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Stability Analysis of Multi-machine Power System Using SVC Under the Condition of Contingency

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ABSTRACT
This paper presents a test condition for stability analysis of two machine four bus system to mitigate the condition of contingency using Static Var Compensator (SVC). The contingency condition of single and three phase ground fault is created to study the rotor angle behavior of the system. The system will go-out of synchronization and the condition of voltage instability alert will generate. The stability analysis is carried-out for the six-cycle system fault; hence FACTS controller is installed. Fault is a frequently occurring contingency condition and it creates a sever voltage stability conditions. An SVC which is a static compensator is installed in this work to retain the system stability. Test results are presented and compared for with and without SVC installed. A load flow study is also carried out to analyse the bus voltage and angle for the system buses under the contingency condition.

Keywords - Contingency Analysis, Flexible AC Transmission System (FACTS), Power System Stabilizer (PSS), Static Var Compensator (SVC), Voltage Stability.

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I. INTRODUCTION

The Modern Power System (MPS) is always at a verge of stability issues. It is always stressed and surmounted by the versatile load characteristics which are a big threat to its stability. Moreover, the behaviour of the MPS is gradually changing due to high integration power converters for Power Quality (PQ) assessment as well as for hybrid generation interfacing. Hence it is always advisable to carry out the stability analysis of MPS [1]. Stability is the condition of maintaining normal operating conditions when subjected to disturbances. Power system disturbances may be small or large. Small disturbances generate perturbation in machine torque and the excitation system can take care of it and can retain rotor angle stability. Large disturbances create transient stability condition which is a sever threat to the power system. If transient stability is not checked and restore it can result is switching action of concern circuit breaker whose severe consequences will be complete blackout of the electric grid. Hence stability analysis is utmost important [2].

Seeing to the severity of instability in power system, numerous devices are been foresighted in literature to retain the stability under dynamic operating conditions [3]. Earlier static compensators like synchronous generators, capacitors or reactors were used depending upon the type of instability conditions. These static compensators are either mechanically switched or are of fixed type which not solve the problem efficiently or even they can worsen if they are of fixed type under normal operations [4]. Then the era of power converters or automatically switched controller with thyristors or semiconductor-based devices came into existence which can be connected automatically as per the system conditions. The more advanced form of these types of converters which are widely adopted in MPS transmission side is FACTS controllers [5,6].

This paper presents the performance analysis of one such FACTS controller named SVC. SVC stands for Static Var Compensator which is semiconductor based used to restore the condition of transient stability when subjected to large system disturbances. In this work condition of power system faults both single and three phase faults are analysed as the contingency condition and the stability analysis is carried out with and without SVC. One more tool named as Power System Stabilizer is also used to retain stability.

II. POWER SYSTEM STABILITY

In the previous section power system stability is defined which can be elaborated as the condition of normal operation of all the MPS elements with stable equilibrium even though it is subjected to the contingency [7]. Contingency is a common term given to all type of abnormal operating condition of MPS like; faults, sudden load variations, switching in off high power devices, integration of high rating power converters, high penetration of renewable resources, etc. all these events have different operating states and may lead to various stability issues which are presented in figure 1 [8].

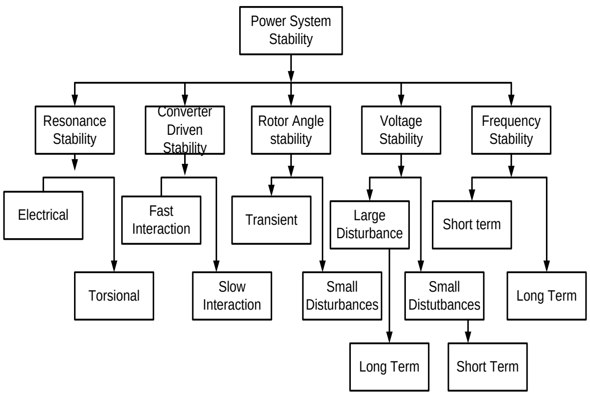

Fig. 1 Classification of Stabnility in MPS

The term resonance stability is related with subsynchronous resonance (SSR), it can be either associated with an entirely electrical resonance or with an electromechanical. The SSR, can manifest in two possible forms: (i) due to a resonance between series compensation and the mechanical torsional frequencies of the turbine-generator shaft, and (ii) due to a resonance between series compensation and the electrical characteristics of the generator [9].

In MPS a new class of stability is introduced due to wide spread use of power converters. these converters use both DC and AC power for their operation and generates harmonics due to continues AC-DC or vice-versa conversion. These harmonic degrades the PQ of the system and generates stability issues due to changes in the flows on major tie-lines, which may in turn affect damping of inter-area modes and transient stability margins.

