

# The Impacts of Electric Strengths Between AC Buses on Sub-synchronous Resonance

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**Abstract**—This paper analyzes relationship between electric strengths and the risk of sub-synchronous resonance (SSR). Firstly, the compensation impact factor (CIF) method is used to replace the process of determining sub-synchronous damping characteristics of an AC system. Then the risk of SSR can be reflected by the CIF indicator and the relationship between electric strength and CIF is obtained. Finally, a proper electric strength range is drawn at a planning stage for the AC system. The proposed analysis method does not need too much computation resource and have an excellent accuracy. Simulation results show that CIF indicates the risk of SSR when electric strengths between AC Buses changes and the proper range of electric strength can avoid the threats of SSR for the AC system.

**Keywords**—*sub-synchronous resonance; electric strength; compensation impact factor; sub-synchronous damping characteristics*

## I. INTRODUCTION

Series compensation using fixed capacitor is an economic and practical option for enhancing power transmission capacity and transient stability for a long-distance AC transmission system [1-4]. However, sub-synchronous energy will be excited between thermal plants and series compensators and threatens the systems [5-8]. The grid structure and electric strength have effects on damping the sub-synchronous resonance (SSR) as the resonance frequency changes with different grid structure and electric strength [9]. Therefore, SSR could be avoided if the electric strengths between AC Buses are within a proper range.

The existing literatures [10-15] analyzing SSR cost too much computation resource and are lack of accuracy. Frequency scanning method [10-11] can determine the system resonance frequency without high request of computation resource. However, this method is unable to get sub-synchronous damping characteristics to evaluate the impact of electric strength on SSR. Therefore, the accuracy of frequency scanning method is insufficient to determine the risk of SSR. Eigenvalue [12-13] and test signal [14-15] methods can obtain the sub-synchronous damping characteristics but they require extensively computation works. [16] proposes a compensation impact factor (CIF) method to determine risk of SSR by analyzing the relationship between sub-synchronous damping characteristics and CIF indicators. Therefore, this method can

demonstrate how electric strength affects SSR, if the relationship between CIF and electric strength can be determined.

This paper uses the CIF method to evaluate the impacts of electric strengths between AC Buses on SSR. Firstly, the relationship between CIF and electric strength are discussed to imply how CIF changes with variation of the electric strengths. Then the CIF, rather than the sub-synchronous damping characteristics, is used to evaluate the risk of SSR. As a result, the analysis process of SSR is quite simple and the accuracy are sufficient. Finally, a proper range of electric strength is obtained for a system planning stage. Two main advantages are drawn from this paper, i.e., 1) the SSR analysis process by using CIF would be simple without too much computation resource, and 2) a proper electric strength range can be determined at system planning stage.

The rest of this paper are organized as follows, Section II introduces the CIF method briefly. Section III analyzes the relationship between electric strengths and SSR by calculating damping characteristics. Section IV validates the proper electric strength range and Section V draws conclusions of this paper.

## II. THE COMPENSATION IMPACT FACTOR

CIF [16] is the method to evaluate the risk of SSR caused by fix compensation capacitor for thermal generators. The calculation of CIF needs little information on generator shafts. Therefore the equivalent model for an AC system is quite simple, considering using power source model for the generators. Figure 1 shows active power, which are divided into “causing disturbance group” and “restraining disturbance group”, for computing CIF for a generator.

In Figure 1, the generator connects to the system through a compensated line and  $N$  non-compensated lines. The “non-compensated line” represents the parallel path to the compensated line.  $P_C$  is the active power flow in the compensated line while  $P_{UC-1}$  through  $P_{UC-N}$  represents the active power flow going through each non-compensated line respectively. The positive directions of these active power flows are shown in Figure 1.

The definition of CIF is shown in (1). Assuming that a fault happens at  $t_1$  and then the system recovers to the steady state at



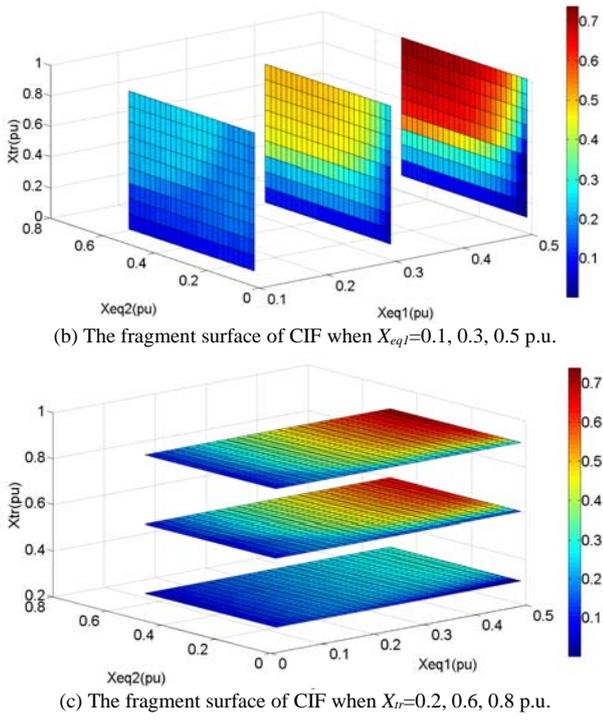


FIGURE III. THE CIF WHEN ELECTRIC STRENGTH CHANGES

Figure 3(b) shows that when  $X_{eq1}$  is fixed, lower values of  $X_{eq2}$  and  $X_{tr}$  obtain a lower CIF value for the generator. Therefore, strong electric strengths between Bus① and Bus③ and between Bus② and Bus③ are helpful to reduce SSR risk. Compared FIGURE III(a) with FIGURE III(b), SSR risk area is more sensitive with the change of  $X_{eq1}$  rather than the change of  $X_{eq2}$ .

