Investigation of SSR Risk in Akkuyu NEPP

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Abstract

Subsynchronous Resonance (SSR) is the build-up of electrical and mechanical vibrations in power system as a result of interactions and energy interchanges between a turbine generator set and the rest of the power system which leads to significant shaft damages In general, power plants close to the series compensation may prone to several subsynchronous interactions, hence the risk analysis studies should be conducted to prevent possible hazardous effects. In this paper, SSR risk for Akkuyu NEPP which will be built in the southern region of Turkey close to series compensated transmission lines is investigated. The paper first provides brief information related to SSR phenomenon, types of SSR and techniques to analyze phenomenon. After, SSR study methodology for Akkuyu NEPP case and results are presented. Results of this study have revealed that there will be no SSR risk exists for planned network connection of Akkuyu NEPP.

1. Introduction

Series capacitor is an inexpensive way to increase flexibility of power systems especially where transmission line capacity and flow controllability is of concern. Especially in Turkish Power System in which large distances exist between demand and generation, usage of series capacitors is inevitable. However, this solution constitutes risk for nearby generators which is widely known as Sub-synchronous Resonance (SSR) phenomenon. SSR is the build-up of electrical and mechanical vibrations in power system as a result of interactions and energy interchanges between a turbine generator set and the rest of the power system which leads to significant shaft damages [1]. As well known, the drive shafts and couplings have finite stiffness so that each turbine mass coupled to the drive shaft will be slightly displaced with respect to the others. Consequently, any change in the rotor torque will cause movement in the masses, so that under certain conditions, the shaft torques can become excessive to be dangerous for the mechanical system. Therefore SSR risk for generators should be investigated in detail in order to prevent hazardous effects as reported in [2].

particularly;

- Induction Generator Effect
- Torsional Interactions Effect
- Transient Torque Effect.

For all of these interactions, shaft resonances of a specific turbine generator and the electrical resonances of the series compensated transmission network is investigated.

In order to identify and analyze SSR risk in a power plant, several techniques exist such as frequency scan, eigenvalue and time domain simulation. Among them frequency scan is relatively cost effective method in terms of calculation complexity especially when the system in consideration is relatively large. Moreover, frequency scanning technique offers to screen out those system conditions that are potentially hazardous from an SSR standpoint [3].

In this paper SSR risk in Akkuyu Nuclear Electric power plant which is planned to be built in the southern region of Turkey is investigated. This paper first, describes the information related to SSR and the methodology utilized in the study. Then, simulation study and results are given with conclusive remarks.

2. Types of SSR and Analysis Methodology

2.1. Types of SSR

An uncompensated transmission system will have positive electrical damping in the subsynchronous frequency range. Adding series capacitor compensation in a power system with synchronous frequency f_0 can cause negative electrical damping at electrical resonance frequency f_n. When the complementary frequency $f \_ f_n$ matches a resonance frequency of the mechanical system of one turbo-generator in the system, torsional interaction occurs. Torsional interaction with the negative damping effect becomes unstable and excessive if the inherent mechanical damping is lower than the negative damping effect [4]. This phenomenon is called subsynchronous resonance and it is examined under 3 different categories that are;

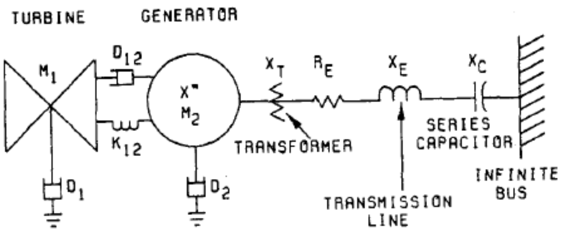
i) Induction Generator Effect: Induction generator effect causes self-excitation of a series capacitor compensated electrical system alone. Since the rotor circuits are rotating faster than the rotating magnetic field produced by the subsynchronous armature currents, the rotor resistance to subsynchronous currents viewed from the armature terminals is negative.. If the generator negative resistance exceeds the external system resistance, regenerated energy is not absorbed by the system and the currents of this particular frequency are self-excited. Such self-excitation would be expected to result in excessive voltages and currents [5].

