ARPN Journal of Engineering and Applied Sciences

DETERMINATION OF STRESS ON TURBINE GENERATOR SHAFT DUE TO SUBSYNCHRONOUS RESONANCE USING FINITE ELEMENT METHOD

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ABSTRACT

Power Capacitors plays a vital role in reactive power compensation. When the capacitors are connected to the transmission line, it improves the reactive power. Although the reactive power is improved, there is a possibility for sub synchronous resonance created by this capacitors in the transmission line which can impact the generator frequency. The sub synchronous resonance causes electro-mechanical stress in the generator shaft which ultimately leads to malfunction of the entire power generating unit. It is necessary to find out operating modes of the generator and turbine when the line is compensated with capacitors. Once the operating modes are clear, it is possible to damp the sub synchronous resonance. In this paper, three phase generator is coupled with a prime mover and capacitors are connected before the load. The stress on the turbine is analysed based on the torque of two rotating machines. Finite element method is used to estimate the stress in the turbine generator shaft system.

Keywords: finite element method, ANSYS, shaft, series compensation, sub synchronous resonance.

1. INTRODUCTION

Misalignment of shafts in the turbine generator system is one among the most common trouble of any drives in a power generating station. Alignment of shaft without any deviation is not practical to achieve since it handles a several tons of mass on it. Couplings connected to the shaft creates parallel and angular misalignment, in several cases it may also create axial and lateral misalignment. Cost of operating a turbine during the tenure is compared with the power generation. Most of the industry follows reactive maintenance where they fix the system when it breaks and preventive maintenance where the operator follows the manual. In order to operate the power generating unit, predictive maintenance is preferred [1]. Natural frequency of the rotating machine with mechanical load is not constant and the frequency which is calculated is not accurate [2]. When the pulsating torque arises in the system, it leads to increasing stress in the shaft of the turbine generator. Weak points in the shafts get damages first and further torque will result in permanent damage. It is ideal to have a method which offers a technical and logical solution to monitor the operation of the turbine which will focus on the alignment. Misalignment arises in the system due to several reasons, one such reason is sub synchronous resonance which comes in to the system due to the series compensation which is essential to have the reactive power under control. Series capacitors connected in the power transmission line to compensate the reactive power requirement. The high-power capacitors are rated up to 100MVAR till 132kV transmission line [3]. When these high rated capacitors are connected to the transmission line, it injects a frequency into the transmission line which can be either sub synchronous frequency or super synchronous frequency. Several literature survey have recorded that sub synchronous resonances arises in both the generator terminal and also at substation. The main objective of this research is focused on determining the weak points in the shaft which connects turbine generator system when it has pulsating torque due to the addition of series capacitors. Experiments are carried over on two rotating mass having electrical load and series capacitors.

2. SIMPLIFIED SHAFT ASSEMBLY MODEL

In a large-scale machine, there is a coupler connected between the generator and the turbine. In case of thermal power plants, the turbines are separated based on the load that takes from the system. High pressure turbine, low pressure turbine and intermediate pressure turbine are involved in the power generation. Including the generator and exciter, there are six masses in the total turbine shaft system. When the shaft is loaded with external torque, decoupled Newton's law can be applied to explain the system and circumstances [7]. So even for a small torque, the amplitude will increase over time. Figure-1 represents a simplified shaft model and Figure-2 represents the experimental set up which is analogous to the same model represented in Figure-1. If there is no damping or enough protection, the shaft will be stressed more and it gets damaged. It can be extended when the system has multiple masses especially in thermal power plants and hydro power plants. Figure-2 represents two rotating mass in the experimental set up.

VOL. 14, NO. 1, JANUARY 2019 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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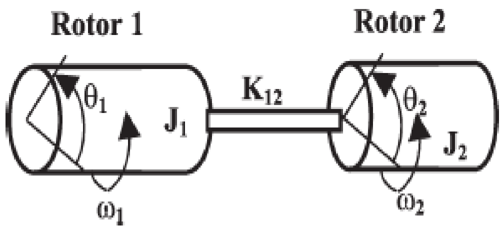

Figure-1. Simplified flexible shaft with two rotors.

Figure-2. Experimental set up for stress determination.

3. EXPERIMENTAL SETUP

In this research paper, experimental set up denotes generation of electric power using a turbine. The generated power is transferred the load. Capacitors are added to the system to compensate the reactive power obtained in the system. It is clear from the experimental set up, generation; transmission, distribution and reactive power compensation is involved. The machines are not high power machines which are used in the power plants and it is not possible to test in the machine which is online in the power system. To overcome the problem, a prototype is made in the laboratory using low power machines. Experimental setup consists of a two rotating machines, resistive load and capacitors the ratings of the machines are given in Table-1. The two rotating machines are connected through the same shaft using a coupler. The shaft is made of stainless steel and the coupler is made with galvanized iron.

Figure-3. Experimental set up.

Table-1. Machine parameters.

