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Damping the Oscillation in an HVDC/HVAC System with a Novel PSS Controller

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Abstract**:** In this paper to damp and control the oscillations in the model system which includes two ties (AC and DC), after any change, a new controller was employed. This controller as a damper can decrease the rotor angle deviations in a short time. This hybrid power system stabilizer use the rotor speed oscillations, capacitor voltage deviations and rotor angle changes as sampling parameters and control the exciter voltage and HVDC's rectifier control signal. This process is applied with genetic algorithm helps and genetic algorithm is employed to find the best values for gains of the controller in a very short time. The simulation results show the improvement in the dynamic performance of the test AC/DC system.

Keywords: HVAC/HVDC, Genetic Algorithm, Feedback control, Stability.

1. INTRODUCTION

In this paper a simple approach is used to model parallel-connected HVAC and HVDC systems [1]. This model is based on a typical AC/DC system in which the AC generator is connected to an infinite bus system through a parallel AC tie line, and an HVDC link. In addition to the state-space representation, a block diagram representation is formed to analyze the system stability characteristics. The dynamic characteristics of the system are expressed in terms of the newly developed so-called H constants [2]. The block diagram approach was first used by Heffron and Phillips [3] to analyze the small-signal stability of synchronous machines. The purposed model is not suitable for a detailed study of large systems; it is useful in gaining a physical insight into the effects of various system dynamics and in establishing the basis for methods of enhancing stability through synchronous machine and HVDC converter controls. In this model, it is possible to analyze the small-signal stability of the system and low frequency oscillation phenomena with the synchronous machine represented by models of varying degrees of detail and the HVDC link in different control modes [1].

Also to control and prevent the oscillations in this system, a new control method is used. In this article an optimum feedback is designed that can improve the overall power system dynamic performance. There is no specific method in feedback design which is based on trial and error. The best constant values for state feedback matrix are laboriously obtained through trial and error, although time consuming. Genetic algorithm as an optimal method is employed to find the best gains for feedback controller in a very short time.

Section 2 describes power system model and the steady state of the system is shown in Section 3. The design of the proposed control algorithm is detailed in Section 4. The computer simulation results are presented and discussed in Section 5. Finally, Section 6 is the conclusion.

2. THE STUDY POWER SYSTEM MODEL

The configuration of the study system is shown in Fig. 1.

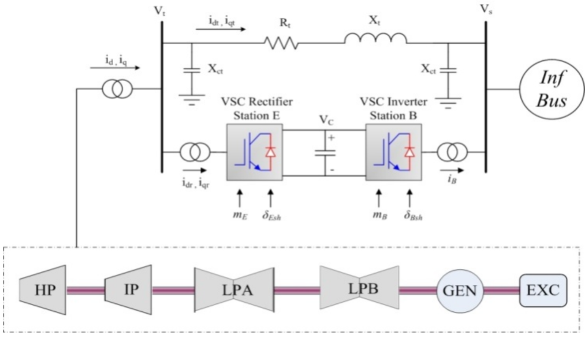

Fig. 1 Single line diagram of the study system.

This model consists of a single machine connected through two transmission line (HVAC and HVDC), to an infinite bus. The mechanical system associated with the machine consists of a high pressure (HP) turbine, an intermediate pressure (IP) turbine, two low pressure turbines (LPA, LPB), the generator (G) and exciter (EXC) as is shown in Fig. 1.

In this model, a synchronous generator is connected to a large power system through parallel-connected HVAC and HVDC transmission lines [4] and [5]. And a static three-phase load and a capacitor bank are connected to the machine bus.

3. BLOCK DIAGRAM REPRESENTATION

In small signal representation, the dynamic characteristics of the system are expressed in term of the so-called H constants [3] and [6]. The block diagram and the equations for the associated constants are developed here. And ΔU_{E1} and ΔU_{E2} are supplementary control signals. The details of the parameters in this block diagram are discussed in [1]. The short expression for these parameters is present in the next section.

