

Case Study

Evaluation of a Gearbox's High-Temperature Trip

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INTRODUCTION

A typical nuclear generating station has a number of safety-related systems required to safely shut down the reactor during any upset operating condition. Because these systems are on stand-by duty and have a very limited number of operating hours, the independent regulatory agency requires that all critical equipment in these safety-related systems be periodically checked for availability. Various tests are performed to satisfy this requirement, and the test results are carefully reviewed to confirm equipment conditions.

One such safety-related critical system is emergency power generation (EPG). The primary function of this system is to immediately generate electric power for safety-related equipment if the normal power supply is disrupted. To improve the system reliability, two independent EPG systems are provided:

EPG1 and EPG2. The major component of each EPG system consists of a gas turbine with gearbox and generator. (See fig. 1, 2, 3)

A 24-hour test run was started July 14, 2002, to establish EPG2 reliability following maintenance on the fuel system and lowering of the lubricating oil pressure set point on pressure control valve PCV901. (See fig. 4) The test revealed EPG2 failed after 23.5 hours of operation at full load on high gearbox bearing oil drain temperature.

The temperature element is located inside the gearbox, below the bearing, in the oil drain path from the bearing. The operator also noticed a significant lubricating oil leak from the gearbox bearing seal. Approximately one minute before the trip, the fuel pressure, engine temperature (T5) and the output of generated power (MWs) were unstable.

Figure 1. Schematic of generating set

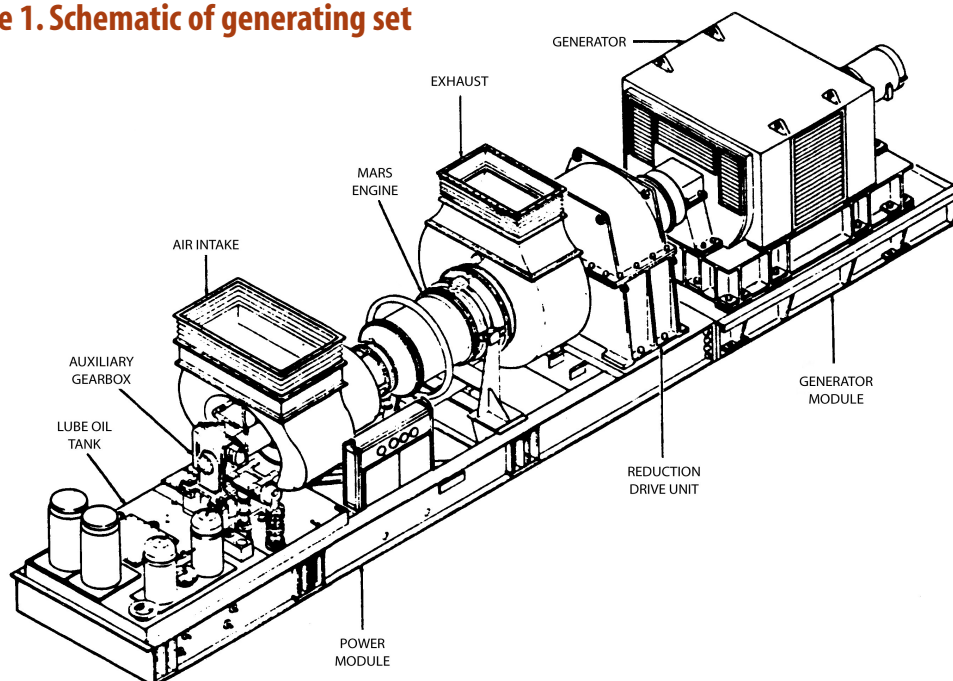
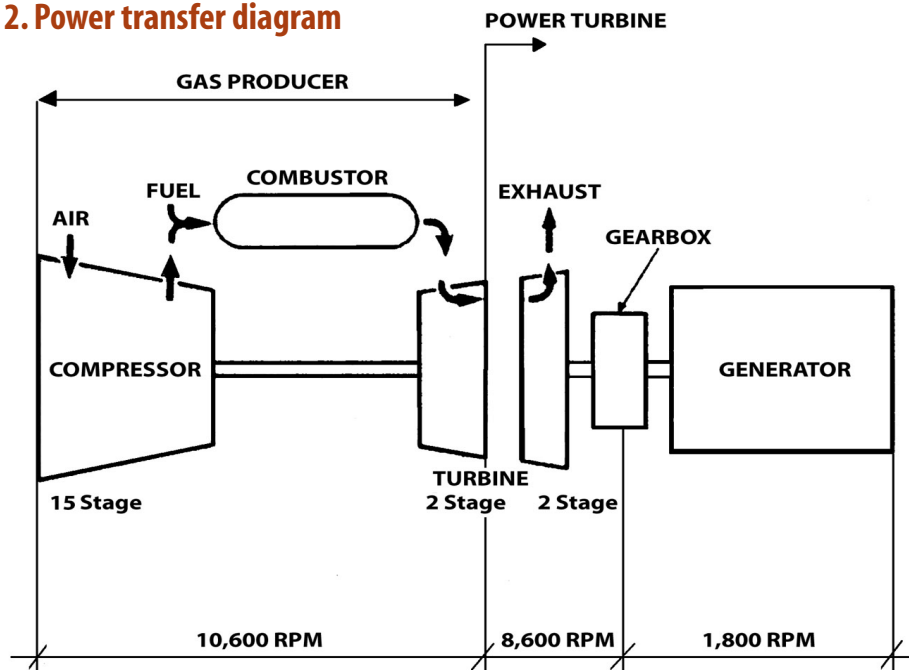