ii) Torsional Interaction: Torsional interaction is a form of self-excitation due to the interaction between the turbine-generator shaft system and a series compensated electrical network. Small signal disturbances in a power system cause simultaneous excitation of all natural modes of the electrical and mechanical systems. When a torsional oscillation occurs to the turbines and generator rotating system at a subsynchronous frequency fn, while the generator field winding itself on the rotor is rotating at an average speed corresponding to the system frequency f, there will be voltages and currents induced in the generator armature three-phase winding at frequencies f-fn. Should the induced current of the subsynchronous frequency f - fn coincide or be very close to an electric resonance frequency fe (f - f_n = f_e) of the generator and transmission system, the torsional oscillation and the electrical resonance will be mutually excited or reinforced resulting in sustained or growing oscillations. In such a case, the electrical resonance acts as a negative damping to the torsional oscillation, and the torsional oscillation acts as a negative resistance to the electrical resonance [5].

iii) Torque Amplification: Following a significant system disturbance in a series compensated system; the resulting electromagnetic torque oscillates at a frequency f-f_e. If this frequency is close to any natural frequency of the turbine-generator shaft system, the resulting shaft torques could be much larger than those produced by a three-phase fault in an uncompensated system due to the resonance between the electrical and mechanical system [5].

2.2. Analysis Methodology

Identification, evaluation and mitigation are three main steps in SSR studies that ensure safe operation. Therefore the first step is to identify the possible SSR risk for the turbine generator set. In order to do that natural torsional oscillation frequencies of turbine generator set should be investigated. As T-G set consist of several rotating parts connected through coupling shafts as shown in Figure 1. Mathematical model of the T-G, called as spring mass model, shows as that the coupling shafts between each mass can be modeled as torsional spring with a stiffness constant. It is obvious that the natural torsional oscillation frequencies of the T-G set can be identified utilizing the mass, spring and speed information. As defined in the earlier section fundamental complement of this mechanical frequency is the electrical oscillation frequency in which SSR risk should be investigated.



M = rotational mass inertia
K = shaft stiffness
D = damping

Fig. 1. Turbine Generator with Series Compensated Transmission Line [5]

There are several several techniques exist such as frequency scan, eigenvalue and time domain simulation to investigate and evaluate SSR risk. Briefly, frequency scanning technique involves the determination of the driving point impedance over the frequency range of interest as viewed from the neutral bus of the generator under study. It is a cost effective linear method used to identify potential induction generator effect, torsional interaction and transient torque amplification problems which are potential SSR problems. The second one, Eigenvalue technique utilizes linearized set of system differential equations in order to calculate damping of torsional modes. Although it is an effective tool, due to disadvantages such as limited validity and inability to show effects of nonlinearity, this technique is not utilized. Finally the time domain simulation technique use step-by-step numerical integration to solve linear and nonlinear set of system equations. It utilizes highly detailed grid model and well suited for identifying torque amplification risks.

In this study several important gird configurations and generator dispatch scenarios are examined utilizing frequency scan and digital time simulations techniques. For the calculations entire Turkish grid model which is expected for 2020 is used.

3. Simulation Studies and Results

3.1. System Considered

For the SSR analysis, required data are collected from TEİAŞ and manufacturers of the plant, and converted into suitable forms for use in DigSILENT Power Factory program.

The grid configuration and load flow results for the investigated cases are obtained from previous grid connection studies of Akkuyu NPP conducted by TÜBİTAK MAM Energy Institute Power Systems Analysis and Planning Technologies Group [6-7]. As defined in these reports, grid connection of Akkuyu NPP is planned over six 400kV substations and two autotransformers as shown in Figure 2.

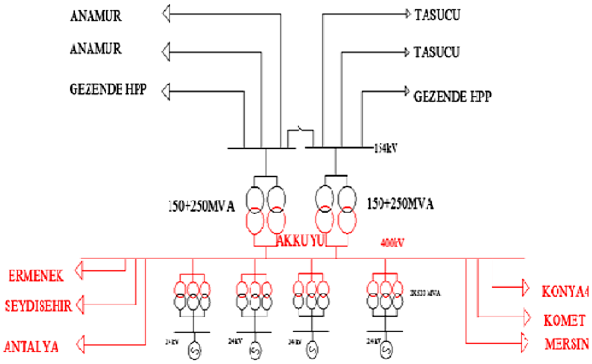


Fig. 2. Akkuyu SS Grid Connection Scheme

Although none one of the grid connections include series compensation, which reduces the SSR risk for Akkuyu NPP, connected substations such as Seydisehir and Konya includes series compensated transmission lines which may constitutes resonance risk for Akkuyu NPP.

