the power system under different loading conditions is investigated using three tuning methods namely Ziegler-Nichols PID, PSO PID and MPSO PID.

Nang Sabai [21] discussed and demonstrated how SVC has successfully been applied to control transmission systems dynamic performance for system disturbance and effectively regulate system voltage. SMIB system is modeled to design a controller for SVC devices on transmission lines. SVC is a shunt connected to FACTS devices and plays an important role as a stability aid for dynamic and transient disturbances in power systems. UPFC controller is another FACTS device that can be used to control active and reactive power flows in a transmission line. The modeling of SVC and UPFC [22] for transient stability evaluation is studied and tested on a 10 generator, 39 Bus, New England Test System.

Some fundamental issues on SVC such as control approaches in order to improve systems damping, the differences between continuous and discontinuous control of SVC reactive power output and the best SVC location in a power system to achieve the maximum damping improvement are discussed [23]. The time domain simulations of the proposed control approach in a one machine system to increase swing oscillation damping and in four machine system to increase damping of an inter-area oscillation mode demonstrate that the developed analysis theory and the proposed SVC control approach may be applied to solve practical power system damping problems.

E. Hammad presented a fundamental analysis of the application of SVC for stabilizing power systems [24]. Basic SVC control strategies are examined in terms of enhancing the dynamic and transient stabilities, improving tieline transmission capacity and damping power oscillations. Existing concepts can be divided into two categories; pure voltage regulation and voltage regulation with auxiliary damping controls. A third possibility would be to have normal voltage regulation and a separate control loop for system stabilization.

Armit Garg [25] investigated the effects of SVC on voltage stability in power system. The effectiveness of SVC on regulating system voltage are also discussed and demonstrated in the paper. When the system voltage is low, the SVC generates reactive power (SVC capacitive). When system voltage is high, it absorbs reactive power (SVC inductive).

According to C. Udhayanashankar [26], power electronics based technology known as FACTS devices can be used individually or in coordination with other controllers. Even though PI controlled SVC is simpler and cheaper, it is not suitable for nonlinear characteristics. In order to overcome this, the controller is designed as a combination of both PI controller and Fuzzy Logic controller, thereby gaining the joint advantages of both types. The designed model has been tested in a two machine three bus system.

A systematic approach for designing SVC supplementary controller is presented by Yong Chang [27]. This approach is used to improve the damping of power system oscillation. The principle for damping oscillation by SVC is first analyzed and the concept of synthetic residue index is then presented which is used to choose the proper input wide area signals. Parameters of the controller are determined by means of test signal method and residue root locus. The effectiveness of the proposed controller is demonstrated on a two area system.

A new method of determining the maximum power transfer capability of a high voltage AC transmission line with different series and shunt compensation schemes is presented by M. H. Haque [28]. The method determines the maximum power transfer limit by finding the critical value of the receiving end current beyond which the power cannot be increased by increasing the value of the current because of voltage instability. The proposed method is applied to a transmission line with several series and shunt compensation schemes to determine the various critical quantities.

Mojtaba Noroozian [29] examines the enhancement of power system stability properties using thyristor controlled series capacitors (TCSCs) and SVC. A control strategy for damping electromechanical

power oscillations using an energy function method is derived. This control strategy will contribute to the damping swings without deteriorating the effect of the other power oscillation damping devices.

3. ANALYSIS PERFORMANCE ON PREVIOUS WORKS

The UPFC, SVC, TCSC and SSSC have been installed between bus-2 and bus-3 in the system [1]. It is considered that a 3-phase symmetrical short-circuit faults of 300 milli-seconds duration occurs at bus-3. UPFC takes 0.6s for settling time in post fault period for power system stability enhancement. While TCSC, SVC, and SSSC take 1.5s, 7s and 11s respectively. UPFC decreases the oscillations in generator rotor angle of Area-1 and Area-2. The UPFC can independently control many parameters because it is a combination of SSSC and STATCOM. Among the available FACTS devices, the UPFC is the most versatile in improving steady state stability, dynamic stability and transient stability. SVCs have been used for high performance steady state and transient voltage control compared with classical shunt compensation. It is also used to dampen power swings, improve transient stability and reduce system losses by optimizing reactive power control. TCSC roles are in scheduling power flow, decreasing unsymmetrical components, reducing net loss, providing voltage support, limiting short-circuit currents, mitigating sub-synchronous resonance, damping the power oscillations and enhancing transient stability. SSSC is a series which connect FACTS family. The purpose of a SSSC is to control power flow in steady state as well as to improve transient stability of a power system.