Figure 2. Power transfer diagram

INVESTIGATION SCOPE

The scope of this case study was to investigate the EPG2 trip on July 15, 2002, and establish the root cause(s) of the event. The investigation's scope included the following:

- * A review of recorded data and the recent operating history of EPG2. The review was also to include a very similar event on EPG2 that occurred one year prior.
- * Investigate and address the root cause(s) of the high temperature trip itself and observed oil leakage from the gearbox shaft seal area.
- * Investigate the other anomalies seen during the 24-hour test run on EPG2, including the increase in fuel pressure, engine exhaust temperature and output power.

DETAILED EVENT DESCRIPTION

A 24-hour test run was started on July 14, 2002, to establish EPG2 reliability following maintenance on the fuel system. The lubricating oil pressure set point had also been lowered to match the recommended set point of 241 kPa (range 207-276 kPa).

EPG2 tripped from full load after 23.5 hours of operation due to high gearbox bearing oil drain temperature. The logic initiated a cooldown cycle, and EPG2 operated unloaded at synchronous speed for 10 minutes.

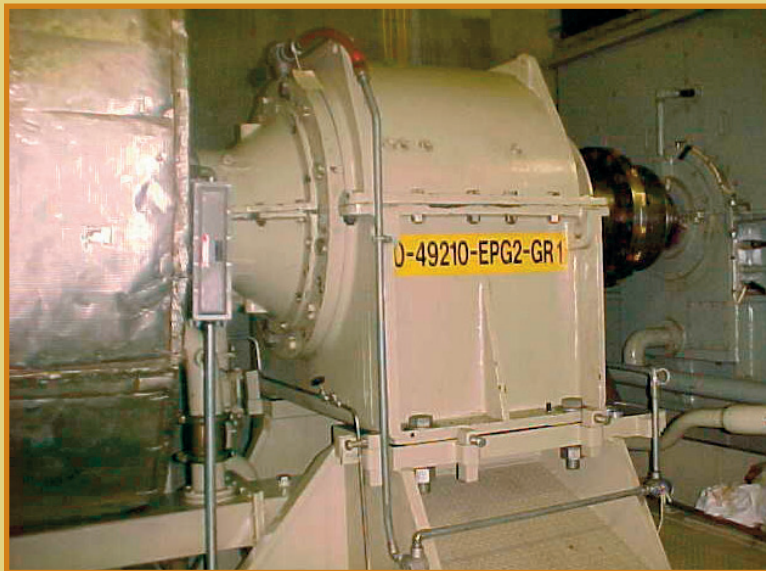
The gearbox bearing oil drain temperature continued to rise during the cooldown cycle. The operator also noticed a significant lubricating oil leak from the gearbox bearing shaft seal during the cooldown cycle. One minute prior to the trip, the turbine engine temperature and fuel pressure increased. The load on the turbine began to increase and the MWs became unstable.

