SVC Application for Stability Improvement of Multi Machine Power System

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Abstract: This paper presents the application of Static Var Compensator (SVC) to stability improvement in a multi-machine electric power system installed with SVC. A adaptive supplementary stabilizer based on SVC is designed. To show effectiveness of SVC in damping oscillations, different disturbances are applied and simulated. The adaptive stabilizer is compared with a conventional stabilizer. Several nonlinear time-domain simulation tests visibly show the ability of SVC in damping oscillations.
[Mojtaba Shirvani , Ahmad Memaripour , Mostafa Abdollahi , Asadollah Salimi . **SVC Application for Stability Improvement of Multi Machine Power System.** *Life Sci J* 2012;9(4):3944-3948]. (ISSN: 1097-8135). http://www.lifesciencesite.com. 588

Keywords: Static Var Compensator, Low Frequency Oscillations, Multi Machine Electric Power System, Adaptive Control.

1. Introduction

The ability of synchronous machines of an interconnected power system to remain synchronism after being subjected to a small disturbance is known as small signal stability that is subclass of phase angle related instability problem. It depends on the ability to maintain equilibrium between electromagnetic and mechanical torques of each synchronous machine connected to power system. The change in electromagnetic torque of synchronous machine following a perturbation or disturbance can be resolved into two components: (i) a synchronizing torque component in phase with rotor angle deviation and (ii) a damping torque component in phase with speed deviation. Lack of sufficient synchronizing torque results in non-oscillatory instability; where lack of damping torque results in low frequency oscillations.

Low frequency oscillations are generator rotor angle oscillations having a frequency between 0.1 -2.0 Hz and are classified based on the source of the oscillation. The root cause of electrical power oscillations are the unbalance between power demand and available power at a period of time. In the earliest era of power system development, the power oscillations are almost non observable because generators are closely connected to loads, but nowadays, large demand of power to the farthest end of the system that forces to transmit huge power through a long transmission line, which results an increasing power oscillations.

The phenomenon involves mechanical oscillation of the rotor phase angle with respective to a rotating frame. Increasing and decreasing phase angle with a low frequency will be reflected in power transferred from a synchronous machine as phase angle is strong coupled to power transferred. The LFO can be classified as local and inter-area mode.

Local modes are associated with the swinging of units at a generating station with respect to the rest of the power system. Oscillations occurred only to the small part of the power system. Typically, the frequency range is 1-2 Hz.

Inter-area modes are associated with swinging of many machines in one part of the system against machines in other parts. It generally occurs in weak interconnected power systems through long tie lines. Typically frequency range is 0.1-1 Hz.

With regard to the proposed LFO, many methods have been investigated to damp out such oscillations in power systems. Recently, with development of flexible AC transmission system (FACTS) devices, these devices have been widely used to damp out the oscillations [1-5].With the practical applications of converter-based FACTS controllers such as the static synchronous compensator (STATCOM), static synchronous series compensator (SSSC) and unified power- flow controller (UPFC), modeling and analysis of these FACTS controllers in power-system operation and control is of great interest. Power-flow calculations are fundamental to the operation, planning and control of power systems. In recent years, significant work has been done in the modeling of the FACTS controllers in power flow and optimal-power-flow studies [6-11].

The ultimate objective of applying reactive shunt compensation such as SVC in a transmission system is to increase the transmittable power. This may be required to improve the steady-state transmission characteristics as well as the stability of the system. Var compensation is thus used for voltage regulation at the midpoint (or some intermediate) to segment the transmission line and at the end of the (radial) line to prevent voltage instability, as well as for dynamic voltage control to increase transient stability and damp power oscillations.

The objective of this paper is to investigate the ability of SVC for dynamic stability improvement via damping low frequency oscillations. A multi machine power system installed with a SVC is considered as case study. The advantages of the proposed methods are their feasibility and simplicity. Different load conditions are considered to show effectiveness of SVC. Simulation results show the validity of SVC in stability improvement at large electric power systems.

2. System under study

Figure 1 shows a multi machine power system installed with SVC. Detail of the system data are given in [12]. In this paper, turbine-governor system is also modeled to eliminate steady state error of responses.