SVC is controlled externally by another controller [2-7]. Simulation results show that the system parameters (V, P, Q, dω) become unstable without SVC. Then, SVC is imposed to the system and parameters become stable. SVC rating is only 50MVA with controllers and 200MVA without controllers. PI, PI and PID controllers are the cheapest and most efficient controller. An advantage of these controller is that only a small controller can handle a robust interconnected power system efficiently.

PSS and SVC control are used to improve transient stability of multi-machines power system [8]. During 1-∅ fault, voltage stability time is 5s for SVC without control, 4s for SVC with PSS and 3s for SVC with PI controller. During 3-∅ fault, the system voltage becomes stable within 5.5s for SVC without control, 4s for SVC with PSS and SVC with PI controller. SVC with PI controller are less damping for both steady state and dynamic conditions.

M. Haque [9] observed that in SMIB system, SVC increases the CCT from 67.7 to 154.4ms. The corresponding CCT was determined by the TEF method and TDS method for various SVC ratings. The CCTs of the fault are found to be exactly the same for both methods. Fuzzy logic controller are being tested on their effectiveness for power system stability by some researchers [10-17]. The widest stable region is obtained when the SVC and the FLPSSs are coordinated [10]. Narrower stable region is observed when the parameters of the SVC and the FLPSS are separately tuned. The damping of oscillations is highly improved and the stable region is highly enlarged using the SVC and/or the FLPSSs.

Qun Gu [11] tested the effectiveness of fuzzy logic controller for achieving stability on a four-generator, two-area system using simulation with four different schemes. FCS increases CCT in all four schemes. Angle oscillations diminish to zero after 5s with FCS whereas without FCS there is still 0.1 pu peak to peak value after 10s. The system oscillation is started by a 3-phase-to-ground short circuit occurring at 0.2s and clears after 100ms [12]. SVC itself, when added with stabilizer will improve the system damping. The use of PSS only for two-area system is not effective. However it is possible to allow the cooperation between PSS and FCSVC to get more effective damping and shorter setting time.

FCS is being tested on SMIB System using a simulation [13]. When there is no controller, rotor oscillations change from 58 degrees maximum to 8 degrees minimum and speed deviation also changes from 1.8 to 0.8. Rotor oscillations change from 46 degrees maximum to 22 degrees minimum and speed deviation also changes from 0.94 to 0.5 for PID controller. As for FLC, rotor oscillations change from maximum 35 degrees to minimum 24 degrees and also speed deviation changes from 0.7 to 0.48. For three phase fault condition, fault condition at 0.3 seconds, existing for the period of 0.1 second and cleared at 0.4 seconds. Next, for over loaded condition, power of load increased to 1.5 pu at 0.5 second with 0.5 second duration.

The generator is modelled as a classical 2nd order differential equations [14]. The fault is cleared after 0.05 seconds. The system response is oscillatory and going towards instability. The damping is improved with SVC but oscillations are still present. The oscillations are fully damped out and the system comes back to the original steady state in the presence of FLC. Simulation IEEE type DCl exciter has been included but the fault is cleared after 0.1 seconds. The generator is represented by the 6th order differential equations.

FLC performance is performed on a one-machine infinite-bus and a two-area 4-machine 13-bus system [15]. Fault occurs at the ends of transmission lines and clears after 0.05s. The generator speed deviation on one-machine-infinite-bus system as a function of time for a light operating condition (P=1.5 pu)

and a heavier operating condition (P=2.5 pu), respectively. FLC is effective under both operating conditions. In 4-machine-13-bus system, the speed deviations of all generators as functions of time for a light operating condition (P0=2.2 pu) and a heavy operating condition (P0=4.5 pu) respectively. FLC shows effective damping against power oscillations by preventing the machine from going unstable.

