IMPROVING DAMPING OF POWER SYSTEM OSCILLATIONS USING AN SVC

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ABSTRACT:

In today's practical power systems, the small-signal instability, mainly caused due to insufficient damping of system oscillations, has become a serious threat for the stable operation. This paper discusses the application of a Static Var Compensator (SVC), used for supporting the voltage in a system, to enhance power system small-signal stability. A power system consisting of a generating station and an infinite bus (large system) connected by a high voltage transmission line is used in this study to demonstrate the application of an SVC to improve small-signal stability. The SVC considered is installed at a sub-station at the middle of the transmission line to improve the voltage profile in the system. The EMTDC/PSCAD Transient Simulation Software is used in this study to model the system and controllers under consideration. Simulations performed under different disturbances revealed the presence of poorly damped oscillations in the system; especially, there are very poorly damped oscillations in the power flow in the transmission line. A feedback loop is incorporated to the SVC control system to improve the damping of system oscillations. The simulation results are presented to reveal the successful application of the SVC to improve small-signal stability of the power system.

INTRODUCTION

When a disturbance occurs in a power system the system may become unstable. The disturbance in the power system may be small or large. The small signal or small disturbance stability is the ability of the power system to maintain synchronism under small disturbances. Instability in an interconnected power system can be of two forms [1]:

(a) Steady increase in rotor angle due to lack of sufficient synchronizing torque - Aperiodic drift
(b) Rotor oscillations of increasing amplitude due to lack of sufficient damping torque - Oscillatory instability.

In today's practical interconnected power systems, the small signal stability is mainly a problem due to insufficient damping of oscillations. Most power systems have experienced problems due to this [1,2]. We can identify four types of small signal stability oscillations [1]:

(a) Local modes: Associated with the swinging of units at a generating station with respect to the rest of the power system
(b) Inter- area modes: Associated with the swinging of many machines in one part of the power system against machines in other parts
(c) Control modes: Associated with controls of generating units and other equipment.

(d) Torsional modes: Associated with the turbine generator shaft system rotational components.

Most electric power supply utilities are facing a great challenge in meeting the increased load demand. In addition, they are expected to have highest reliability and minimum transmission expenditure. Moreover, there are significant difficulties in acquiring right of way for new transmission circuits. Therefore, enhancement of the power transfer on existing transmission facilities is now of great interest. However, it should not reduce the security of operation and stability margins of the systems. In this regard, many practical power systems use Static Var Compensators (SVCs) to improve power transfer levels while maintaining power system stability requirements [1,3,4].

Basic objectives in introducing SVCs to power systems are:
(a) Maintain network voltage profile near to the rated value
(b) Increase power transmission capability
(c) Enhance system transient stability
(d) Improve damping of system oscillations.

This paper attempts to address the issue of improving the damping of small signal oscillations in power systems using an existing SVC which is implemented mainly for maintaining network voltage. The paper presents a simple classical auxiliary controller, which is added to the existing SVC control system to improve damping of system oscillations.

STATIC VAR COMPENSATOR (SVC)

SVCs have the ability to affect the active and reactive power flow by influencing the voltage profile of a power system. Important properties of the SVC's are:
(a) Ability to maintain a substantially constant voltage at its terminals by continuous adjustment of the reactive power it interchanges with the power system
(b) Speed of response.

In practice, there are different types of Static Var Compensators. Static means that unlike the synchronous condenser (which is also used to supply reactive power to the systems and maintain voltage), they have no moving parts. They are used to improve power factor and correct phase unbalance in addition to the objectives mentioned earlier.

Most widely used configurations of SVC are as follows:
(a) Thyristor Controlled Reactor with Fixed Capacitors (TCR-FC)
(b) Thyristor Controlled Reactor with Thyristor Switched Capacitors (TCR-TSC).

TCR-FC Type

A single line schematic diagram of a Thyristor Controlled Reactor with Fixed Capacitor (TCR-FC) is given in Figure 1 below.