Figure 3(c) shows that when  $X_{tr}$  is fixed, lower values of  $X_{eq1}$  and  $X_{eq2}$  produce a lower CIF value for the generator. Therefore, strong electric strengths between Bus① and Bus② and between Bus① and Bus③ can eliminate the risk of SSR. When  $X_{tr}$  increase from 0.2 to 0.6 p.u., SSR risk area increases significantly. However, when  $X_{tr}$  continuously increasing, the SSR risk area is not changing obviously.

Therefore, strong electric strength between AC Buses are helpful to eliminate SSR risk for the generator. In the system shown in Figure 2,  $X_{eq1}$  and  $X_{tr}$  affects the SSR risk more obviously than  $X_{eq2}$ .

#### IV. SIMULATION TESTS

##### A. Damping Characteristics

The test system in Figure 2 is adopted here to show the sub-synchronous damping characteristics when the electric strengths change. This section is to demonstrate that the relationship between electric strength and damping characteristics is the same as that between electric strength and CIF. Therefore, CIF, which is more easier to obtain, can be used to analyze the effect of electric strength on the risk of SSR.

Define Zone 1 as no SSR risk area and its sub-synchronous damping is greater than 1. Zone 2 is the weak damping zone whose damping is within  $[-1,1]$ , considering the calculation error. Zone 3 is the risk zone where the damping is below  $-1$ . Figure 4 shows the 3 zones with each point of  $(X_{eq1}, X_{eq2}, X_{tr})$ .

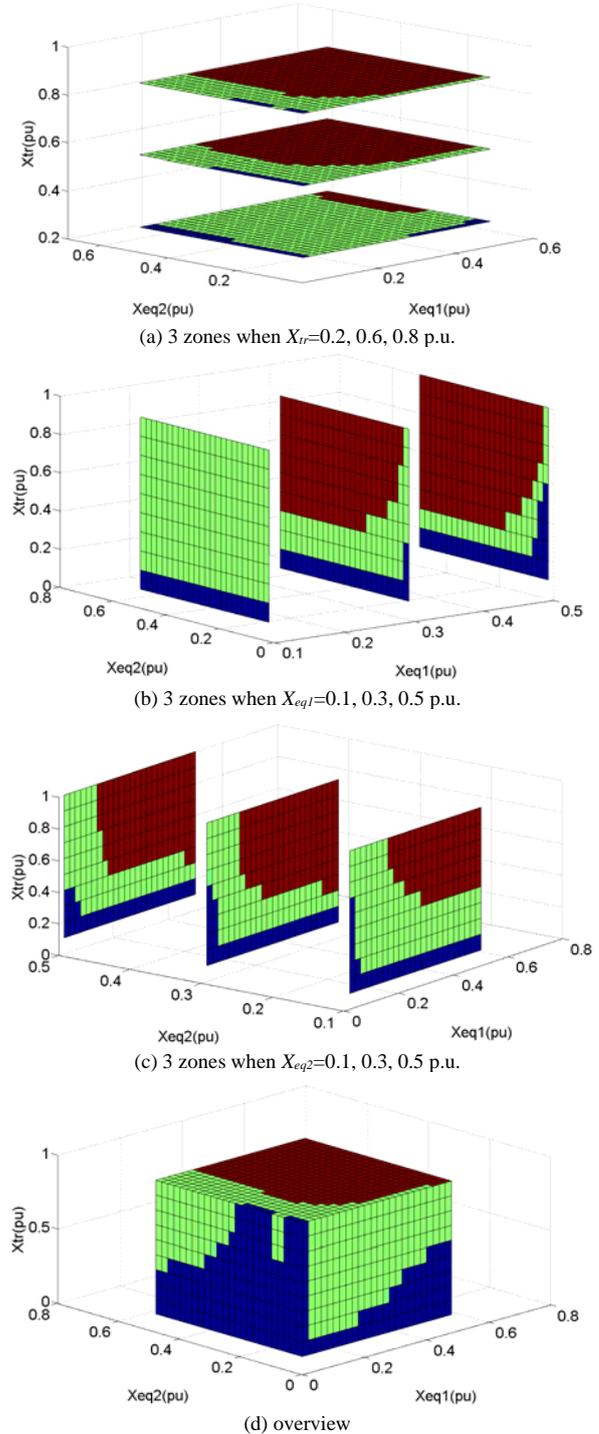


FIGURE IV. THE 3 ZONES (ZONE 1: BLUE, ZONE 2: GREEN, ZONE 3: RED)

Figure 4(a) shows that the area of Zone 3 is small when  $X_{tr}=0.2$ . When  $X_{tr}$  increases, the area of Zone 1 and Zone 2 reduce significantly and the risk of SSR increases.