Rotor angle stability is the ability of the interconnected MPS with multi-machines connected to remain in synchronism under normal operating conditions and to regain synchronism after being subjected to a trivial or huge contingencies [10].

The job-tenure of a power engineer is spent in maintaining the voltage stability of the MPS. Since the MPS is heavily stressed and always undergoes the events which results in the condition of instability. The voltage stability may be small signal which can be overruled using available transmission capability enhancement or short duration load shedding. For restoring the transient instability compensation devices are installed.

The condition of frequency instability occurs when the system undergoes deviation in frequency. In transmission system the allowable frequency deviation is ±3%. More than this frequency restoration measures needed such as; (i) the initial inertial response of synchronous generators, (ii) the primary frequency response of generators and load damping, and (iii) automatic generation controls bringing the frequency back to its nominal value.

This paper focuses on the restoration of voltage stability when subjected to large disturbances of single and three line to ground faults.

III. STATIC VAR COMPENSATOR

SVC is a shunt connected FACTS device whose inductive and capacitive current in output can be controlled in accordance to the AC voltage of the connected system. The thyristor valves used in SVC are rated for lower voltages as the SVC is connected to an EHV line through a step-down transformer. [11] The application of SVC was initially for load compensation of dynamically changing loads such as arc furnaces and frequency converter transformers. Its wide application in transmission compensation were commenced in five decades ago [12]. The main objective so SVC are:

- To improve the MPS stability with DVR.
- Damping of low frequency oscillations due to rotor swing.
- Controlling of dynamic overvoltage in the system.

- Damping of SSR due to torsional modes.
- Improving the power transfer capability in long transmission lines.

The SVC regulates voltage by controlling the amount of reactive power injected into when deficient or reactive power absorb when surplus in the power system. An SVC is a parallel combination of controlled reactor and fixed shunt capacitor. The single line diagram of typical SVC connected in transmission system is shown in figure 2 [13]. The main operational principle of SVC is to compensate for reactive power demand of the system when and where needed. Hence its zone of applications promptly listed as regulation of voltage, stability restoration under the condition of transient instability and harmonic mitigation [14]. In comparison to other compensating devices SVC has simple control architecture and can be easily implemented and has numerous advantages which includes reduced transmission losses, enhance power factor, low interference, wide ranged voltage control, etc.

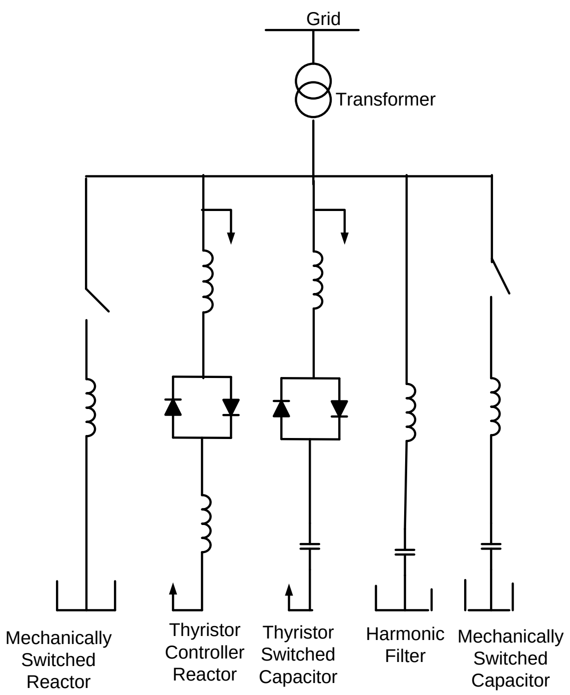

Fig. 2 Schematic of SVC method

An SVC is a source of controlled reactive-power which is dedicatedly designed to provide the required reactive-power both absorption and generation by means of controlled switchable reactor and capacitors. The exchange of reactive power between the SVC and the AC power system can be controlled by varying the amplitude of the three-phase output voltage, of the SVC. That is, if the amplitude of the output voltage is increased above that of the utility bus voltage level, then a current flows through the reactance from the compensator to the AC system and the converter generates capacitive-reactive power for the ac system. If the amplitude of the output voltage is decreased below the utility bus voltage level, then the current flows from the ac system to the converter and the compensator absorbs surplus-reactive power from the AC system [15]. If the output voltage equals the ac system voltage, the reactive-power exchange becomes zero, in which case the SVC is said to be in a floating state, which can be explained via equation (1)-(3);

$$I_{GRID} = \frac{V_{SVC} - V_{GRID}}{X} \quad (1)$$

$$Q = \frac{V^2{}_{SVC} - V_{AC} V_{GRID} Cos\alpha}{X} \quad (2)$$

$$P = \frac{V_{AC} V_{GRID} Sin\alpha}{X} \quad (3)$$

Where, V_{SVC}, V_{GRID}, and α are output voltage of SVC, grid voltage and firing angle of SVC respectively.