3.2. Determination of Torsional Modes and Electrical Damping Factors

According to the mass-spring model information the torsional modes are calculated and given in Table 1. It is clear from the table that the calculated torsional frequencies that are supplied by the manufacturer and calculated are similar which ensures that the calculation model is appropriate and constructed shaft model for Akkuyu NPP is correct. Moreover the eigenvalues obtained from this shaft model is given in Figure 3 which also shows the torsional frequencies.

Table 1. Frequencies of torsional vibrations

Frequency, Hz	Frequency, Hz
(Calculated by plant owners)	**(Calculated by TÜBİTAK MAM Energy Institute)**
8.2	8.22
14	14.04
15.1	15.13

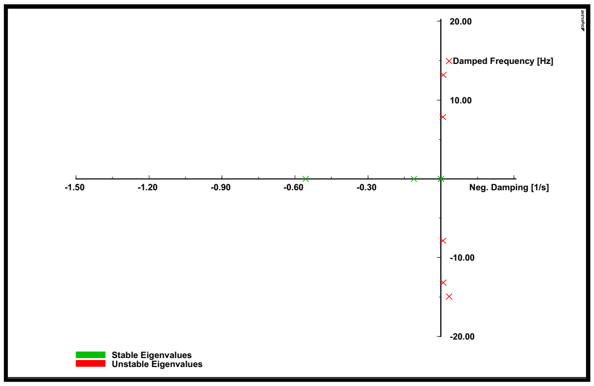


Fig. 3. Shaft Model Eigenvalues

According to the calculated torsional vibration frequencies, electrical oscillation frequencies are found as 41.78 Hz, 35.96 Hz and 34.87 Hz (ie. fe=50-fn) .

3.3. Network Frequency Scan

The equivalent electrical system impedance as seen from the Akkuyu NPP (behind the subtransient reactance of the unit considered) has been calculated for a number of contingencies for the frequency range of 1 - 150 Hz. The cases investigated include all combinations of n, n-1 and n-2 contingencies together with different system loading conditions, namely summer maximum and spring minimum, and different plant generation levels which makes total of 338 cases.

From the frequency scanning curves electrical dampings are calculated for identified electrical frequencies.The electrical negative damping (undamping) of the nth mechanical mode is directly related to the SSR conductance for that mode and is approximately defined by [3] as:

$$\sigma_{en} = \frac{50 - f_n}{8 f_n H_{eq}} G_n \qquad (1)$$

where

fn : nth mechanical modal frequency (Hz)

Heq : equivalent modal inertia (pu)

Gn : conductance of the electrical system including the generator on the machine base at (50-fn) Hz and found as

G_n =SSR Resistance/((SSR Resistance)^2+(SSR Reactance) (2)

Typically, the mechanical damping in SSR analysis can be taken as zero or can be approximated by

$$\sigma_{mn} = 0.005 f_n \qquad (3)$$

For the stability of the torsional modes, it is expected that;

$$\sigma_{mn} > \sigma_{en} \qquad (4)$$

The results of electrical damping calculations show that, in all cases, electrical negative dampings (σ_ei) are smaller than the corresponding mechanical modal dampings. As a result no torsional interaction problem is expected.

The following conclusions are drawn from the frequency scan analysis:

i) For all the 338 contingency analysis, the load flow scenarios have met convergence tolerance, including the (n-2) analysis, without any significant overload in the system. Considering the fact that, normally, the Turkish electricity transmission system is designed according to the (n-1) criterion, this fact shows the strength of the transmission system in the region. Effectively, this means that Akkuyu NPP is located at a very meshed region of Turkish electricity transmission system, drastically decreasing the SSR risk.

ii) No dips in the reactance as seen from the machine terminals occur. In addition, the total damping factor of the drive shaft is always positive, which means that the torsional interaction risk is not expected.

iii) In none of the cases simulated, SSR reactance at a subsynchronous frequency is zero or close to zero, as can be observed from the figures attached. Therefore, no induction generator problem is expected.