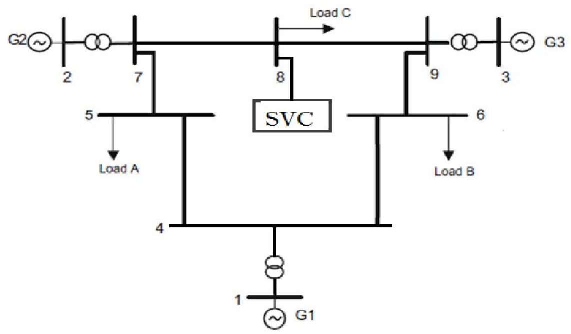

Figure 1. Multi-machine electric power system installed with SVC

2.1. SVC model

The SVC is implemented as a time constant regulator to voltage support as depicted in Figure 2. In this model, a total reactance b_{SVC} is assumed and the following differential equation holds [13]:

$$\dot{b}_{SVC}=\left(K_r\left(V_{ref}-V\right)-b_{SVC}\right)/T_r \quad (1)$$

The model is completed by the algebraic equation expressing the reactive power injected at the SVC node [13]:

$$Q=-b_{SVC}V^2 \quad (2)$$

The regulator has an anti-windup limiter, thus the reactance b_{SVC} is locked if one of its limits is reached and the first derivative is set to zero [13].

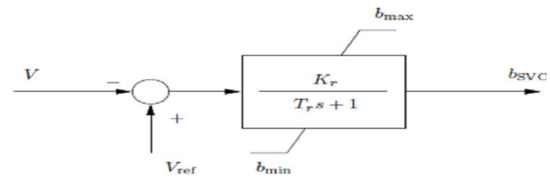

Figure 2. SVC model as a time constant regulator

2.2. Dynamic model of the system with SVC

The nonlinear dynamic model of the system installed with SVC is given as (3). The dynamic model of the system is completely presented in [12] and also dynamic model of the system installed with SVC is presented in [13]. By controlling b_{SVC}, the output reactive power of the shunt compensator is controlled.

$$\begin{cases}\dot{\omega}=\left(P_m-P_e-D\omega\right)/M\\ \dot{\delta}=\omega_0\left(\omega-1\right)\\ \dot{E}_q'=\left(-E_q+E_{fd}\right)/T_{do}'\\ \dot{E}_{fd}=\left(-E_{fd}+K_a\left(V_{ref}-V_t\right)\right)/T_a\\ \dot{V}_{dc}=\dfrac{3m_E}{4C_{dc}}\left(\sin(\delta_E)I_{Ed}+\cos(\delta_E)I_{Eq}\right)\end{cases} \quad (3)$$

3. Model Reference Adaptive System

The general idea behind Model Reference Adaptive Control (MRAC) or Model Reference Adaptive System (MRAS) is to create a closed loop controller with parameters that can be updated to change the response of the system. The output of the system is compared to a desired response from a reference model. The control parameters are update based on this error. The goal is for the parameters to converge to ideal values that cause the plant response to match the response of the reference model. Figure 3 shows the general diagram of MRAS [14].

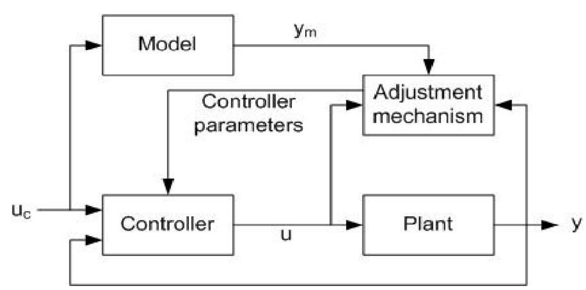

Figure 3. General diagram of MRAS

The idea behind MRAS is to create a closed loop controller with parameters that can be updated to change the response of the system to match a desired model. There are many different methods for designing such a controller. This tutorial will cover design using the MIT rule in continuous time. When designing an MRAS using the MIT rule, the designer chooses: the reference model, the controller structure and the tuning gains for the adjustment mechanism. MRAS begins by defining the tracking error, *e*. This is simply the difference between the plant output and the reference model output [14]:

$$e = y_{plant} - y_{model} \tag{4}$$

From this error a cost function of *theta* (*J(Θ)*) can be formed. *J* is given as a function of theta, with theta being the parameter that will be adapted inside the controller. The choice of this cost function will later determine how the parameters are updated. Below, a typical cost function is displayed.

