Mitigating Subsynchronous resonance torques using dynamic braking resistor

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Abstract – Series compensation has proven to increase stability in transmission of electric power. On the other hand, insertion of series capacitor results in severe subsynchronous torques. The subsynchronous torque leads to generator-turbine shaft damage. Mitigation of subsynchronous transient torques is achieved through resistor bank connected to generator terminals. The insertion of resistor bank is controlled by fuzzy logic controller. The proposed controller has been tested on IEEE First Benchmark Model and it proved to have good damping for the torsional torques.

Index Terms - Dynamic braking resistor, First Benchmark Model, fuzzy logic control, subsynchronous resonance.

I. INTRODUCTION

Since the two shaft failures at Mohave station at 1970 and 1971, subsynchronous resonance has become topic of interest by utility industry. By definition, subsynchronous resonance is a case where the electric network exchanges significant amount of power with the mechanical network [1]. Intensive studies showed that insertion of series capacitor may result to SSR. When dealing with SSR, the main danger is the possibility of shaft damage. Several countermeasures have been reported to counteract SSR.

The published countermeasures include excitation control, static VAR compensators as well as many other countermeasures [2-4]. Moreover, dynamic braking resistor is used as a powerful countermeasure for SSR [5, 6]. This countermeasure is used to control the power consumed by a resistor bank for the purpose of damping the torsional modes of turbo-generators.

The proposed control technique for controlling the dynamic braking resistor is the fuzzy logic controller (FLC) [7]. The proposed fuzzy logic controller (FLC) is used to control the insertion of resistor bank to sustain the transient stability of the combined turbine-generator system under different SSR effects.

The advantage of applying dynamic braking resistor as a countermeasure is its effectiveness in damping self-excitation SSR as well as transient torque SSR. However, ref. [7] showed only the application of FLC to control dynamic braking resistor to overcome self-excitation SSR. The severity of transient torques on turbine-generator shaft is much greater than that of self-excitation SSR.

Hence, it is important to test the proposed controller behaviour on the case of transient torque. Therefore, this paper examines the application of FLC-driven dynamic braking resistor in mitigating transient torque SSR. The system under study is the well-known IEEE First Benchmark Model (IEEE FBM) [8]. The results show that the proposed controller is adequate for damping SSR.

II. DYNAMIC BRAKING RESISTOR

Dynamic braking resistor has previously been considered for augmenting system stability as well as for improving the transient response of power systems following major system disturbances [9]. The resistor bank is connected to the machine terminals. Fig. 1 shows a schematic of dynamically controlled resistor bank.

During normal system operation, the resistor bank is disabled and no power is dissipated. Following a system disturbance, the power consumed by the resistor bank is controlled so as to damp the torsional oscillations of the turbo-generator. After the torsional oscillations decay to a small level, the resistor bank is again disabled from service. Bonneville Power Administration (BPA) has implemented dynamic braking resistor for enhancing transient stability [9]. The resistor is 1400 MW, 240 KV. It consists of 45,000 ft of ½ inch stainless steel wire on three towers. Dynamic braking resistor has been reported to be used in different countries like: Japan, China, Russia and australia [10].

III. CASE STUDY

The system under study is the IEEE First Benchmark Model (IEEE FBM) which is shown in Fig. 2.
The synchronous machine model is developed with three-phase ac armature windings on the stator, one field winding on the rotor, and three damper windings on the rotor[11].

The parameters of the equivalent circuit of synchronous generator are calculated using Canay’s conversion[12]. The parameters of the synchronous generator are stated in Reference [8]. These parameters are in the form of IEEE and IEC standards[13, 14]. Hence, Canay’s conversion[12] is used to transform these parameters into equivalent circuit parameters.