Figure 4(b) shows that when  $X_{eq1}=0.1$ , there is only Zone 1 and Zone 2, and the risk of SSR are very low. With the increase of  $X_{eq1}$ , the area of Zone 3 increases, so does the risk of SSR.

Figure 4(c) shows that when  $X_{eq2}$  increases, the area of Zone 1 reduces while that of Zone 3 increases. This phenomenon means that the generator has a great opportunity to suffer SSR if the electric strength between Bus① and Bus③ becomes weak.

Figure 4(d) gives an overview of the relationship between electric strength and damping characteristics. The stronger the electric strength between AC Buses is, the lower risk of SSR the generator suffers.

Compared Figure 3 and Figure 4, CIF can take the place of the damping characteristics to demonstrate the relationship between electric strength and SSR.

### B. SSR Test

This section presents 3 ( $X_{eq1}$ ,  $X_{eq2}$ ,  $X_{tr}$ ) points (listed at Table 3) which are located at Zone 1, Zone 2 and Zone 3 respectively. Frequency spectrum analysis, damping characteristics and shaft torque are presented to prove that strong electric strength is critical for the generator to avoid the risk of SSR.

TABLE III. PARAMETERS OF ELECTRIC STRENGTHS

Case	$X_{eq1}(pu)$	$X_{eq2}(pu)$	$X_{tr}(pu)$	CIF	ZONE
1	0.03	0.03	0.013	0.03	1
2	1.56	0.06	1.287	0.24	2
3	1.56	3.88	1.287	4.57	3

Figure 5 shows SSR test results with different electric strengths.

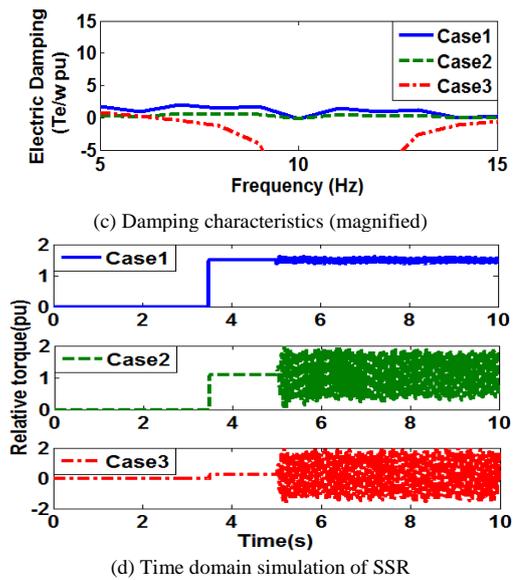
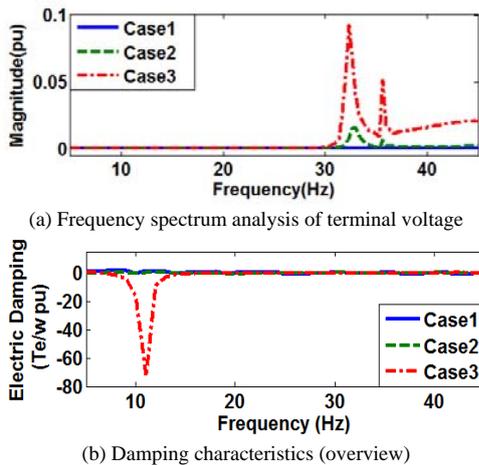


FIGURE V. SIMULATION TESTS OF SSR

Figure 5(a) shows the magnitudes of terminal voltage at sub-synchronous frequency component. In Case 1 there is no sub-synchronous disturbance at the terminal voltage while Case 2 and Case 3 have at disturbance energy at 37.5Hz.

Figure 5(b) shows the damping characteristics of the 3 cases and Figure 5(c) are the amplified part of Figure 5(b). At 12.5Hz, the damping of Case 1 is positive while that of the other cases are negative.

Figure 5(d) are the time domain simulation of the SSR for the 3 cases. There is dramatic SSR in case 2 and 3 while no SSR threat in case 1.

Therefore, the CIF can be used to analyze the risk of SSR instead of damping characteristics. Strong electric strength can assist the generator to avoid the SSR risk. The proper range of electric strength are the group of ( $X_{eq1}$ ,  $X_{eq2}$ ,  $X_{tr}$ ) points in Zone 1.

### V. CONCLUSIONS

This paper analysis the relationship between electric strength and the risk of SSR by using the CIF indicator. The computing process for forecasting risk of SSR is simplified because CIF is easier to obtained rather than the damping characteristics. Therefore, the proposed analysis method is more practical and convenient.

Strong electric strength between AC Buses is helpful to reduce risk of SSR. The proper range of electric strength is the group of ( $X_{eq1}$ ,  $X_{eq2}$ ,  $X_{tr}$ ) points in Zone 1 where the SSR will not happen.

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