Also the risk of transient torque is investigated by computing the % dips in the reactance within +- 3 Hz of the electrical oscillation frequencies. As no dips are observed it can be said that the transient torque problem is not expected. However, in order to investigate the transient torque phenomenon in depth EMT simulations is carried out which are described in the next, chapter.

3.4. Torque Amplification Analysis

To complement the previous studies, the transient response of the system, especially on the masses of Akkuyu NPP turbine-generator is investigated for critical contingencies. The data provided by the generator manufacturer have been utilized in the analysis performed by DigSILENT Power Factory.

For all the load scenarios mentioned in the previous section and considered in the frequency scanning analysis, the dynamic models of the drive shaft and the generator have been constructed and the three phase fault is applied for each 380kV connection of Akkuyu NPP for the scenario showing highest SSR risk, namely summer 2023, which makes a total of 6 simulation cases. For each line, disturbance (three phase fault) is applied at t=0 sec and cleared at t=0.15 sec. The torsional torque between the different sections of the corresponding drive shaft for all scenarios are shown in Figure 4 – Figure 9. This figure illustrates that mechanical damping is capable of attenuating oscillations hence no torque ampplification occur in drive shaft of the machine.

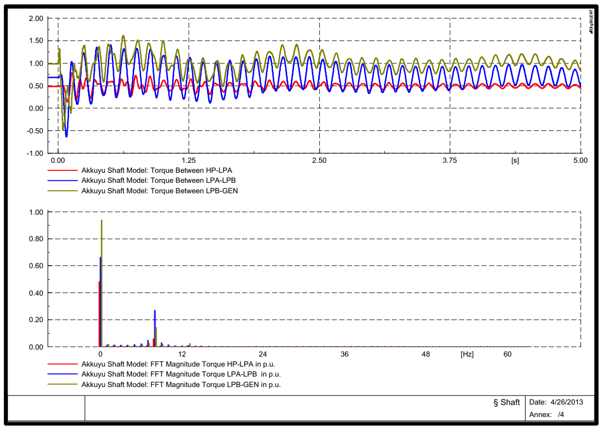


Fig. 4. Torques in Drive Shaft (Fault in Akkuyu SS- Antalya SS Line)

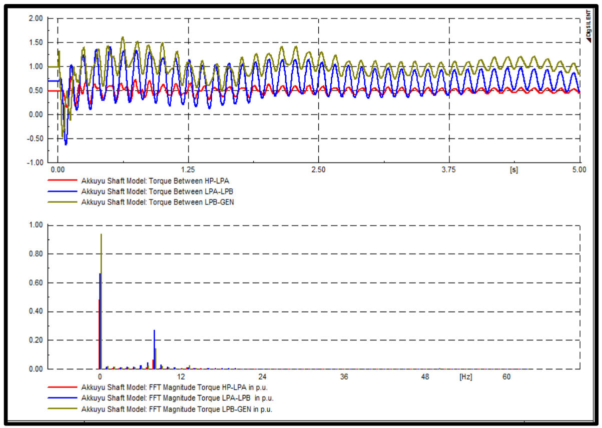


Fig. 5. Torques in Drive Shaft (Fault in Akkuyu SS- Ermenek SS Line)

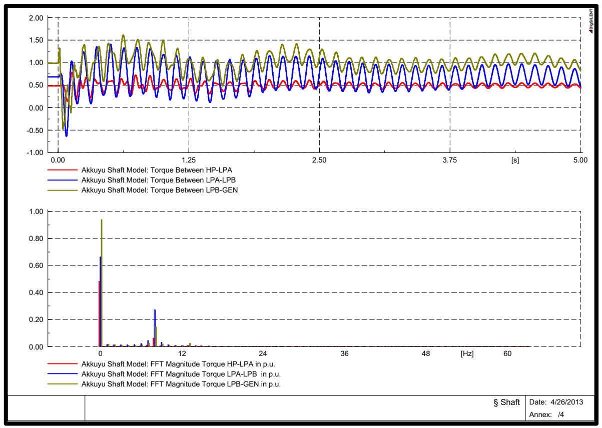


Fig. 6. Torques in Drive Shaft (Fault in Akkuyu SS- Komet SS Line)