The voltage equation is given by[15, 16]:

\[ \begin{bmatrix} V_d \\ V_q \\ V_0 \\ V_f \\ V_g \\ V_D \\ V_Q \end{bmatrix} = - \begin{bmatrix} R_d & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & R_q & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & R_b & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & R_f & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & R_g & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & R_D & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & R_Q \end{bmatrix} \begin{bmatrix} i_d \\ i_q \\ i_b \\ i_f \\ i_g \\ i_D \\ i_Q \end{bmatrix} - \begin{bmatrix} \psi_d \\ \psi_q \\ \psi_b \\ \psi_f \\ \psi_g \\ \psi_D \\ \psi_Q \end{bmatrix} + \begin{bmatrix} U_d \\ U_q \\ U_0 \\ U_f \\ U_g \\ U_D \\ U_Q \end{bmatrix} \tag{1} \]

Where:
- \( V_d, V_q \) and \( V_0 \) are d-axis, q-axis, 0-axis voltages.
- \( V_f, V_g, V_D \) and \( V_Q \) are field and damper bars voltages respectively.
- \( R_d \) is armature resistance.
- \( R_f, R_g, R_D \) and \( R_Q \) are field and damper bars resistances respectively.
- \( i_d, i_q \) and \( i_b \) are d-axis, q-axis, 0-axis currents.
- \( i_f, i_g, i_D \) and \( i_Q \) are field and damper bars currents respectively.
- \( \psi_d, \psi_q \) and \( \psi_b \) are d-axis, q-axis, 0-axis flux linkages respectively.
- \( \psi_f, \psi_g, \psi_D \) and \( \psi_Q \) are field and damper bars flux linkages respectively.
- \( U_d, U_q \) are d-axis and q-axis speed voltages.

The mechanical part of the system is described by the rotational form of Newton's second law:

\[ [T] = [J] \frac{d}{dt} [\theta] + [D] \frac{d}{dt} [\theta] + [K][\theta] \tag{2} \]
The universe of discourse is normalized to be in the range of (-1 to 1).

Fig. 4 shows the membership functions of the change of error (CE).

These membership functions are similar to those of speed error (E). Furthermore, the universe of discourse is normalized to be in the range of (-1 to 1).

Fig. 5 shows the membership functions of the braking power (Pb). The membership functions of (Pb) are similar to those of (E) and (CE). The universe of discourse is in the range of (0 to 3).

IF (E) is PB AND (CE) is PB THEN (Pb) is PB

This rule is explained as follows: if the generator speed is much greater than reference speed (E is PB) AND the speed of the generator is getting away from the reference speed (CE is PB), then the control action taken must be PB to stabilize the generator speed.

The rest of the rules are formulated as the above rule. For the case of 4 linguistic variables for (E) and 4 linguistic variables for (CE) the resulting rule table would have 16 rules.

Table I shows rule table of the proposed fuzzy logic control.

<table>
<thead>
<tr>
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<th>PB</th>
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The output of the FLC (Pb) is limited to 1 PU. Therefore, the maximum output power is 892.4 MW. This output power is feasible [9].

The dynamic braking resistor is connected if the generator speed exceeds predetermined value. For the given system the dynamic braking resistor is connected after the fault occurrence. As soon as the system is restabilised it will be disconnected.

The proposed controller utilizes the dynamic braking resistor which is well-known of enhancing system stability. Therefore, the proposed controller is capable of suppression of different transients imposed on the system.

V. SIMULATION RESULTS

The torsional interaction case is the IEEE FBM [8] with 3-phase short circuit located at point B at time 0 and the fault is cleared at time 0.075 sec. The results of simulation are presented with and without controller.

Fig. 6 shows the generator terminal voltage with and without control. The waveform of the voltage in case of no controller used is growing indicating unstable operation. In case of using FLC braking resistor the waveform of voltage indicates good damping of disturbance. Fig. 7 shows the generator terminal current in two cases (without and with control). Fig. 8 shows the capacitor voltage without control. Fig. 9 shows the capacitor voltage with control. Fig. 10 through Fig. 15 show the speed deviations for different masses. Fig. 16 through Fig. 20 show the torsional torques for different shaft sections.
Fig. 6. Generator terminal voltage deviation

Fig. 7. Generator terminal current deviation

Fig. 8. Capacitor voltage without control

Fig. 9. Capacitor voltage with control

Fig. 10. High Pressure turbine speed deviation

Fig. 11. Intermediate Pressure turbine speed deviation
The results show good damping behavior for proposed controller. Both electrical and mechanical transients are mitigated down to acceptable range.

VI. CONCLUSIONS

Application of fuzzy logic to control dynamic braking resistor for damping transient SSR has been tested in this paper. The proposed controller has proved to be effective in mitigating torsional torques in turbine-generator set. The studied system is the IEEE first benchmark model. The disturbance is 3-phase short circuit for 75 mSec. Different waveforms show the suppression of torsional oscillations in the case of fuzzy logic control.

REFERENCES


