An Adaptive Stabilizer Based on Static Synchronous Series Compensator

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Abstract: Low frequency oscillations (LFO) are mainly occurred in power systems due to insufficient damping torque. In order to damp out LFO, a supplementary stabilizing signal is required to be injected into power system. In this paper the application of Static Synchronous Series Compensator (SSSC) to damp out the LFO is investigated. A supplementary stabilizer based on SSSC is assumed. An adaptive method is used to design the proposed stabilizer. The nonlinear time domain simulation results show the ability of the method in damping power system oscillations.
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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].

SSSC is a voltage-sourced converter-based series compensator and was proposed within the concept of using converter-based technology uniformly for shunt and series compensation, as well as for transmission angle control. It has been successfully applied in power systems.

In this paper, SSSC is used to increase power system stability. A supplementary stabilizer is equipped based on SSSC. The proposed stabilizer is designed by using adaptive control method.

2. Test system

Figure 1 shows a two area system installed with SSSC. Bus 4 is aggregation of a large number of generators and it can be modeled as an infinite bus. The SSSC is installed in one of two parallel lines. The system data are given in [12].

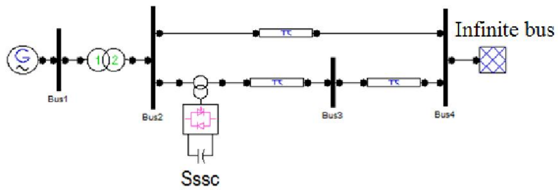

Figure 1: power system installed with SSSC

3. Static Synchronous Series Compensator (SSSC)

SSSC is one of the most important FACTS devices. It is installed in series with transmission line. This device has a voltage source converter serially connected to a transmission line through a transformer. It is necessary an energy source to provide a continuous voltage through a condenser and to compensate the losses of the VSC. A SSSC is able to exchange active and reactive power with the transmission system. But if our only aim is to balance the reactive power, the energy source could be quite small. The injected voltage can be controlled in phase and magnitude if we have an energy source that is big enough for the purpose. With reactive power compensation only the voltage is controllable, because the voltage vector forms 90º degrees with the line intensity. In this case the serial injected voltage can delay or advanced the line current. This means that the SSSC can be uniformly controlled in any value, in the VSC working slot [13].

The Static Synchronous Series Compensator (SSSC) uses a VSC interfaced in series to a transmission line, as shown in the Figure 2. Again, the active power exchanged with the line has to be maintained at zero hence, in steady state operation, SSSC is a functional equivalent of an infinitely variable series connected capacitor. The SSSC offers fast control and it is inherently neutral to sub-synchronous resonance [13].

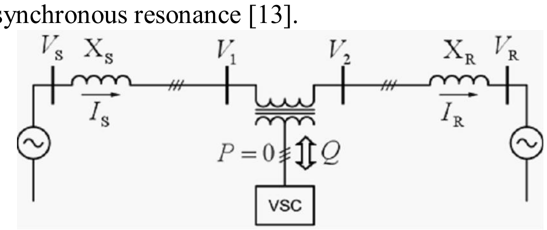

Figure 2: SSSC - A VSC interfaced in series to a transmission line

As mentioned, Static Synchronous Series Compensator (SSSC) is placed in the group of series connected FACTS devices. As shown in Figure 3, SSSC consists of a voltage source inverter connected in series through a coupling transformer to the transmission line. A source of energy is required for providing and maintaining the DC voltage across the DC capacitor and compensation of SSSC losses. Figure 4 shows the model of SSSC which consists of a series connected voltage source in series with impedance. This impedance represents the impedance of coupling transformer.

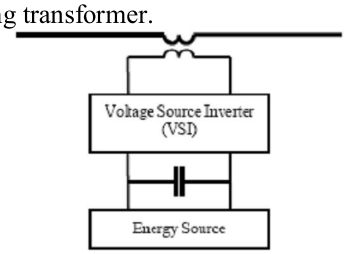

Figure 3: basic configuration of SSSC

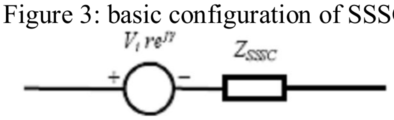

Figure 4: equivalent circuit of SSSC

The SSSC when operated with an appropriate DC supply (an energy source and/or sink, or suitable energy storage) can inject a component of voltage in anti-phase with the voltage developed across the line resistance, to counteract the effect of the resistive voltage drop on the power transmission.

4. 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 5 shows the general diagram of MRAS [14].

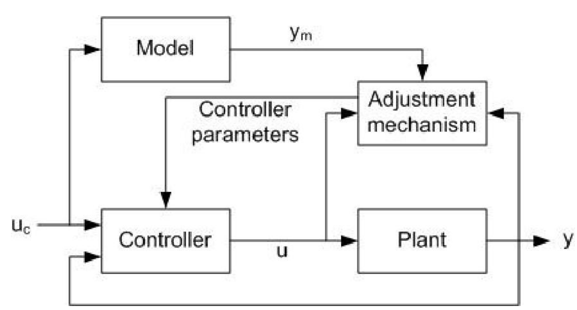

Figure 5: General diagram of MRAS

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]:

$$e = y_{plant} - y_{model} \quad (1)$$

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.