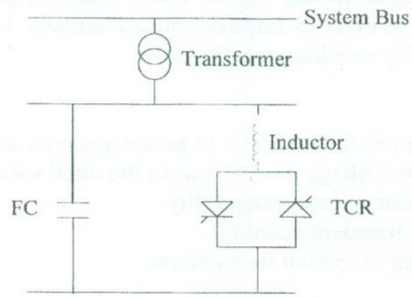

Figure 1

The controlling element of the TCR is a thyristor controller. There are two oppositely poled thyristors, which conduct on alternate half cycles of the system voltage waveform. The TCR current can be varied continuously, without steps, between zero and a maximum value corresponding to full conduction by changing the firing angle of the thyristors. The current is always lagging, so that reactive power can only be absorbed. However, TCR can be biased by the fixed capacitor (FC), so that, its overall power factor is leading and reactive power is generated and supplied into the external system. This type of SVC is used in many power systems in the world (e.g. Hydro Quebec system in Canada). But, this type is not preferred now as method of switching capacitors is less flexible than TCR-TSC.

TCR-TSC Type

A single line schematic diagram of a Thyristor Controlled Reactor with Thyristor Switched Capacitors (TCR-TSC) is given in Figure 2.

The controlling elements of TCR and TSC are thyristor controllers. TCR is same as the TCR in TCR-FC type SVC. TSC consists of several banks of shunt capacitors, each of which is connected or disconnected as needed by thyristor switches. With the present day technology (especially, with the development of power electronics), the TCR-TSC type SVC is preferred because of the flexibility in control. This type is used in the studies presented in this paper.

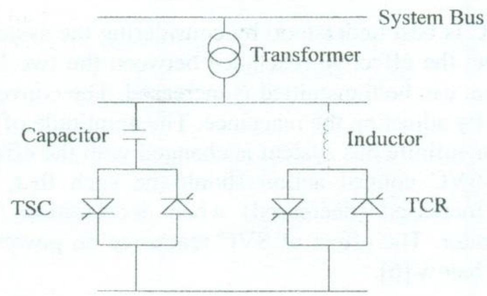

Figure 2

The SVC Model used in Simulation Studies

EMTDC/PSCAD power system simulation software is utilized for developing the systems and controllers in this study. The SVC model available in this software (SVC 400 model [5]) is utilized. This model is primarily that of a Thyristor Controlled Reactor (TCR) and a Tyristor Switched Capacitor (TSC). The SVC transformer is modeled by six single phase transformers, primaries connected in star and the secondaries in star and delta. The TCR elements are connected in delta and the thyristor switches are modeled as changing resistance. The TSC branches are modeled as capacitors. Regardless of the number of TSC branches/stages in operation at a given time, all of these are represented together as an equivalent single capacitor per phase.

TEST SYSTEM AND ITS BEHAVIOUR

The test system model used for demonstrating the use of an SVC to enhance damping of system oscillations consists of a hydro power station at one end and a large power system (infinite bus) at the other end (as shown in Figure 3).

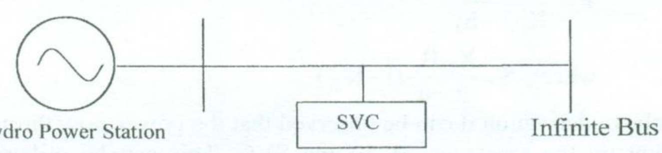

Figure 3

The two ends are connected with a 500 kV, three phase line 600 km in length. A substation is located at the middle of this line for the installation of the SVC. Under normal operating condition the system is stable and the power is transferred from the generator to the large power system.

The effect of the SVC is best understood by considering the system above. When the SVC is capacitive, the effective reactance between the two buses is reduced and the real power that can be transmitted is increased. The converse is true when the SVC is inductive by adjusting the reactance. The amplitude of the power angle curve of the generator-infinite bus system is changed with the effective reactance. The change in the SVC control action should be such that, the transmitted electrical power is increased (decreased) when deceleration (acceleration) is required in the generator. The effect of SVC reactance on power flow along the line can be shown as below [6]:

Each half of the line in the test system given in Figure 3 is represented by its π - equivalent circuit (as given in Figure 4 below).