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Electrical Torque Equation (H_1~H_4)

Electrical torque of a synchronous machine at synchronous speed is approximated by:

$$T_e = I_d V_d + I_q V_q \tag{1}$$

By using [1], the change in electrical torque may be expressed as a function of $\Delta\delta$, $\Delta E'_q$, $\Delta\alpha_R$ and ΔI_R, as follows:

$$\Delta T_e = H_1 \Delta\delta + H_2 \Delta E'_q + H_3 \Delta\alpha_R + H_4 \Delta I_R \tag{2}$$

The expression for H_1~H_4 are given by (3).

$$\begin{bmatrix} H_1 \\ H_2 \\ H_3 \\ H_4 \end{bmatrix} = \begin{bmatrix} 0 \\ I_{q0} \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} F_d & F_q \\ Y_d & Y_q \\ T'_d & T'_q \\ Z'_d & Z'_q \end{bmatrix} \begin{bmatrix} (X_q - X'_d) I_{q0} \\ E'_{q0} + (X_q - X'_d) I_{q0} \end{bmatrix} \tag{3}$$

Excitation Voltage Equation (H_5~H_8)

Linear equation of exciting winding's voltage is:

$$\Delta E'_q = \frac{H_5}{1 + sT'_{do} H_5} \left[\Delta E_{fd} - H_6 \Delta\delta - H_7 \Delta\alpha_R - H_8 \Delta I_R \right] \tag{4}$$

And H_5~H_8 are:

$$H_5 = \frac{1}{1 + (X_d - X'_d) Y_d}$$

$$\begin{bmatrix} H_6 \\ H_7 \\ H_8 \end{bmatrix} = (X_d - X'_d) \begin{bmatrix} F_d \\ T'_d \\ Z'_d \end{bmatrix} \tag{5}$$

Rectifier AC Bus Voltage Equation (H_9~H_{12})

Now, the change in generator terminal AC voltage as a function of $\Delta\delta$, $\Delta E'_q$, $\Delta\alpha_R$ and ΔI_R, is:

$$\Delta V_t = H_9 \Delta\delta + H_{10} \Delta E'_q + H_{11} \Delta\alpha_R + H_{12} \Delta I_R \tag{6}$$

And H_9~H_{12} are:

$$\begin{bmatrix} H_9 \\ H_{10} \\ H_{11} \\ H_{12} \end{bmatrix} = \begin{bmatrix} 0 \\ V_{q0} / V_{t0} \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} F_d & F_q \\ Y_d & Y_q \\ T'_d & T'_q \\ Z'_d & Z'_q \end{bmatrix} \begin{bmatrix} -X'_d \dfrac{V_{q0}}{V_{t0}} \\ X_q \dfrac{V_{d0}}{V_{t0}} \end{bmatrix} \tag{7}$$

Rectifier DC Current Equation (H_{13}~H_{16})

The change in rectifier current is:

$$\Delta I_R = \frac{1}{sL + H_{13}} \left[H_{14} \Delta\delta + H_{15} \Delta E'_q + H_{16} \Delta\alpha_R - \Delta V_C \right] \tag{8}$$

And H_{13}~H_{16} are:

$$H_{13} = R + \frac{3}{\pi} X_{co} - 3K_r H_{12} \cos\alpha_{R0} \tag{9}$$

$$\begin{bmatrix} H_{14} \\ H_{15} \\ H_{16} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ -3K_r V_{t0} \sin\alpha_{R0} \end{bmatrix} + 3K_r \cos\alpha_{R0} \begin{bmatrix} H_9 \\ H_{10} \\ H_{11} \end{bmatrix} \tag{10}$$

4. CONTROLLER DESIGN

4.1 Feedback Designing Method

The usual methods employed up to now are based on the root geometrical models in which only the output of the system is used as feedback into a dynamic controller. In this part, the advanced control designing based on state variables is used [7]. In feedback method the designer is able to place the system specified equation roots in the desired response on the complex coordinate plane.

$$U(t) = -KX(t) \tag{11}$$

Where *K* is a vector with constant feedback gains; the compensated system specified equation is obtained.

4.2 Genetic algorithm learning

Genetic algorithm is a searching strategy inspired by natural selection and natural genetics. Simple genetic algorithm includes individual selection from population based on the fitness, crossover and mutation with some probabilities to generate new individuals [8].

With the genetic operation going on, the individual maximum fitness and the population average fitness are increased steadily. With the simple genetic algorithm, the control parameters can be searched out, but they vary greatly with different crossover probability pc, mutation probability m, and population size. Control parameters often converge to different results in several experiments, which are not the optimized solution and will not lead the two links to the attractive basin.