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

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:

$$\frac{d\theta}{dt} = -\gamma\frac{\delta J}{\delta\theta} = -\gamma e\frac{\delta e}{\delta\theta} \quad (3)$$

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:

$$J(\theta) = |e(\theta)|$$
$$\frac{d\theta}{dt} = -\gamma\frac{\delta e}{\delta\theta_c}sign(e)$$
$$where \quad (4)$$
$$sign(e) = \begin{cases} 1, & e > 0 \\ 0 & e = 0 \\ -1 & e < 0 \end{cases}$$

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 6. The plant model can be given as (5).

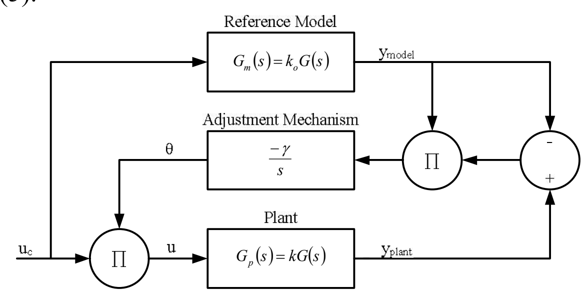

Figure 6: Adaptive feed forward gain

$$\frac{Y(s)}{U(s)} = kG(s) \quad (5)$$

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 *ko*:

$$\frac{Y(s)}{U_c(s)} = k_oG(s) \quad (6)$$

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

$$J(\theta) = \frac{1}{2}e^2(\theta) \rightarrow \frac{d\theta}{dt} = -\gamma e\frac{\delta e}{\delta\theta} \quad (7)$$

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

$$e = y - y_m = kGU - G_mU_c$$
$$= kG\theta U_c - k_oGU_c \quad (8)$$

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:

$$\frac{\delta e}{\delta \theta} = kGU_c = \frac{k}{k_o} y_m \quad (9)$$

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

$$\frac{d\theta}{dt} = \gamma' \frac{k}{k_o} y_m e = -\gamma y_m e \quad (10)$$

The block diagram for this system is the same as the diagram given in Figure 6. To tune this system, the values of *ko* and *gamma* can be varied [14].

5. Stabilizer design

5.1. Adaptive stabilizer

To get a suitable performance and tracking characteristics, a reference model should be adopted for MRAS system. In this paper, since the SSSC 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;

$$y = \frac{0.05s(s + 2)}{s^2 + 2s + 2} u \quad (11)$$

5.2. Conventional stabilizer

In order to comparison, a conventional stabilizer is designed based on SSSC. The transfer function model of a conventional stabilizer is as (12). 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.

$$U_{out} = K_{DC} \frac{ST_W}{1+ST_W} \frac{1+ST_1}{1+ST_2} \frac{1+ST_3}{1+ST_4} \Delta\omega \quad (12)$$

Table 1: Optimal parameters of conventional stabilizer

Parameter	K_{DC}	T_1	T_2	T_3	T_4
Optimal value	1.037	0.4	0.2	0.45	0.2

6. Simulation result

The proposed stabilizer is evaluated based on the test system. A large signal disturbance is considered to show effectiveness of the proposed stabilizer. The simulation results are depicted in figures 7-9. It is seen that the system with conventional stabilizer contains insufficient damping and the responses are pendulous. But the adaptive stabilizer can greatly enhance power system stability and damp out the oscillations and the advantages of the proposed stabilizer are visibly seen.

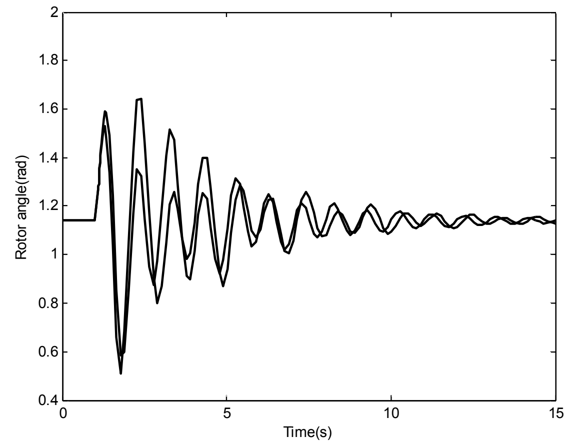

Figure 7: rotor angle following 10 cycle three phase short circuit in bus 3
Solid: adaptive stabilizer **dashed**: conventional stabilizer