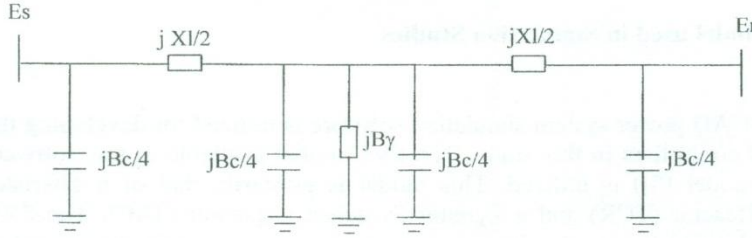

Figure 4

The capacitive shunt susceptances, Bc/4 connected at the ends can be omitted from the analysis if the terminal synchronous machine and infinite bus absorb their reactive power at all times. Then the degree of compensation for the central half is given by,

$$K_m = \frac{B_\gamma}{\frac{1}{2}B_c}$$

where, B_γ is the compensating susceptance of SVC, K_m is arbitrarily taken as positive if B_γ is inductive, negative if B_γ is capacitive and unity when $B_\gamma = B_c/2$. B_c is Shunt susceptance of the whole line.

The active power transmission through the line is

$$P = \frac{E_s E_r \operatorname{Sin}\delta}{X_l(1-S)}$$

$$\text{where, } S = \frac{X_l}{2}\frac{B_c}{4}(1-K_m).$$

From the above derivation it can be observed that the power flow through the line is dependent on the reactance, B_γ of the SVC. This can be utilized to damp oscillations in the power system by adding an auxiliary control loop to the SVC control system.

SVC CONTROL LOOP

A diagram of the structure of the SVC controls is given in the Figure 5 below.

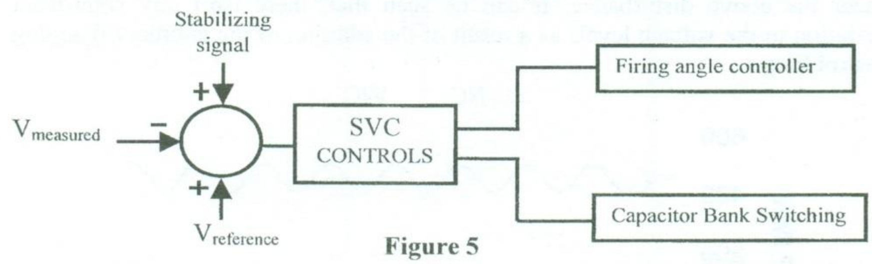

Figure 5

As shown above, a stabilizing signal is added to the voltage reference signal ($V_{reference}$) of the SVC to improve damping of system oscillations.

DAMPING CONTROL LOOP

In this study, the stabilizing control signal is derived in response to the speed deviations (frequency deviations) of the hydro generator. The control block diagram of this stabilizing loop is given in Figure 6. The speed signal is initially passed through a Washout Filter to avoid any detrimental effects due to the changes in the system steady state operating condition. A proportional and derivative controller is utilized to derive the stabilizing signal. In this case, a trial and error approach is utilized to find suitable values for the proportional gain (K_P) and derivative gain (K_D).

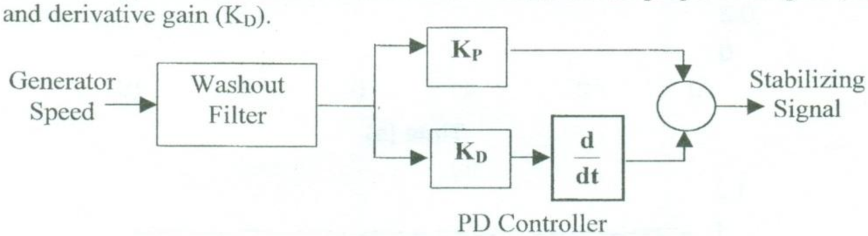

Figure 6

SIMULATION RESULTS

The system response without auxiliary damping control unit and with the auxiliary control loop under different disturbance conditions is observed. It is found that, the response without the auxiliary control unit becomes unstable due to the poorly damped oscillations. For example, the Figure 7 gives the system response when a line to ground short circuit fault occurs on Phase A of the three phase transmission circuit at a point close to the SVC.

As shown in Figure 7 (a), the power flow in the transmission line oscillates after the disturbance (curve NC) without the auxiliary damping controller. But, the damping of the oscillations in power flow significantly improves when the auxiliary damping controller is included (curve WC).