$$J(\theta) = \frac{1}{2}e^2(\theta) \tag{5}$$

To find out how to update the parameter *theta*, an equation needs to be formed for the change in *theta*. If the goal is to minimize this cost related to the error, it is sensible to move in the direction of the negative gradient of *J*. This change in *J* is assumed to be proportional to the change in *theta*. Thus, the derivative of *theta* is equal to the negative change in *J*. The result for the cost function chosen above is:

$$\frac{d\theta}{dt} = -\gamma\frac{\delta J}{\delta\theta} = -\gamma e\frac{\delta e}{\delta\theta} \tag{6}$$

This relationship between the change in theta and the cost function is known as the MIT rule. The MIT rule is central to adaptive nature of the controller. Note the term pointed out in the equation above labeled "sensitivity derivative". This term is the partial derivative of the error with respect to *theta*. This determines how the parameter *theta* will be updated. A controller may contain several different parameters that require updating. Some may be acting n the input. Others may be acting on the output. The sensitivity derivative would need to be calculated for each of these parameters. The choice above leads to all of the sensitivity derivatives being multiplied by the error. Another example is shown below to contrast the effect of the choice of cost function:

$$J(\theta) = |e(\theta)|$$

$$\frac{d\theta}{dt} = -\gamma\frac{\delta e}{\delta\theta_c}\operatorname{sign}(e)$$

where (7)

$$\operatorname{sign}(e) = \begin{cases} 1, & e > 0 \\ 0 & e = 0 \\ -1 & e < 0 \end{cases}$$

To see how the MIT rule can be used to form an adaptive controller, consider a system with an adaptive feed word gain. The block diagram is given as Figure 4. The plant model can be given as (8).

$$\frac{Y(s)}{U(s)} = kG(s) \tag{8}$$

The constant *k* for this plant is unknown. However, a reference model can be formed with a desired value of *k*, and through adaptation of a feed forward gain, the response of the plant can be made to match this model. The reference model is therefore chosen as the plant multiplied by a desired constant k_o:

$$\frac{Y(s)}{U_c(s)} = k_o G(s) \tag{9}$$

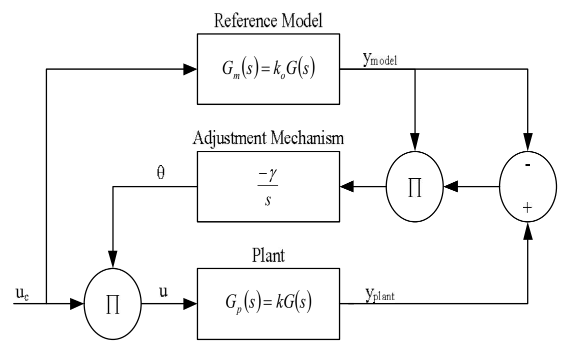

Figure 4. Adaptive feed forward gain

The same cost function as above is chosen and the derivative is shown:

$$J(\theta) = \frac{1}{2}e^2(\theta) \rightarrow \frac{d\theta}{dt} = -\gamma e\frac{\delta e}{\delta\theta} \tag{10}$$

The error is then restated in terms of the transfer functions multiplied by their inputs.

$$e = y - y_m = kGU - G_m U_c = kG\theta G_c - k_o G U_c \tag{11}$$

As can be seen, this expression for the error contains the parameter *theta* which is to be updated. To determine the update rule, the sensitivity derivative is calculated and restated in terms of the model output:

$$\frac{\delta e}{\delta\theta} = kGU_c = \frac{k}{k_o}y_m \tag{12}$$

Finally, the MIT rule is applied to give an expression for updating *theta*. The constants *k* and *ko* are combined into *gamma*.

$$\frac{d\theta}{dt} = \gamma'\frac{k}{k_o}y_m e = -\gamma y_m e \tag{13}$$

The block diagram for this system is the same as the diagram given in Figure 4. To tune this system, the values of *ko* and *gamma* can be varied [14].