A similar failure occurred on June 27, 2001, due to low load (~0.75 MW) when EPG2 tripped on a high gearbox bearing oil drain temperature accompanied by an oil leak. At the time, this was diagnosed as an instrumentation fault.

EPG2 was instrumented and retested and it tripped once again from full load after seven hours running on July 28, 2002, on the gearbox bearing oil drain temperature. This was again accompanied by a significant oil leak from the gearbox bearing seal area and

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Figure 3. Reduction gearbox

increasing turbine engine temperature, fuel pressure and load.

A root cause team was formed following the EPG2 trip on July 15, 2002. The significance of the three coincident problems seen during the trip was missed at first and, initially, the gearbox bearing oil drain temperature high trip was thought to be due to a faulty RTD since the bearing was in excellent condition. The cause of the oil leakage was believed to be due to a combination of the gearbox pressurizing in conjunction with a low seal air supply pressure to the gearbox bearing oil seal. (See fig. 5)

The increase in fuel pressure, power output and exhaust gas temperature just prior to the trip was believed to be due to the bleed valve drifting open slightly when it should have remained closed. Flooding of the gearbox seemed impossible due to the large, six-inch diameter drain line leading from the gearbox to a larger rectangular drain header.

Following the identical trip of EPG2 on July 28, 2002, during testing, the root cause team reviewed both the failures and investigated all the probable causes of the failures of July 15 and 28. Among other causes, high lubricating oil pressure causing high

oil flow to the gearbox, foaming of the lubricating oil, and high differential pressure between the oil tank and the gearbox resulting in slower draining of the gearbox were investigated. The gearbox is a dry sump design and is fitted with a large, six-inch-diameter drain line to ensure that the oil doesn't hold up. (See fig. 6)

The conclusion reached by the team was that EPG2 tripped on high gearbox bearing oil drain temperature due to flooding of the gearbox with oil and consequent churning of the oil inside the gearbox caused by rotating parts (planetary gear train) coming in contact with the oil.

The flooding was caused by excessive foaming of the lubricating oil inhibiting gearbox draining, as well as higher than normal oil flow to the gearbox caused by higher than recommended oil supply pressure. In addition, the team noted that the pressure in the vented lubricating oil tank was above atmospheric pressure due to the high level of air detrainment occurring. The pressure in the gearbox was slightly negative. The team concluded that this might have inhibited draining of the gearbox back to the tank.

The flooding of the gearbox explains the change in operating parameters. The churning of the oil increased the load on the turbine by 400 kW. In response to the increase in load, the fuel pressure and exhaust temperature increased and the power output became unstable due to the variable nature of the churning.

The manufacturer of the gearbox estimated that the churning of the oil could result in an increase in load of 400 to 800 kW depending on the height of the oil level. The churning caused the oil in the gearbox to heat up rapidly. This hot oil splashed on the temperature detector located just below the main output shaft bearing, causing it to falsely indicate a high bearing temperature, which resulted in the EPG2 trip. The gas turbine manufacturer has independently confirmed that this effect has been seen before on different machines (albeit with a higher speed step-up gearbox).