Some modifications are proposed based on the simple genetic algorithm. The individual fitness is selected as where the error is adopted as the fitness. Sampling number *N* (the total calculation steps) may be set as a large number such as 500. This encourages the control parameters with which control task is achieved quickly by a larger fitness, which will benefit the best individual selection in the next generation. The flowchart of simple genetic algorithm is shown in Fig. 2.

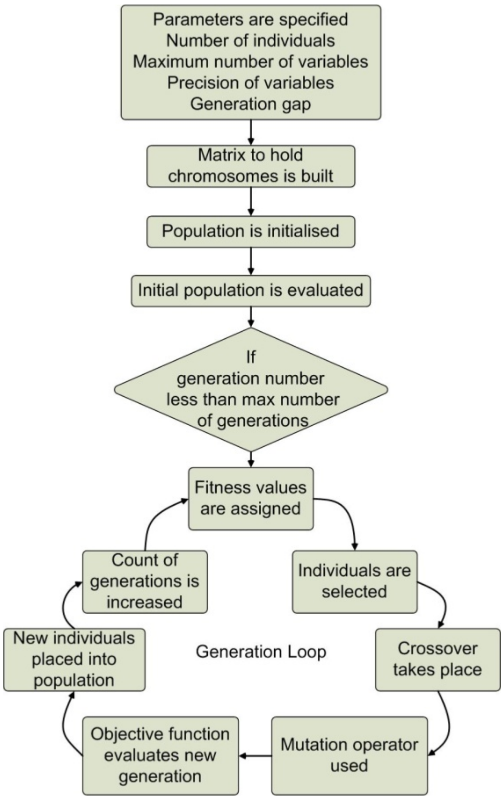

Fig. 2 Flowchart of genetic algorithm.

4.3 Feedback tuning Method based Genetic Algorithm

The parameters of the regulating gains in feedback are laboriously obtained through trial and error, although time consuming. Genetic algorithm is employed to find the best values for feedback controller's parameters in a very short time.

In this control method reference model supplies the expected performance of system, GA optimizes pole placement. The indexes of the active current characteristics are required as: $Mp<0.5\%$, $ts<1$sec, where Mp is overshoot and ts is settling time. In this control method the system control block diagram is shown as Fig. 3.

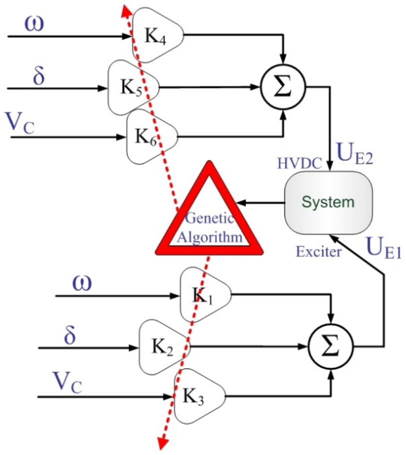

Fig. 3 Genetic Model in and the gains feedback Control.

In this figure, it can be seen that the feedback parameters are δ, ω, and V_C. These parameters are more important in this system, because the δ, ω, are belong to the generator and other δ, ω, in of the shaft (HP, IP, LPA, LPB turbines and exciter) are relative with them.

Also V_C, is another important index in the HVDC system, and when this parameter is controlled, almost the other parameters in HVDC line, will be controlled. With notice to effects of these parameters, to control, and to damp the oscillations in the system, in feedback control method, these parameters are applied. And to optimizing the effects of these parameters, genetic algorithm is used, and by this optimizing method, the optimal gains are obtained. The structure of the controller is shown in Fig. 3. The outputs of this controller are the input of the HVDC and exciter.

5. THE RESULT OF SIMULATION

In this simulation, the step load disturbance applied to the model system was 10% of area capacity for all the simulations. Also for comparing the results, the simulation of the system without HVDC line, with HVDC line without purposed controller, and the controlled system are present.

In the following Figures, illustrate the system dynamic response for various cases. By using the controller in DC power, the deviations in responses are damped faster, and better. By this controller the deviations are damped in very short time. Also only the final and optimal values of parameters of gains were used and presented in these figures, and the manual parameters of gains were not showed.