Machine 1		Machine 2	
Source	**AC**	**Source**	**DC**
Output power	2.2kW	Output power	3.7kW
Max speed	1500rpm	Max speed	1500rpm
Voltage (Max)	415V AC	Voltage (Max)	220V DC
Current (Max)	4A	Current (Max)	19A
Insulation class	F	Insulation class	F

The coupler ensures that misalignments in the machines are minimum. It also helps in transmission of mechanical power and torque between the two rotating shafts. DC motor in the system drives the three-phase synchronous generator. When the dc excitation is given to the synchronous generator, it starts generating power. The electric power is transferred to the load. Capacitors are connected to the system to improve the reactive power requirement [6].

The experimental results are tabulated in Table-2. The experimental results show that the torque produced in the machine keeps increasing when the compensation increases. Increase in torque causes more stress on the shaft which leads to misalignment. As the compensation increases, torque produced by the machine increases. Since the machine is given F class insulation [4], the temperature rise must not go beyond 155 degree Celsius. The compensation in any transmission line will be in the range of 10%-55%.Line current increases by 42% for every 10% increase in the compensation. The synchronous generator in the experimental setup is rated till 4 amperes. It is not possible to increase the compensation by more than 30% in the experimental set up considering the safety of the equipment. Based on the linearity obtained in the torque, current and speed was predicted. During the operation, it was identified that the illumination of the lamp increases as well as the vibration in the machine mount increases when the compensation increases. Since the work of the turbine is done by the DC Motor, the stress on the motor increases even for 10% compensation. Brush in the DC motor started giving sparks when the compensation increases beyond 30%.

VOL. 14, NO. 1, JANUARY 2019 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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Table-2. Output parameters - I.

Results				
Degree of compensation (%)	**Voltage induced** (volts)	**Current generated** (amps)	**Speed of the shaft** (rpm)	**Torque induced in the machine** (Nm)
10%	448	2.1	1543	3821
20%	481	3.4	1560	7643
30%	514	3.8	1597	9461
Predicted results (ratio method)				
40%	547	4.2	1627	10981
50%	607	4.5	1786	12234

4. SIMULATION RESULTS AND DISCUSSIONS

Finite element method started with analysing static, deformation and elastic problems. Technology has improved which made finite element method to analyse the dynamic problems where both vibration and transient condition are studied in the system. It is used to study the fluid flow and heat transfer in various non-structures. In finite element method, the simulation is carried on large structures which have complex geometry. The simulation software breaks the complex structure into tiny parts that interacts which each other. Modelling of the static or dynamic structure is the first step in the analysis. Boundary conditions are marked and the equilibrium equations are solved. From the values of the nodal displacement, the stress and strain are analysed. In this research paper ANSYS software package is used for modelling and analysis for the parameters identified in the experimental set up. The shaft which connects the two machines in the experimental set up is modelled i with the exact dimension of the experimental setup. The coupler is designed in such a way it improves mechanical strength and also it automatically adjust the misalignment.

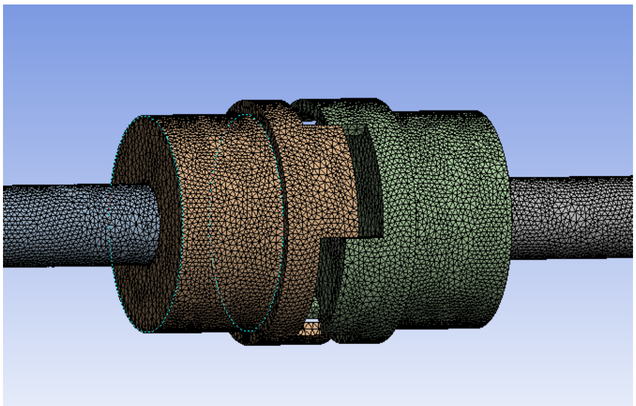

Figure-4. Meshing of the coupler.

Material properties are taken into consideration during the design. The model is tested for the total deformation, equivalent elastic strain, equivalent stress &strain energy. It is clear from the results, the stress and the strain in increasing when the torque is increasing. Experimental results shows that when the compensation increases, torque between the two running machine increases. Minimum deformation occurs in the coupler as it enhances the mechanical strength and it damps the misalignment when the rotating shaft deviates from the equilibrium. Figure-4 shows that the equivalent stress on the coupler is minimum when compared to the shaft and damage caused by series compensation directly impact the shaft more when compared to coupler. The weak points in the entire set up will have more stress when compared to others.

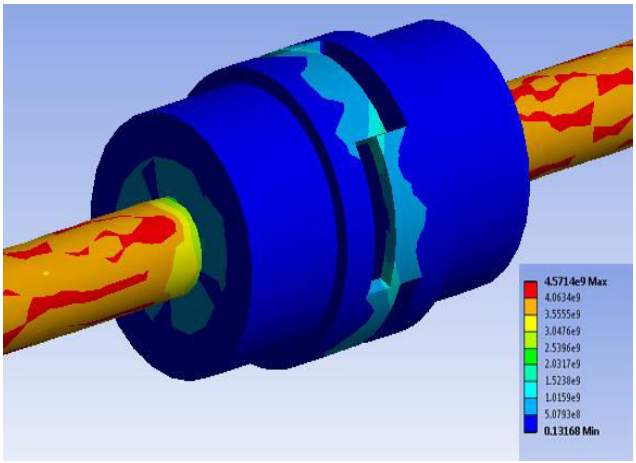

Figure-5. Equivalent stress on the coupler when torque 12234 N.m.