IV. SIMULATION RESULTS

In this work performance analysis of two-machine power system is presented for single and three phase to ground fault. When the system suffers this contingency, its stability is in alert state. The faults whether symmetrical or unsymmetrical, creates the condition of transient instability due to large disturbances. As soon as the fault occurs MPS witnesses the alert state and if fault is not cleared soon the system will reach the emergency state and its stability is threatened. If the fault still persists, then the system break down will occur and the shutdown of the synchronous generator will lead to the condition of blackout. Hence to restore stability fault must be cleared as soon as possible and simultaneously compensation must be provided to retain the voltage stability.

In this work SVC is installed in transmission system to restore the stability under the contingency of fault. The complete simulation model of the system under study is shown in figure 3. The detailed model of the SVC is shown in figure 4. The test system is consisting of two salient pole synchronous machine with voltage level 13.8 KV and 1000MVA short circuit capacity followed by two step down transformers with 13.8 kV/500 kV voltage level. The bus connected at machine terminals are named as M1 and M2. Other than these three buses are more connected namely B1, B2 and B3. To analyse the stability behaviour of the system, firstly Single Line-Ground Fault (SLGF) is created at bus B1 and then Three-Line-Ground Fault (TLGF). Under the contingency condition of faults, the effect of SVC is studied and the load flow analysis is also carried out for pre fault and post fault condition. Also, the system stability without SVC and with SVC is also presented. The SVC is connected at B2 and a linear load of 500MW is connected at B3.

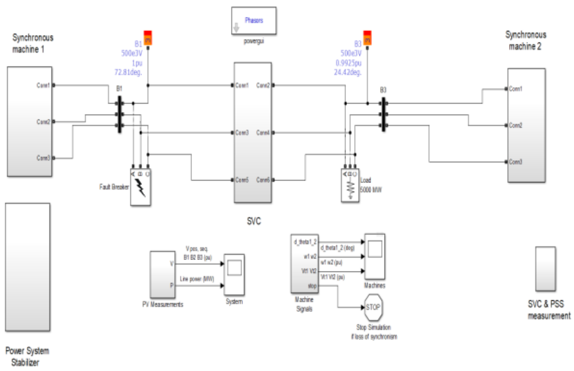

Figure 3 Simulation model of the two machine system under study

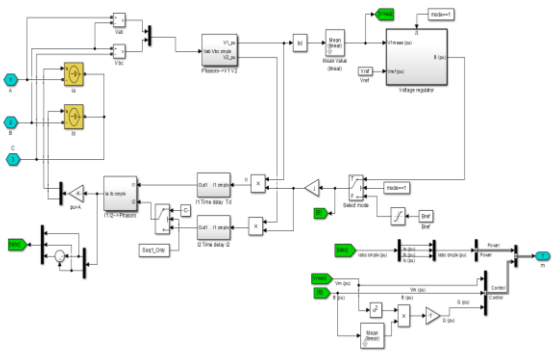

Figure 4 Simulation model of SVC

For stable operating condition the bus voltages are stable and 1 Per Unit (PU) as shown in figure 5 with constant required power flow of 900MW. A SLGF is triggered at 5 sec. and continues to 5.1 sec, but after the fault clearance also the system continues to oscillate and looses its stability as shown in figure 6. As the fault occurs at 5 sec, voltage at buses fluctuates and system tries to maintain stability but the bus voltages continue to oscillate. At this condition Power System Stabilizer (PSS) is switched in and the system regain its stability at 6 second after the fault clearance as shown in figure7.