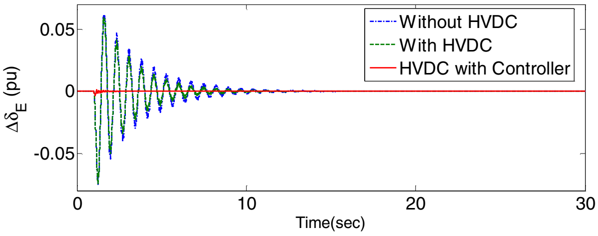

Fig. 4 Oscillation in the exciter shaft angle, (EXC), after 10% increase in the load.

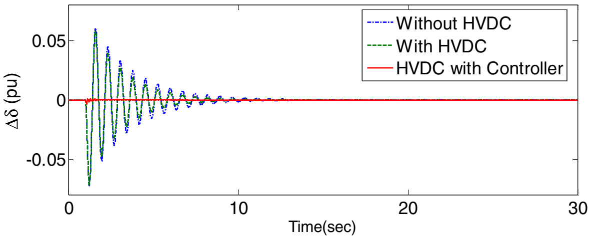

Fig. 5 Oscillation in the generator shaft angle, (G), after 10% increase in the load.

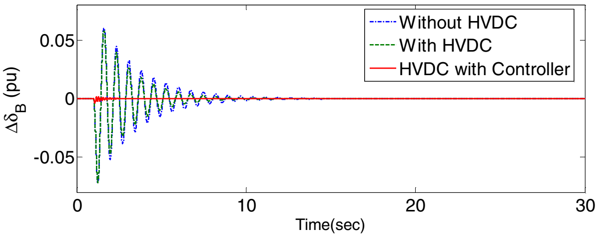

Fig. 6 Oscillation in the low pressure turbine's shaft angle, (LPB), after 10% increase in the load.

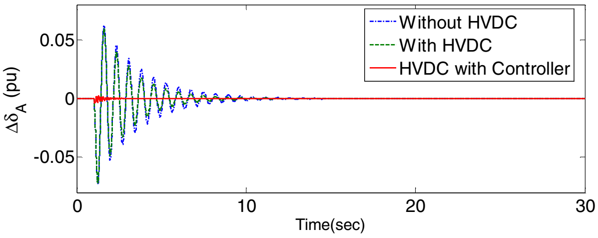

Fig. 7 Oscillation in the low pressure turbine's shaft angle, (LPA), after 10% increase in the load.

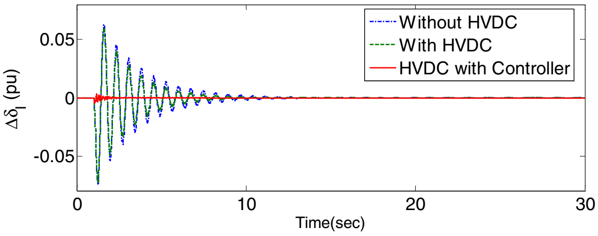

Fig. 8 Oscillation in the intermediate pressure turbine's shaft angle, (IP) after 10% increase in the load.

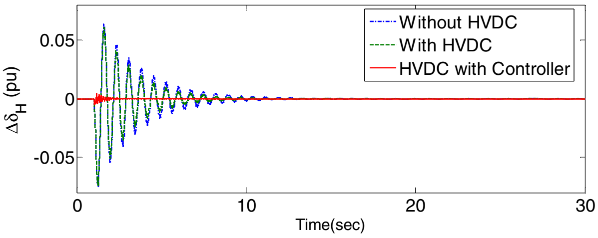

Fig. 9 Oscillation in the high pressure turbine's shaft angle, (HP), after 10% increase in the load.

Fig. 4 to Fig. 9, show the shaft angle deviation response in the 6 masses system, that the deviation response of this parameter is compared in 3 cases: system without HVDC line, with HVDC line without purposed controller, and the controlled system, that it can be seen that by this controller, the shaft angle deviations are damped. The difference between the oscillations in these parts of the shaft is very small, and it is not sensible in these figures.

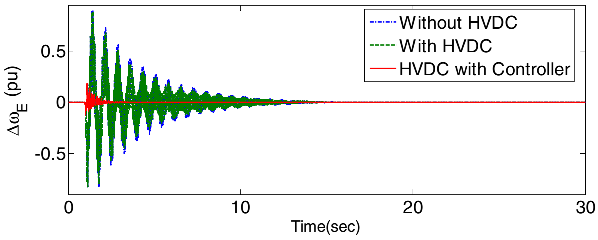

Fig. 10 Oscillation in the exciter shaft angular speed, (EXC), after 10% increase in the load.