Figure-5 shows the equivalent stress happening between the rotating mass and the point which connects the shaft and rotating mass. The stress originates from the center of the circular rotating mass and flows circularly towards the edge. The shaft which connects the rotating mass gets more stresses when compared to the rotating mass

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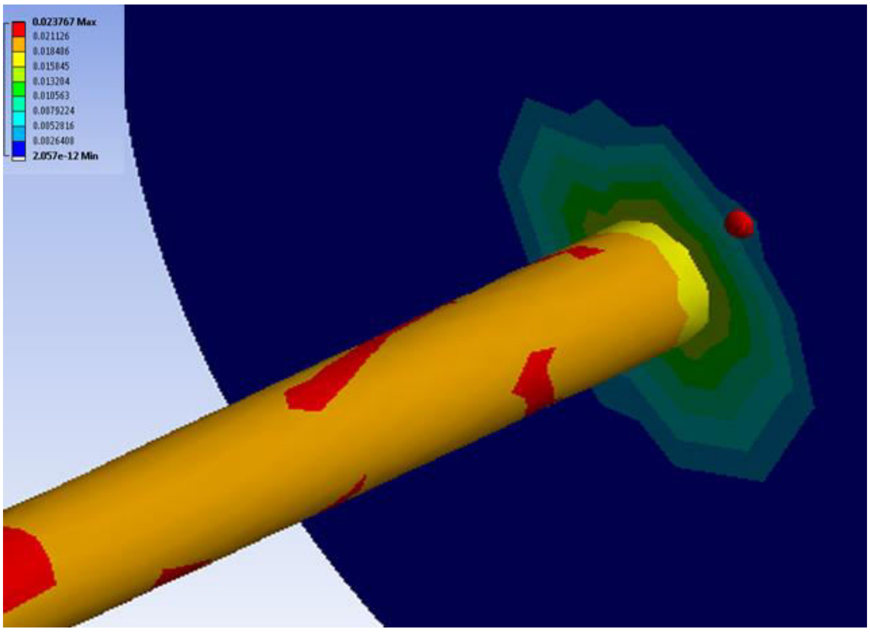

Figure-6. Equivalent stress on the rotating shaft of the generator.

Table-3. Output parameters -II.

Torque	Total deformation		Equivalent elastic strain	
	Maximum	Minimum	Maximum	Minimum
3821	$1.772e^{-5}$	$1.4493e^{-15}$	.00742	$6.424e^{-13}$
7643	$3.546e^{-5}$	$2.899e^{-15}$	.01484	$1.285e^{-12}$
9461	$4.389e^{-5}$	$3.588e^{-15}$	.01838	$1.590e^{-12}$
10981	$5.094e^{-5}$	$4.165e^{-15}$	.02133	$1.843e^{-12}$
12234	$5.676e^{-5}$	$4.640e^{-15}$	.02376	$2.057e^{-12}$

Table-4. Output parameters -III.

Torque	Equivalent stress		Strain energy	
	Maximum	Minimum	Maximum	Minimum
3821	$1.427e^{9}$	.04112	2.5129	$4.79e^{-21}$
7643	$2.855e^{9}$	.08226	10.054	$1.91e^{-20}$
9461	$3.535e^{9}$	.10183	15.406	$2.94e^{-20}$
10981	$4.103e^{9}$	.11819	20.754	$3.96e^{-20}$
12234	$4.571e^{9}$	.13168	25.761	$4.91e^{-20}$

5. CONCLUSIONS

Capacitors are used in transmission lines for reactive power compensation. When capacitors are connected along the line, it leads to resonance. Resonance in the line may create sub synchronous frequency or super synchronous frequency which leads to fatigue in the turbine generator shaft system. In this research paper, an experimental set up which demonstrates generation, transmission and distribution with low power rated machine is experimented. It is observed that the capacitors improve the reactive power and at the same time it causes stress in the turbine generator shaft system due to the frequency change in between the turbine and generator. The vibration caused in the turbine generator mount increases when the capacitors are added to the line. These vibrations are the result of the frequency mismatch.The coupler in the machine helps in improving the misalignment and continuous operation may lead to severe damage in the turbine generator shaft system.

ACKNOWLEDGEMENT

The authors are grateful to Christ (Deemed to be) University - Department of EEE, Faculty of engineering for providing the laboratory facilities and Department of EEE, Ghousia College of engineering Ramanagaram (Affiliated to Visvesvaraya Technological University), Karnataka India.

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