A Review on Mitigation of SSR in Series Compensated System by Using Induction Machine Damping Unit

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Abstract-- **The Sub-synchronous resonance (SSR) is the phenomenon which is caused by the series capacitor. Due to SSR two shaft failures was occurred at Mohave unit in 1970 and 1971. To mitigate SSR phenomenon many mitigation methods have been developed and successfully implemented, and many series capacitors have been installed and operated without incidents. Various FACTS controllers is used to mitigate SSR effects. Induction Machine Damping Unit (IMDU) is new proposed technique which is used to mitigate SSR phenomenon without using any controller. IMDU is generally connected to the system mechanically and electrically, it is mechanically connected to the shaft and electrically connected to the generator bus. IMDU is nothing but the induction machine which is worked as a motor or generator as per the SSR phenomenon occurred. The IMDU for damping SSR is simulated in MATLAB software using simulink and sim power system toolbox. Here the IEEE SBM model is used to analyze the SSR.**

Keywords— SSR, FBM, SBM, IMDU

I. INTRODUCTION

The first series capacitor application to transmission network was introduced in 1930's. In 1937, Charles Concordia reported the potential for adverse interactions between the series capacitor and turbine-generators (T-G), but such interactions never materialized until 1970. In 1970, and again in 1971, the Mohave generator in Nevada, USA experienced a gradually growing vibration that eventually led to a fracture of the shaft section between the generator and the rotating exciter. The interaction between series capacitor and torsional system is known as sub-synchronous resonance and it is abbreviated as "SSR".

Basically series compensation of a transmission line gives rise to the problem of sub-synchronous resonance in the

system which has many effects in which has two distinctive effects, namely induction generator effect and torsional interaction effect. SSR phenomenon is associated with the

energy exchanged between the turbine-generator mechanical and electrical systems.

There are many FACTS controllers devices which are used to mitigate the SSR phenomenon. But the IMDU is a new and latest concept to mitigate SSR.

An IMDU is a high power, low energy induction machine, with small rotor resistance and leakage reactance values, designed to operate close to synchronous speed. It is mechanically coupled to T-G shaft and electrically connected to the generator bus. The main contribution of this report include, an IMDU doesn't require any controller.

II. PRINCIPLE OF SUB-SYNCHRONOUS RESONANCE

Sub-synchronous resonance (SSR), as defined here, encompasses the oscillatory attributes of electrical and mechanical variables associated with turbine-generators when coupled to a series capacitor compensated transmission system where the oscillatory energy interchange is lightly damped, un-damped, or even negatively damped and growing. The electrical system frequency for a simple radial system (as shown in Figure-) is calculated using Equation which is shown below.

$$f_{er} = f_0 \frac{\sqrt{X_c}}{\sqrt{X'' + X_E + X_T}}$$

Sub-synchronous oscillation

Sub-synchronous oscillation is an electric power system condition where the electric network exchanges significant energy with a turbine-generator at one or more of the natural frequencies of the combined system below the synchronous frequency of the system following a disturbance from equilibrium. The above excludes the rigid body modes of the turbine-generator rotors.

A. Effect of Sub-synchronous resonance

Sub-synchronous resonance has many effects in which we are only considering the two basic effects.

1) Torsional interaction

2) Induction generator effect

3) SSR stability

4) Transient torque amplification

Torsional Interaction involves both the electrical and mechanical system dynamics. Generator rotor oscillations at a torsional mode frequency (fn) induce armature voltage components of sub-synchronous frequency (fen = fo – fn) and super-synchronous frequency (fen = fo + fn) When the frequency of the sub-synchronous component of armature voltage (fen) is close to an electrical system natural frequency (fer) the resultant sub-synchronous current will produce a rotor torque which is phased to sustain the rotor oscillations. If the component of sub-synchronous torque in phase with rotor velocity deviation equals or exceeds the inherent damping torque of the rotating system, the system will become self-excited. This interplay between the electrical and mechanical system is called torsional interaction.