Next, the effectiveness and feasibility of FLC is demonstrated with Single Machine Infinite Bus (SMIB) system and multimachine (WSCC) system [16]. A three phase fault is simulated at the load end at t=0.1s and cleared after 0.05s in SMIB system. The system response without SVC is oscillatory and leads to instability. SVC with conventional PID controller gives better damping but oscillations are still present. Meanwhile, with the FLC based SVC, the oscillations are fully damped out and the system comes back to original steady state. The bus voltage of SVC with the proposed FLC is reduced during fault conditions. If PID controllers are employed, the SVC voltage increases during fault period which causes additional voltage injection in the system instead of current injection. The angular speed deviations are quickly reduced using FLC controller.

D. Z. Fang [17] proposed the adaptive approach to overcome the drawback of fuzzy logic controller on the 10-generator New England systems. The SVC adaptive damping controller is significantly effective in damping big oscillations of all ten generators. The performance of the proposed varied-gain SVC adaptive controller is more effective than fixed-gain adaptive controller. The nonlinear SVC controllers are designed by employing the Direct Feedback Linearization (DFL) technique with three different conditions [18]. This technique is straightforward and very easy to understand from the physical point of view. Voltage at SVC location is very well controlled under two different control schemes. With the synthetically control strategy, the SVC can fulfill the requirements of voltage control and system damping simultaneously.

Only a small controller can handle a robust interconnected power system efficiently and effectively [19]. Without the use of SVC, settling time is around 8.5sec. However, when SVC controller is used in the center of the network, settling period is reduced to 7.8 sec. Yet, the use of external control to SVC with PID controller in place of washout and lead lag compensators further reduces the stability time to 7 sec. On the application of external control to SVC with washout and 2 stages of lead lag compensation further reduces the oscillations and enhances the stability period to 5.9sec. The use of SVC Auxiliary control with PD reduces the setting time to 5.6 sec which is further reduced to 5.4 seconds using auxiliary SVC controller with PI controller.

Nizar Hadi et. al. [20] stated that MPSO algorithm has a better performance in terms of maximum overshoot, which is smaller than the values obtained through PSO and ZN methods. In addition to this, the settling time is decreased to a very small value and is shorter than the determined value using the other two methods. MPSO-PID controlling scheme offers superior results in terms of system performance parameters. Therefore, the behaviour of the proposed MPSO tuning method shows that the output response can follow the unexpected variations occurred in the power system efficiently

SVC has been applied to control transmission systems dynamic performance for system disturbance and effectively regulate system voltage for Single Machine Infinite Bus (SMIB) system [21]. According to the results, when SVC are applied in series-compensated networks, a different kind of resonance between series capacitors and shunt inductors becomes decisive in the selection of control parameters and filters used in measurement circuits. The effects of SVC and UPFC on transient stability performance of power system are tested on a 10-Generator, 39-Bus, New England Test System [22]. Without FACTS device, critical clearing time (tcr) is 0.17s, with UPFC tcr is 0.189s, with SVC tcr is 0.26s and combination control of SVC and UPFC tcr is 0.248s.

SVC is proposed in a one-machine system to increase swing oscillation damping and is a 4-machine system to increase the damping of an interarea oscillation mode [23]. In a one-machine system, the swing oscillation is negatively damped and the amplitudes of machine angle and line power oscillations are increasing with the time without SVC. The system damping has been improved when SVC is proposed to the system. A stabilizing controller for the SVC is always necessary to provide the required damping torque in an optimal manner [24]. A 3-phase fault is assumed to be cleared in 5 ms. Without the SVC, the system is unstable. The system can easily ride through the disturbance and restore the pre-fault loading condition in a rapid manner with optimized stabilizing SVC controllers. Armit Garg et. al. [25] successfully applied SVC to power system for effectively regulating system voltage.