4. Stabilizer design

4.1. Adaptive stabilizer

To get a suitable performance and tracking characteristics, a reference model should be adopted for MRAS system. In this paper, since the SVC supplementary stabilizer is a regulatory controller, thus, the reference model should have a regulatory nature. In this regard, the reference model is defined as below;

$$y = \frac{0.02s(s\ \ +1.1)}{s^2 + 3s + 2}u \tag{14}$$

4.2. Conventional stabilizer

In order to comparison, a conventional stabilizer is designed based on SVC. The transfer function model of a conventional stabilizer is as (15). This model contains two lead–lag compensators with time constants, T_1–T_4 and an additional gain K_{DC}. The parameters of the proposed stabilizer are tuned by using GA. The detailed procedure of stabilizer design by using optimization methods can be found in [15]. The proposed stabilizer is obtained as Table 1.

$$U_{out} = K_{DC}\frac{ST_W}{1+ST_W}\frac{1+ST_1}{1+ST_2}\frac{1+ST_3}{1+ST_4}\Delta\omega \tag{15}$$

Table 1. Optimal parameters of conventional stabilizer

Parameter	K_{DC}	T_1	T_2	T_3	T_4
Optimal value	9.71	0.23	0.05	0.64	0.1

5. Results and discursions

In this section, the designed adaptive stabilizers are simulated on the test system. A scenario of fault is considered as 6 cycle three phase short circuit in bus 9. The simulation results are presented in Figs. 5-7. Each figure contains two plots: adaptive stabilizer (solid line) and conventional stabilizer (dashed line). It is clearly seen that the adaptive stabilizer is very stronger than conventional stabilizer and can successfully damp out the oscillations.

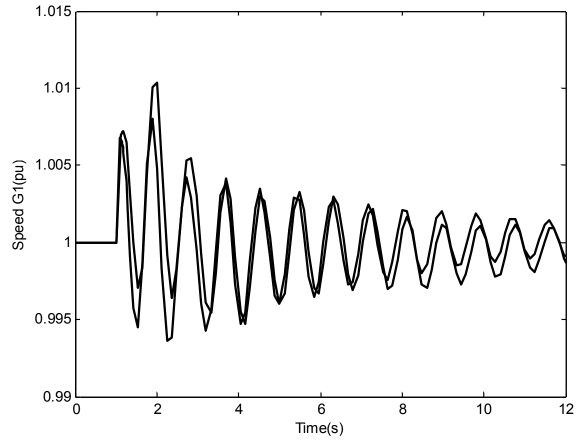

Figure 5. Speed G_1 following fault (solid: adaptive; dashed: conventional)

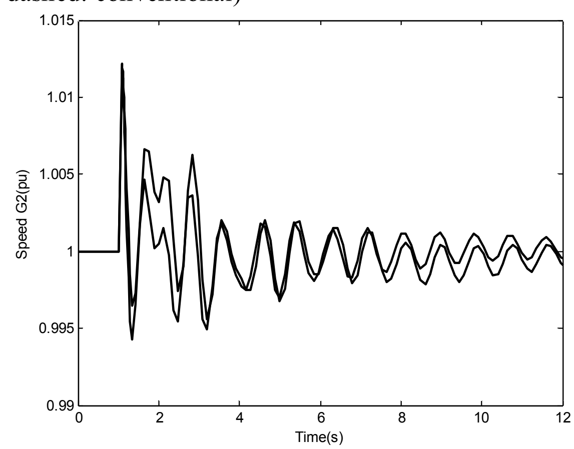

Figure 6. Speed G_2 following fault (solid: adaptive; dashed: conventional)

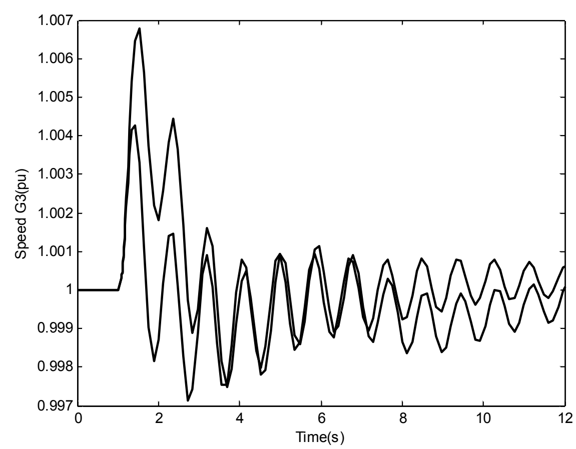

Figure 5. Speed G_3 following fault (solid: adaptive; dashed: conventional)

6. Conclusions

An adaptive supplementary stabilizer was carried out based on SVC. The proposed stabilizer was compared with conventional stabilizer. Simulation result on a multi machine electric power system demonstrated the ability of SVC in damping low frequency oscillations. the adaptive controller showed a robust and stronger performance than conventional stabilizer.

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12/02/2012