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INTER-TURN FAULT IN ROTOR OF SYNCHRONOUS MACHINE

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Background

Synchronous machines in large power plants vary in size from 60MW to 1000MW. The thermal units are two-pole cylindrical pole machines. In Captive Power Plants (CPP) the unit sizes vary from 2 to 20MW and are usually steam or gas turbines. Here also if the speeds are 1500 RPM or 3000 RPM, Rotor are usually cylindrical pole machines. Many times DG sets are used in captive power plants with sizes varying from 1MW to 15MW also. DG sets are typically low-speed machines (500 RPM, 750 RPM, 1000 RPM) to minimize maintenance issues rotors are invariably salient pole machine's (12 pole or 8 pole or 6 Pole).

A case study illustrating the problems faced using salient pole machine for high-speed operation is described below.

In a Petro Chemical Complex, there are a total of 7 nos. Generators of different ratings connected directly to 11kV buses. Out of these 7 nos, there are two nos 13.6 MW Gas Turbine Generators, which operates at 1500 RPM and are with salient pole Rotor construction supplied by vendor no 2. The balance five generators are cylindrical pole machines from Vendor no 1. Grid power is received through 31.5MVA and 40MVA, 66kV / 11kV Transformers on two different 11kV buses. The group of generators on each bus is operating in synchronism with the grid, with the respective Grid Transformers.The two generator under discussion from vendor no 2, the prime mover is a Gas turbine running at 11,000 RPM and connected to the generator running at 1500 RPM through the rigid coupling.

These generators were commissioned about 12 years back. After the initial operation of five years, the units were taken offline for five years due to higher gas prices. After this shutdown period, these generators were taken back in service after required maintenance and also diagnostic testing. The Generators were found healthy in diagnostic Testing.

The Generators are being maintained by Expert Maintenance Engineers and OEM Engineers.

However,recently, in the last one year, two salient pole machines from Vendor 2 failed. Each machine failed twice. In all the cases the cause was the rotor earth fault. The customer is not aware why Vendor 2 has supplied a salient pole machine for high speed (1500RPM) application. One of the reasons could be the reduced cost. Second reason can be that, vendor 2 has a very strong presence in DG sets manufacturing which are slow speed machine and almost by default a salient pole machines are supplied. The manufacturing process and tooling in the shop floor must have been tailor-made for mass production of salient pole machines for DG Set. So,for manufacturing, only a couple of high-speed machines it may be more economical to offer salient pole machines hence, vendor 2 supplied salient pole rotor instead of cylindrical rotor. The cylindrical rotor machine will require a redesign and retooling, thus it will be an expensive machine. However, the reliability of salient pole machines for high-speed applications is a question mark.

Vendor Response:

Vendor 2 attributed failure to following reasons:

Micro-Grid Disturbance in grid

The precise definition of 'Micro Grid Disturbance' is not known. The units are connected to the state grid and are subject to usual voltage and frequency variations in the grid. Especially after 2014 with the formation of a single national grid, grid frequency variation is within 1%. The grid voltage variations are well within 10%. Most of the faults in the EHV system are cleared within 100 msec and in a few cases within 300 msec by backup protection. The captive generators are designed to withstand the above-mentioned grid disturbances.

Pole slip conditions

Most of the faults in the EHV system are cleared within 100msec and in a few cases within 300 msec by backup protection. Hence, the possibility of pole slip is very rare. It is to be noted that small machines rated below 15MW are very rarely provided with pole slip protection. It is recommended only for large machines of size greater than 100MW.

Improper synchronization

All generators are provided with Auto-synchronizers, whose settings are also given by OEM. Operators use only Auto-synchronizer for synchronizing the unit with the grid. If the given settings are correct, chances of improper synchronization are very remote.

Absence of grid voltage for some time and reappearance of voltage

Circuit Breakers from 220 kV to 11 kV are all three-phase operated. These breakers don't have Auto Re-closure facility. Hence, this possibility is also very remote.

Root Cause Analysis

RSO (Recurrent Surge Oscillograph) Test

Before taking the units in service, as part of pre-commissioning checks, the diagnostic testing on Rotor Winding was carried out by a testing agency. RSO (Recurrent Surge Oscilloscope) test was done from both ends of rotor winding is a reliable one to identify inter-turn faults in the rotor winding. With modern instruments the test can be performed with the rotor in position, rotor threaded out or even online when the machine is in service.

RSO waveform indicated that rotor winding had an inter-turn fault. The instrument used was a well-established brand and inter-turn fault was confirmed by making measurements from both ends. The rotor had a pre-existing fault from manufacturing stage itself. This was the root cause. European Principal of Vendor 2 advised the customer strongly to ignore these symptoms as they do not have much faith in RSO test results especially when the tests were conducted with the rotor in position. Though the testing agency requested the Vendor to open up the machine and inspect the rotor, it was overruled. The customer was also in a hurry to bring the unit back in service, hence, commissioned the units. With inter-turn fault in the rotor, the machine was in operation for almost 4 to 5 months before the units tripped on rotor earth fault protection.

During this period, for external grid faults and also during system voltage variation, higher excitation current had to be supplied through the rotor winding. In fact, in case of an external fault, field forcing feature of excitation system raises the excitation field voltage to 1.7 U0. This results in higher current passing through the excitation system/rotor winding every time there is such a requirement. This has resulted ultimately in the rotor winding insulation failure resulting in Rotor Earth Fault.

Vibration

The vibration was monitored continuously. Though vibration showed an increasing tendency it did not reach alarm limits. The O&M team suspected vibration problem is related to alignment issues due to known faulty foundation footing. They were misled as the vibration level increased significantly just before the failure of the rotor which was detected by Rotor Earth Fault Relay.

Rotor Construction

Generally, salient pole machines are used for Low RPM machines, say 250, 500, 750 or maximum 1000 RPM. In this case, Vendor 2 surprisingly delivered a salient pole generators for 1500 RPM machines. Thus this rotor has a very heavy mass and acts as cantilever during rotation. This exerts large friction between the two turns of the rotor winding with thin insulation. This increases the chances of inter-turn failure.

It is pertinent to point out here that the four cylindrical pole machines supplied by Vendor 1 did not suffer any rotor earth fault even though they are also operating on the same 11KV Bus and also under same grid conditions.

Conclusion

The lessons learnt are summarized below

RSO Test

This is a well-proven and important test for detecting inter-turn faults in rotor windings. If the results indicate the presence of a fault in rotor winding, the customer should not prima facie ignore the results even if advised so by OEM. It is better to have a second opinion from an independent expert before taking the machine into service.

Vibration

Increase in vibration is an indirect indication of the failure of the rotor winding. To facilitate differentiation between vibration-induced due to improper mounting/alignment and rotor earth fault, civil foundation / footing / anti vibration pads must be as per accepted codes and standards and the construction at the site is supervised for strict compliance as per design drawings.

Salient Pole Machine

For rated speed above 1000RPM, only cylindrical pole machine is desirable and salient pole machine should be avoided. This shall be incorporated in specification during procurement.

OEM responsibility

The Vendor has to supply machines considering the prevailing grid conditions as the customer's plant can't influence grid conditions even in a minor way. When a failure occurs, despite commissioning test results showing the possibility of fault in the rotor, he must take responsibility for the risk he has taken and done the necessary repairs. It reflects poorly on the Vendor if he tries to justify his action with vague jargons that can't be understood by customer engineers. Also quoting the statements of Principals by Vendor as gospel truth will not solve customer's problem. Only the Vendor knows local grid conditions under which his machines will operate

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