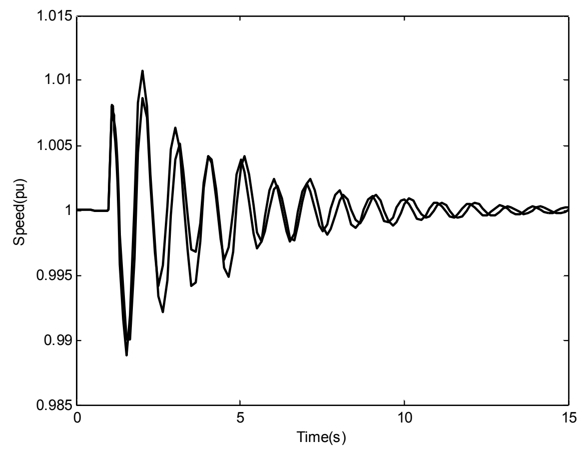

Figure 8: speed following 10 cycle three phase short circuit in bus 3
Solid: adaptive stabilizer **dashed**: conventional stabilizer

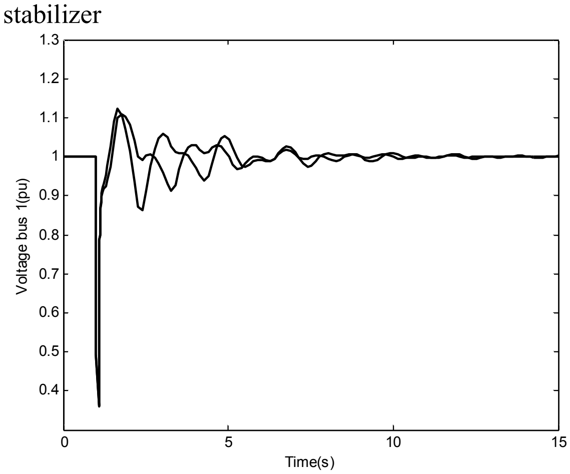

Figure 9: voltage of bus 1 following 10 cycle three phase short circuit in bus 3
Solid: adaptive stabilizer **dashed**: conventional stabilizer

7. Conclusion

A supplementary stabilizer based on SSSC presented. A two area power system assumed to show the ability of the proposed method. Non linear simulation results demonstrated that the designed stabilizer capable to guarantee the robust stability and robust performance under disturbances. Also, simulation results show that the adaptive method is a suitable tool to design stabilizer parameters.

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References

[1] Y.L. Abdel-Magid, M.A. Abido, Robust coordinated design of excitation and TCSC-based stabilizers using genetic algorithms, Electric Power Systems Research, 69 (2004) 129-141.
[2] M.A. Furini, A.L.S. Pereira, P.B. Araujo, Pole placement by coordinated tuning of Power System Stabilizers and FACTS-POD stabilizers, International Journal of Electrical Power & Energy Systems, 33 (2011) 615-622.
[3] J. Machowski, J.W. Bialek, State-variable control of shunt FACTS devices using phasor measurements, Electric Power Systems Research, 78 (2008) 39-48.
[4] S. Panda, Multi-objective PID controller tuning for a FACTS-based damping stabilizer using Non-dominated Sorting Genetic Algorithm-II, International Journal of Electrical Power & Energy Systems, 33 (2011) 1296-1308.
[5] S.K. Rautray, S. Choudhury, S. Mishra, P.K. Rout, A Particle Swarm Optimization based Approach for Power System Transient Stability Enhancement with TCSC, Procedia Technology, 6 (2012) 31-38.
[6] A.A. Alabduljabbar, J.V. Milanović, Assessment of techno-economic contribution of FACTS devices to power system operation, Electric Power Systems Research, 80 (2010) 1247-1255.
[7] T. Jain, S.N. Singh, S.C. Srivastava, Dynamic ATC enhancement through optimal placement of FACTS controllers, Electric Power Systems Research, 79 (2009) 1473-1482.
[8] N.A. Lahaçani, D. Aouzellag, B. Mendil, Contribution to the improvement of voltage profile in electrical network with wind generator using SVC device, Renewable Energy, 35 (2010) 243-248.
[9] M. Nayeripour, M.R. Narimani, T. Niknam, S. Jam, Design of sliding mode controller for UPFC to improve power oscillation damping, Applied Soft Computing, 11 (2011) 4766-4772.
[10] R. Pillay Carpanen, B.S. Rigby, A contribution to modelling and analysis of SSSC-based power flow controls and their impact on SSR, Electric Power Systems Research, 88 (2012) 98-111.
[11] S.A. Taher, S. Akbari, A. Abdolalipour, R. Hematti, Robust decentralized controller design for UPFC using -synthesis, Communications in Nonlinear Science and Numerical Simulation, 15 (2010) 2149-2161.
[12] P. Kundur, N.J. Balu, M.G. Lauby, Power system stability and control, McGraw-hill New York, 1994.
[13] K.K. Sen, SSSC-static synchronous series compensator: theory, modeling, and application, Power Delivery, IEEE Transactions on, 13 (1998) 241-246.
[14] K.J. Astrom, B. Wittenmark, Adaptive control, Addison-Wesley Longman Publishing Co., Inc., 1994.
[15] H. Shayeghi, H.A. Shayanfar, S. Jalilzadeh, A. Safari, A PSO based unified power flow controller for damping of power system oscillations, Energy Conversion and Management, 50 (2009) 2583-2592.

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