Figure shows an example of a measured SSR instability during tests at the Wyodak generating plant when several lines were out of service. This plot shows the torsional angle displacement at the turbine end of the shaft. A series capacitor was inserted at the start of the test, causing a growing torsional oscillation. Bypassing the series capacitor 128 seconds after the start of the test removed the unstable SSR conditions and the torsional oscillations decay.

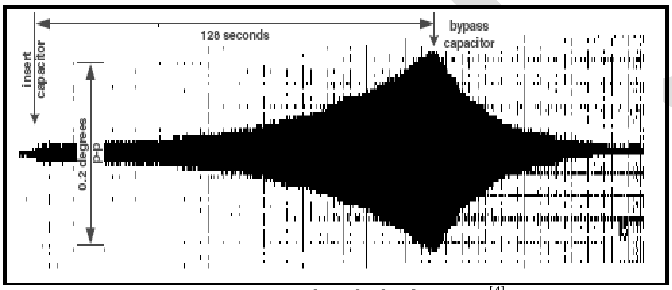


Figure-SSR-Torsional angle displacement[4]

B. Mitigation of SSR

There are many methods to mitigate SSR effects.
1) Reduced Compensation Level and Operating Procedures.
2) Passive SSR Blocking Filters at the Generator.
3) Passive SSR Filters and the Series Capacitor.
4) Thyristor Controlled Series Compensation (TCSC).
5) Supplemental Excitation Damping Controls (SEDC).
6) Torsional Relay Protection.
7) Induction Machine Damping Unit (IMDU) etc..

Here, we will discuss on IMDU.

C. IEEE Second Benchmark Model

Second Benchmark Model which deals with the "parallel resonance" and interaction between turbine-generators with a common mode. Specifically, the following two system configurations are provided as benchmark models.

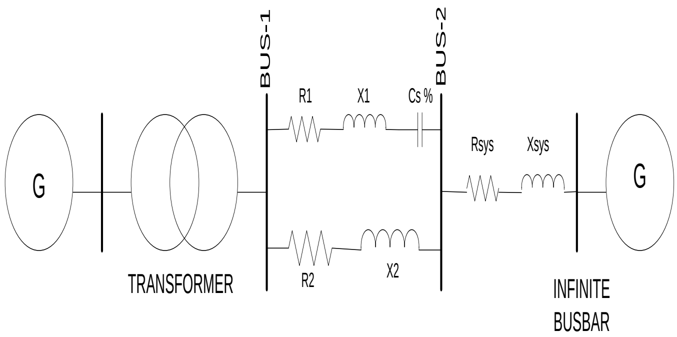
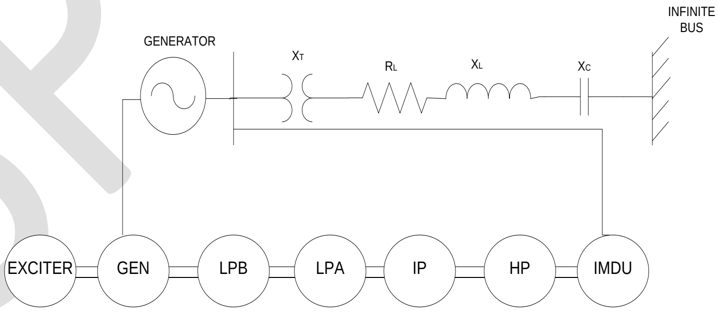


Figure-IEEE second benchmark model

SYS-1. A single generator connected to two lines, one of which is series compensated.

SYS-2. Two different generators, having a common torsional mode connected to a single series compensated transmission line.

D. Induction Machine Damping Unit



An IMDU is a special high-power, low energy induction machine, with small rotor resistance and leakage reactance values, designed to operate close to synchronous speed. It is mechanically coupled to the turbo-generator (T-G) shaft and electrically connected to the generator bus.