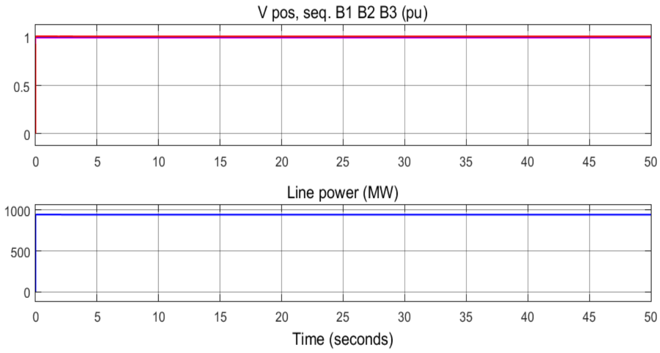

Figure 5 Bus voltages and line power under stable conditions

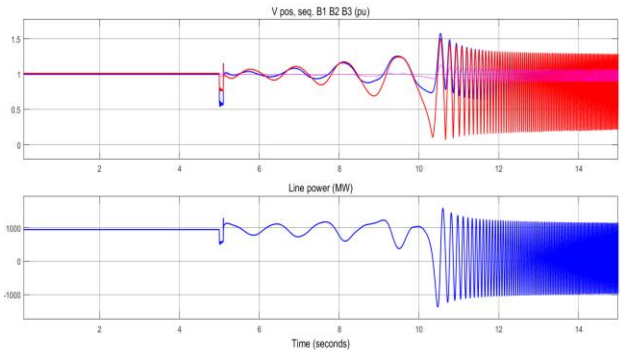

Figure 6 Bus voltages and line power under single line-ground fault without compensation

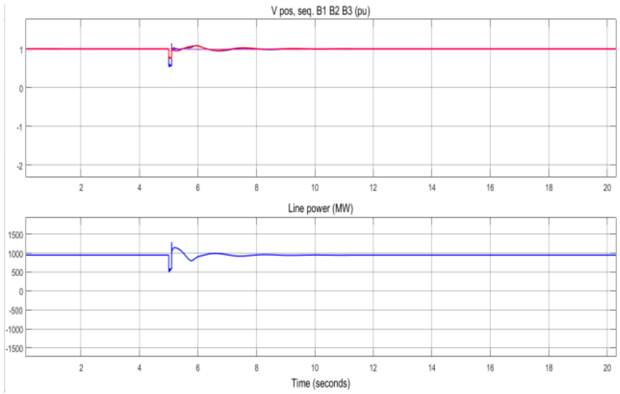

Figure 7 Bus voltages and line power with power system stabilizer

Further analysis is carried out under the condition of TLGF. A TLGF is connected at B2 and the voltage and line power under this condition is shown in figure 8. As soon as TLGF connected system voltages deviates from 1 PU and tries to settle down, but system goes out of synchronism and looses its stability. The rotor angle deviates to infinity, the rotor speed w1 and w2 of the two machines fluctuates exceptionally out of synchronism and the turbine voltages Vt1 and Vt2 continues to oscillate as shown in figure 9. Hence system reaches the emergency state. Even stability is not retained by PSS hence SVC is connected to maintain system stability. As soon as SVC is connected the system retains its stability within 1 sec. fault occurred at 5 sec at cleared at 5.1 sec. SVC stabilizes the system parameters within 6sec after fault clearance. Figure 10 shows the bus voltages and line power after the TLGF is cleared and SVC retains the system stability. The voltage gets stabilize within 3cycles of oscillations. The rotor angle retains to a fixed value of 60^o after some fluctuations, speeds W1 and W2 of the rotors of the two machines also retains to 1PU and the terminal voltages of the turbines of the machine is also fixed to 1 PU as shown in figure 11. The SVC response characteristics is shown in figure 12.

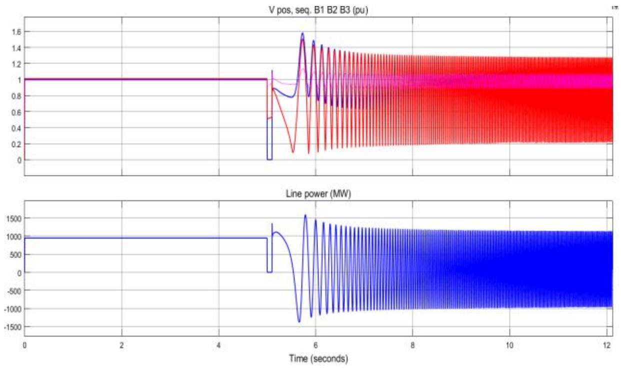

Figure 8 Bus voltages and line power under three line-ground fault without compensation