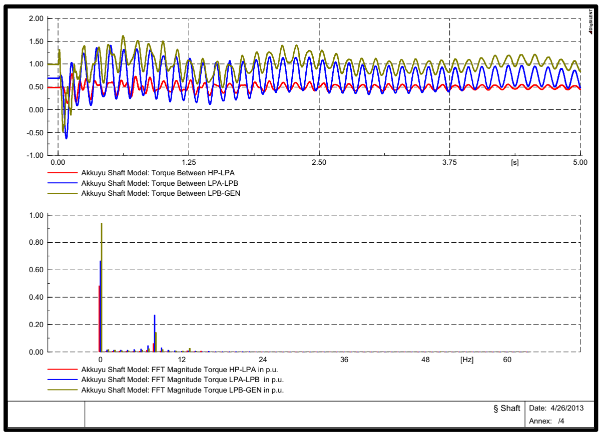


Fig. 7. Torques in Drive Shaft (Fault in Akkuyu SS- Konya SS Line)

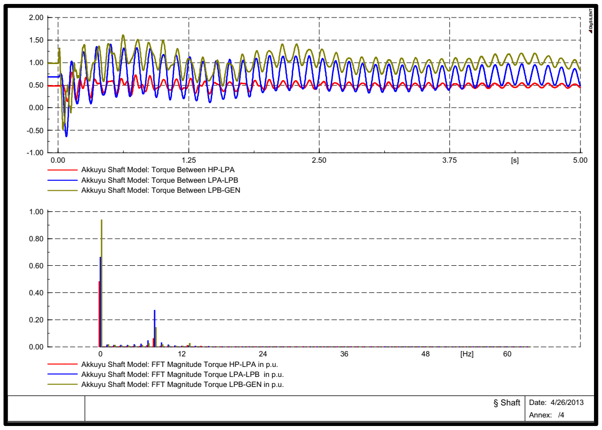


Fig. 8. Torques in Drive Shaft (Fault in Akkuyu SS- Mersin SS Line)

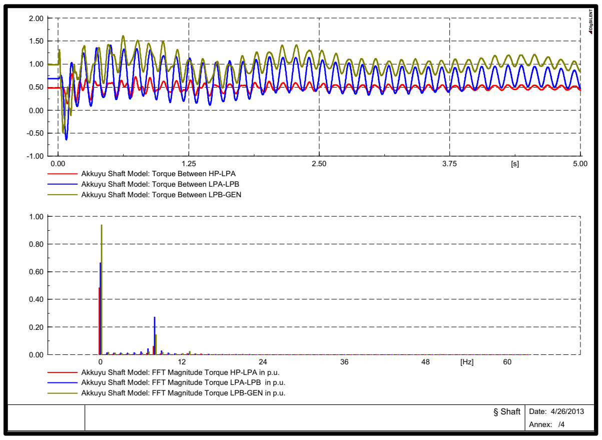


Fig. 9. Torques in Drive Shaft (Fault in Akkuyu SS- Seydişehir SS Line)

Transient torque analysis simulations have shown that no torque amplification problem is expected for Akkuyu NEPP. The case with lowest system damping is simulated; however, still sufficient damping is observed in the simulations.

6. Conclusions

In order to investigate SSR risk, several subsynchronous interactions should be checked to ensure safe operation. There are three main techniques explained to identify and evaluate the SSR risk. In Akkuyu study, several scenarios that are the combinations of different grid topologies, different loading conditions and generation dispatch conditions are examined. Frequency scan results show that there is no torsional interaction and induction generator problems exist for Akkuyu NEPP. Furthermore, no torque amplification problem is observed from time domain simulations. As a result, it can be concluded from the study that there is no SSR risk exists for Akkuyu NEPP. This is an expected result as Akkuyu NEPP is planned to be located at a very meshed region of Turkish electricity transmission system, drastically decreasing the SSR risk.

7. References

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