The researchers combine the advantages of both the controllers (PI and FLC) to derive a better performance out of SVC [26]. For a three phase fault created at t1=5sec, both the generators quickly fall out of synchronism. The results show that the rotor angle stabilization is found to be faster with Fuzzy-SVC controller at t=10sec which is 4.9 sec after fault clearance as compared to t=11sec, which is 5.9 sec after fault clearance with the conventional SVC controller. The speed of G1 is synchronized faster at t=10.5 sec with the proposed controller as against t=11.5 sec, with the conventional type. Additionally, the oscillation of G1 speed also lessens.

The concept of synthetic residue index is presented to choose the proper input wide area signals after the principle of damping oscillation by SVC is analyzed [27]. A three phase fault applied at the receiving end of the circuit between buses 8 and 9 is cleared 0.08 s later. A different series and shunt compensation schemes is presented to determine the maximum power transfer capability of a high voltage AC transmission line [28]. Compensation schemes G and F have higher power transfer capability than other compensation schemes (170% and 167% respectively). The maximum power transfer capability decreases for all the schemes, as the line length is increased up to 400 miles.

A study used TCSC and SVC control strategy that contribute to the damping of power swings without deteriorating the effect of the other power oscillation damping (POD) devices [29] The damping effect is robust with respect to loading condition, fault location and network structure. The maximum boost of TCSC apparent reactance is 15% of the intertie reactance. We note that the impact of TCSCs on damping is higher than SVC.

4.   SUMMARY OF THE POWER SYSTEM STABILITY ENHANCEMENT

Power system stability enhancement has been investigated widely in literature using different ways. A few types of FACTS device have been used for power system stability namely SVC, TCSC, STATCOM, UPFC. This paper is focusing on SVC performance for enhancing power system stability either through SVC controlled itself or SVC controlled externally by other controllers. Some researchers are testing the performance of SVC itself and others are testing SVC with external controller. This SVC performance is being tested either on single system or multi-machine system.

Stability is an important criterion which governs the power system operation. The term stability shows the ability to keep up the machines related to the structure in synchronism. SVC is one of FACTS controller helps in enhancing the stability of the power system with its brisk control qualities and incessant reimbursing limit. The fundamental part of SVC applications is to keep bus voltage at or near a steady level. It is found that a bus voltage controlled SVC does not contribute in a general sense to system damping. A significant responsibility regarding system damping can be refined when a SVC is controlled by some auxiliary signals superimposed over its voltage control loop.

A SVC can be controlled remotely using fittingly made particular deals with controllers which can improve voltage constancy of a tremendous scale control structure. Standard SVC includes a PID controller which is easier to design, execute and control. Nevertheless, they do not give alluring execution if there ought to be an event of incomprehensible unsettling impacts and for different operating points because the power system is non-linear. PSS is used as a piece of model to add damping to the rotor oscillations of the synchronous machine by controlling its excitation current. Any unsettling impacts that occur in power systems in view of fault, can realize actuating electromechanical oscillations of the electrical generators.

The path toward picking the controller parameters to meet given performance specifications is called PID tuning. Most PID controllers are adjusted on-site, an extensive variety of sorts of tuning guidelines have been proposed in the literature. Using those tuning rules, delicate and fine tuning of PID controllers can be made on-site. In the present deregulated circumstance, the system operating conditions may change altogether. A standard controller will not fill in as pictured in such a situation. Fuzzy Logic (FL) control approach has gained interests as a promising tool for solving obfuscated issues overseeing structures whose behavior is very complicated to build.

5.   CONCLUSION

The SVC with only constant voltage control is able to maintain the voltage at the SVC location but cannot produce additional damping to the system. Static VAR compensators (SVCs) are used primarily in power system for voltage control as either an end in itself or a means of achieving other objectives, such as system stabilization. The performance of SVC voltage control is critically dependent on several factors, including the influence of network resonances, transformer saturation, geomagnetic effects, and voltage distortion. When SVC is controlled externally by other controllers, then, system parameters become stable faster than without controller. The power system oscillations are also reduced with controllers compared to that of without controllers. Thus, with both controllers the system performance is greatly enhanced. The use of such auxiliary efficient controller makes the system reliable and cheap. Advantages of such controllers are that only a small controller can handle a robust interconnected power system efficiently and effectively.

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