The system voltages are also observed to check whether there is any detrimental effect due to the addition of the damping controller. The voltage at the generator end (V_{SE}) and at the SVC (V_{MP}) are given in Figures 7(b) and 7(c) respectively, under the above disturbance. It can be seen that, there isn't any significant deviation in the voltage levels as a result of the addition of the auxiliary damping control loop.

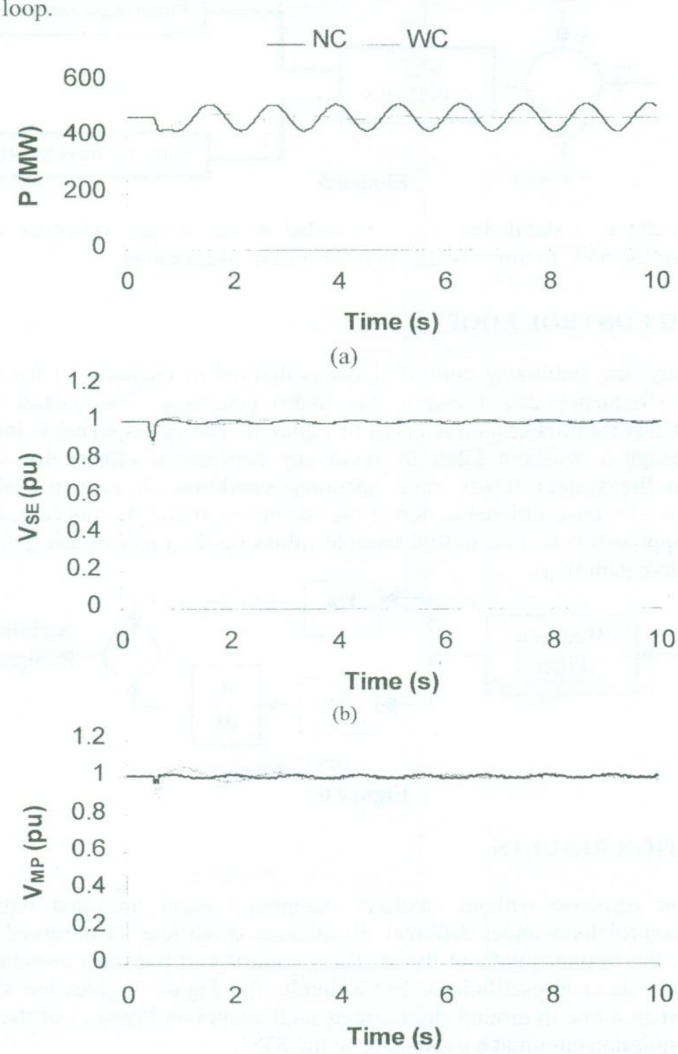

Figure 7

CONCLUSIONS AND DISCUSSION

The use of a Static Var Compensator (SVC) to improve damping of oscillations in power systems has been presented. The presented approach consists of addition of an auxilliary control loop to the existing controls of an SVC. The simulation results using EMTDC/PSCAD power system simulation software for a simple test system revealed the success of modulation control of an SVC to improve damping of system oscillations.

The presented control loop for deriving the stabilizing signal had speed as the feedback signal. In practice, this requires a reliable fast communication link since the SVC is located at a significant distance from the generating station. Therefore, it would be economical and also reliable if a locally available signal such as the power flow or current flow in the line at the SVC can be chosen as the feedback signal.

In addition, the presented Proportional and Derivative (PD) controller gains (K_P and K_D) were chosen by following a trial and error approach. This may be time consuming and also may lead to unsatisfactory system operation at different operating conditions. Hence, a suitable mathematical procedure should be developed for tuning the controller gains.

Moreover, the proposed stabilizing control loop is based on classical control techniques. Modern controllers such as Fuzzy Logic or Optimal Control may perform better than a classical controller under different operating conditions and large system disturbances.

The above mentioned issues should also be addressed when implementing practical stabilizing control loops. Authors are expecting to perform further studies to address these issues under this research project and also to extend the investigations for large interconnected systems.

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