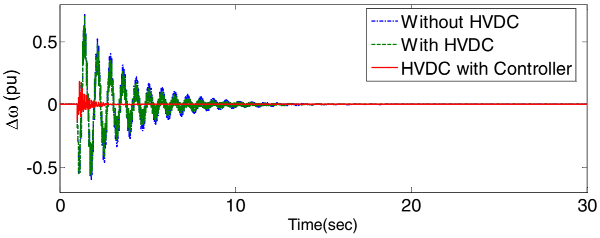

Fig. 11 Oscillation in the generator shaft angular speed, (G), after 10% increase in the load.

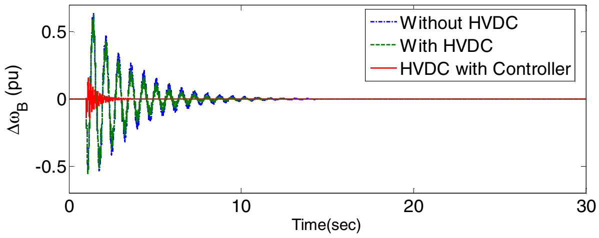

Fig. 12 Oscillation in the low pressure turbine's shaft angular speed, (LPB), after 10% increase in the load.

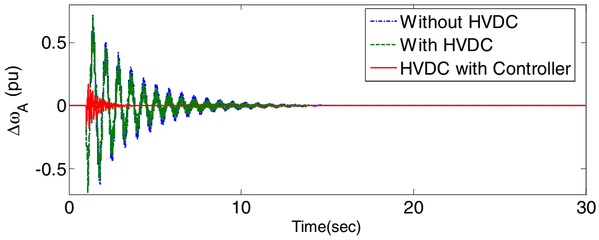

Fig. 13 Oscillation in the low pressure turbine's shaft angular speed, (LPA), after 10% increase in the load.

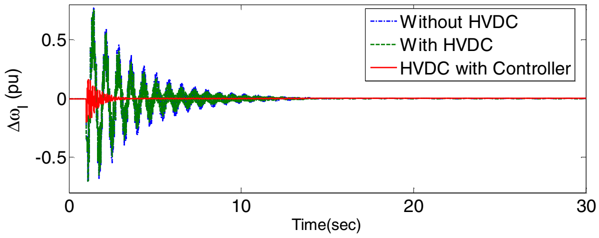

Fig. 14 Oscillation in the intermediate pressure turbine's shaft angular speed, (IP), after 10% increase in the load.

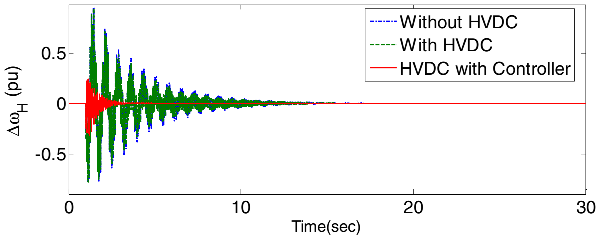

Fig. 15. Oscillation in the high pressure turbine's shaft angular speed, (HP), after 10% increase in the load.

The Fig. 10 to Fig. 15, show the angular speed deviation response in the 6 masses system, after the 10% change in the load. And the deviation response of this parameter is compared in 3 cases: system without HVDC line, with HVDC line without purposed controller, and the controlled system, that it can be seen that by this controller, the angular speed deviations are damped faster.

With notice to these results, the figures 4 to 15, the effect of this controller on this system is very clear. In these results, only one of the pole placement's gains sets is presented, however the other controllers can be effective in this system, too.

6. CONCLUSIONS

The stability of the system which includes two ties (AC and DC), is analyzed and the oscillations were controlled by a new power system stabilizer. In this PSS three parameters (the rotor speed oscillations, capacitor voltage deviations and rotor angle changes) and genetic algorithm is employed to find the best values for gains of the controller in a very short time. The results can show that the proposed GA method can obtain high quality solution with good computation efficiency. Therefore, the proposed method has robust stability and efficiency.

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