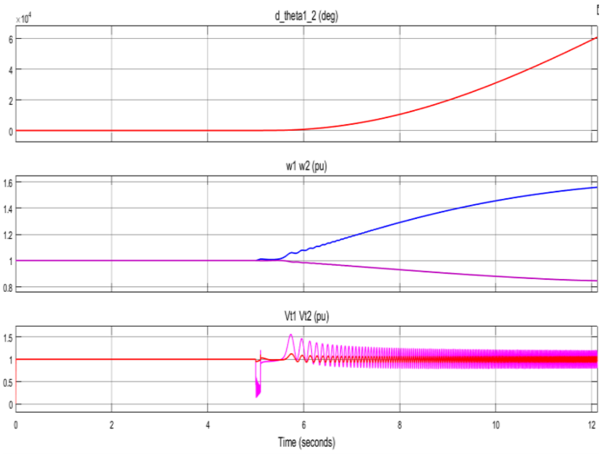

Figure 9 Rotor angle, rotor speed and turbine voltages of two machines without SVC

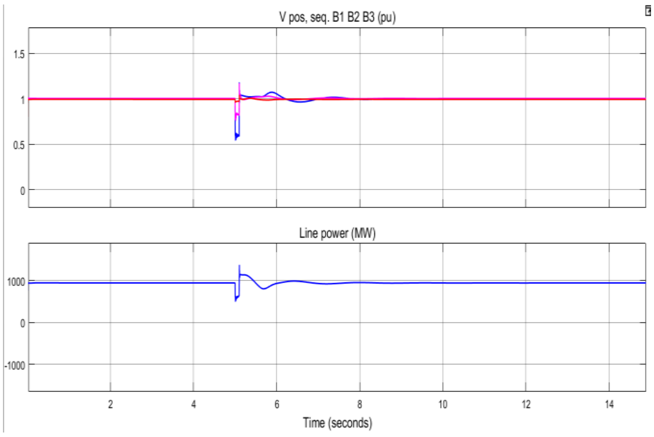

Figure 10 Bus voltages and line power under TLGF with SVC

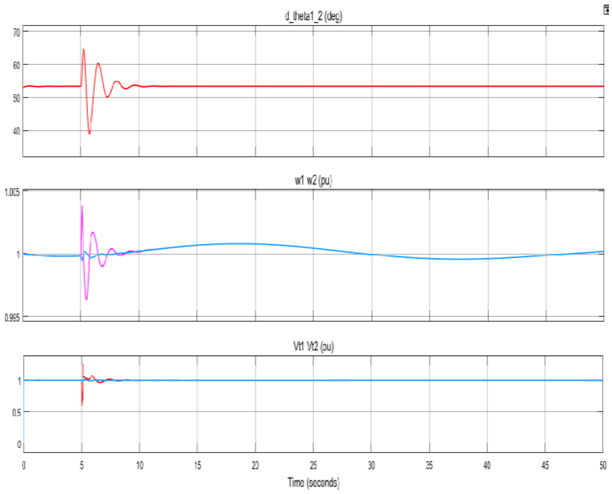

Figure 11 Rotor angle, rotor speed and turbine voltages of two machines with SVC

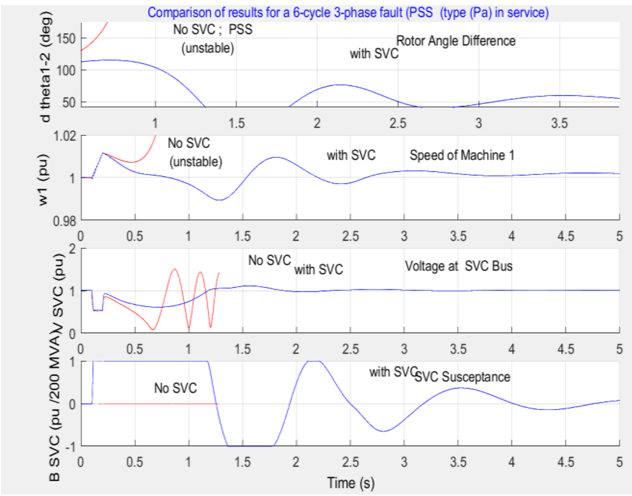

Figure 12 SVC characteristics

V. CONCLUSION

The MPS suffers from contingencies like faults in transmission line. Faults effects the system stability badly. The voltage fluctuates and witnesses the undamped oscillations, the roto of the synchronous generators go out of synchronism and condition of resonance occurs. If these conditions are not taken care immediately this will leads to the emergency state and MPS may witness the complete blackout. In this paper SVC is installed to retain the system stability under various continency condition. It is widely adopted type of FACTS controller used in transmission to supply or observe the reactive power of the system in order to retain stability. It helps in maintaining system voltage, prevent the rotor angle to deviate from its fixed value hence retain the rotor angle stability and fast restoration of the system is possible with its application which is proved in this paper. From the results presented it can be seen that without SVC system is unstable, rotor angle varies widely which leads the condition of out of synchronization of machines. Hence SVC is preferred choice which is also simple to design and implement.

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