When the shaft speed is less than synchronous speed, the IMDU acts as a motor accelerating the shaft. When the shaft speed exceeds synchronous speed, then the machine becomes a generator decelerating the shaft towards synchronous speed. At synchronous speed, the IMDU remains dormant (constant), producing no torque.

Modeling the Induction Machine Damping Unit

For the eigen-value analysis, the torque-speed characteristics of an induction machine, with small rotor resistance, to be used as IMDU can be considered linear between synchronous speed and the critical slip (maximum torque) when operated at constant terminal voltage and frequency. Therefore, the torque of the damping unit can be modeled as being proportional to speed deviation, (deviation from synchronous speed). The slope of the torque-speed characteristic found as: [11]

$$k = \left|\frac{\Delta Tim}{\Delta Wim}\right|$$

The field exciter dynamics is not modeled and the excitation is held constant at 1 pu. The time constant of the mechanical system is very large when compared to the electrical system, and hence, the speed governor dynamics are not included, keeping the input power to the turbines constant. Variables torque produced in the different shaft section, which are functions of the difference of the slip at the ends of the shaft. The differential equations governing the IMDU model are as follows: [11]

$$T\dot{p}1 = Kim(Sim - Shp)$$

$$S\dot{i}m = -Dim - \frac{k}{2Him}Sim - \frac{Tpi}{2Him}$$

E. Simulation and Results

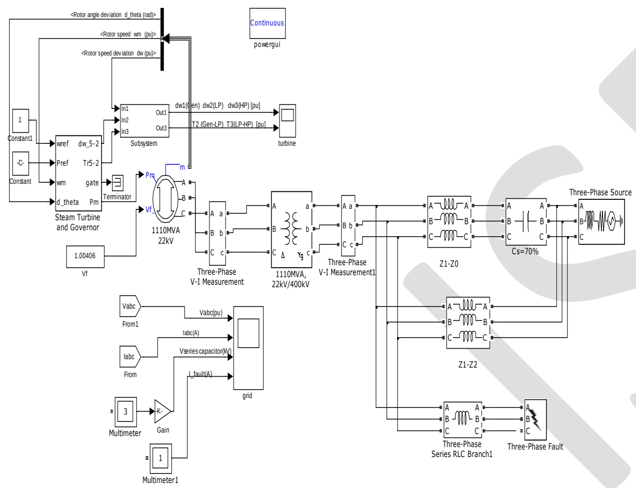


Figure-Simulation of SBM Results

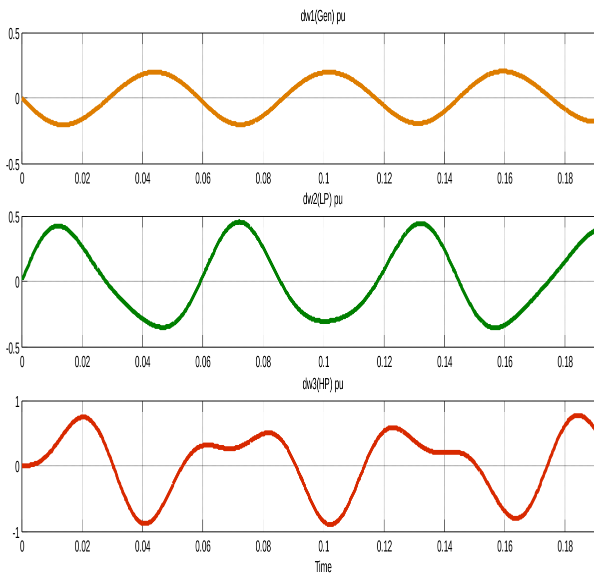


Figure-Results of rotor speed deviation

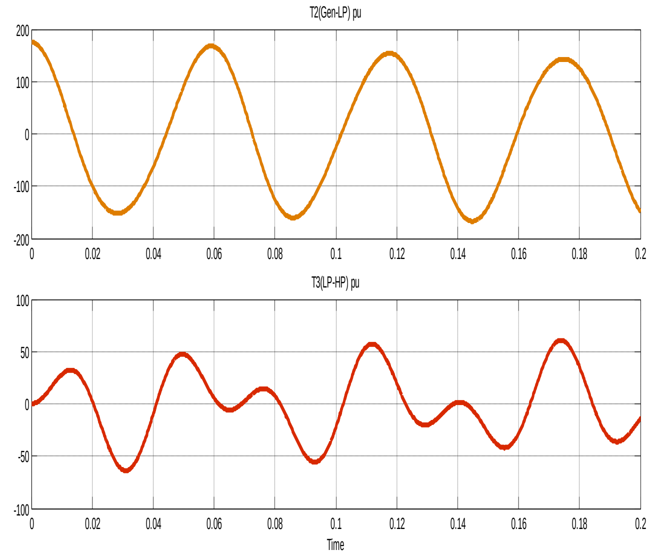


Figure-Results of Torque

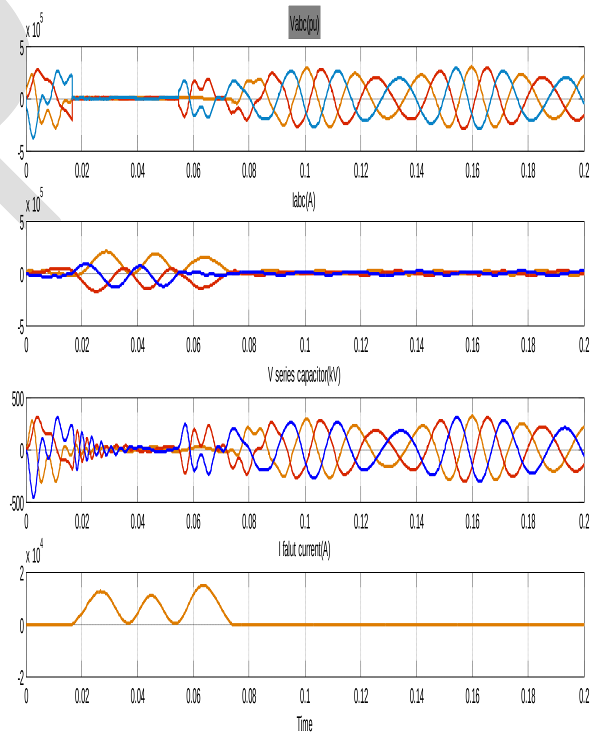


Figure-Resluts of Vabc, Iabc, Vseries capacitor, Ifault current

CONCLUSION

An IMDU is a device which is used to damp out the SSR phenomenon without using any controller. IEEE Second Benchmark Model is used to analyze SSR. Simulation of SBM is carried out for SSR effects.

The inclusion of the IMDU on the T-G shaft can eliminate torsional interaction type of SSR oscillations without the aid of any other controller.

APPENDIX

GENERATORDATA:-1110MVA, 22kV,Ra=0.0036,Xl=0.21

Parameter	Positive sequence	Zero sequence
RL	0.02	0.50
XT	0.14	0.14
XL	0.50	1.56
Xsys	0.06	0.06
XC	0.35	0.35

SYNCHRONOUS MACHINE PARAMETERS

Reactance	Value, Pu	Time Constant	Value, Second
Xd	1.790	Td0’	4.300
Xd’	0.169	Td0’’	0.032
Xd’’	0.135	Tq0’	0.850
Xq	1.710	Tq0’’	0.050
Xq’	0.228		
Xq’’	0.200		

MECHANICAL PARAMETERS

Mass	Shaft	Inertia M(sec)	Spring constant K(pu/rad)
EXC		0.0342165	
	GEN-EXC		2.822
GEN		0.868495	
	LPB-GEN		70.858
LPB		0.884215	
	LPA-LPB		52.038
LPA		0.858670	
	IP-LPA		34.929
IP		0.155589	
	HP-IP		19.303
HP		0.092897	

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