VERIFICATION OF THE ROOT CAUSE INVESTIGATION

A monitored test run was carried out to prove the root cause theory and to identify the cause of the EPG2 failure. It was observed that the lubricating oil level in the gearbox did, in fact, rise to a level significantly above the bottom of the gearbox and stabilized at approximately seven inches from the bottom of the gearbox casing when the lubricating oil supply pressure was 310 kPa.

The corresponding total lubricating oil flow rate was 725 lpm, shared between the gearbox, power turbine and the generator. The manufacturer of the gearbox confirmed that significant churning action begins when the oil level in the gearbox rises above six inches.

The pressure control valve, PCV901, which regulates lubricating oil pressure, was rebuilt and another test run performed with pressure adjusted to 242 kPa and the flow rate reduced to 590 lpm. The lubricating oil level inside the gearbox dropped to three inches from the bottom of the gearbox casing, which is close to where the manufacturer expected the maximum oil level should

be. The oil couldn't be changed, as not enough was available onsite.

A 40-hour test run was then carried out. As a result, EPG2 was stable and operated within normal parameters.

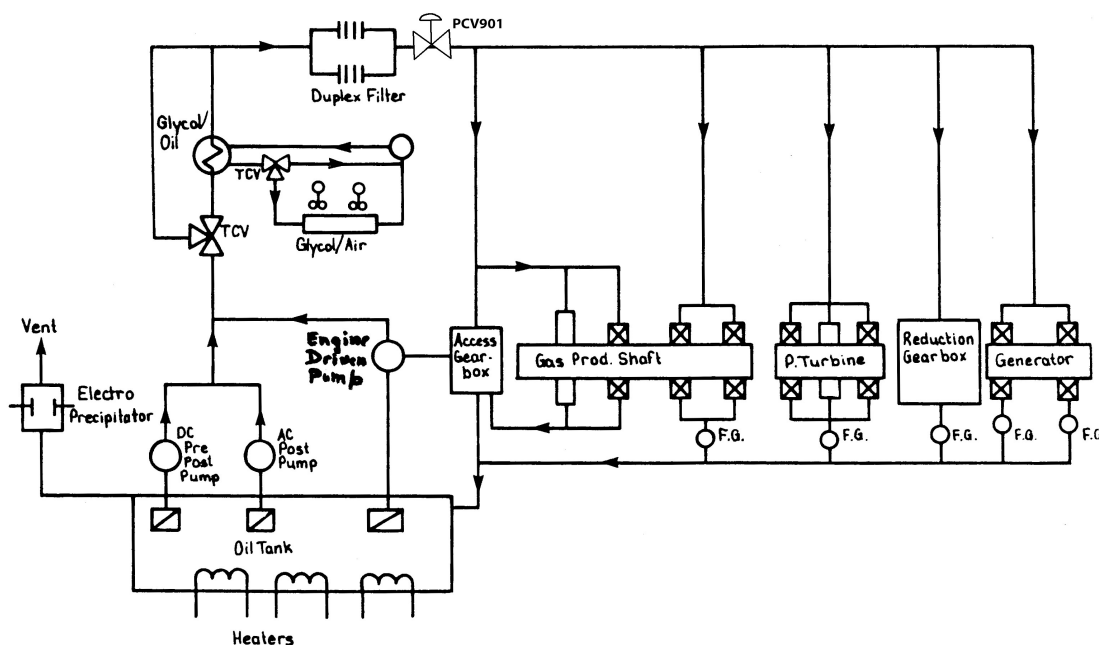
LESSONS LEARNED

Lowering the lubricating oil pressure to the manufacturer-recommended set point resulted in a significant reduction in the lubricating oil level (from approximately seven inches to three inches from the bottom of the gearbox). The lower oil level, coupled with a successful EPG2 extended test run (40 hours), has confirmed that the EPG2 failures occurred due to the flooding of the gearbox. Also, the reduced flow into the gearbox allowed the gearbox to drain effectively, and the flooding problem was resolved.

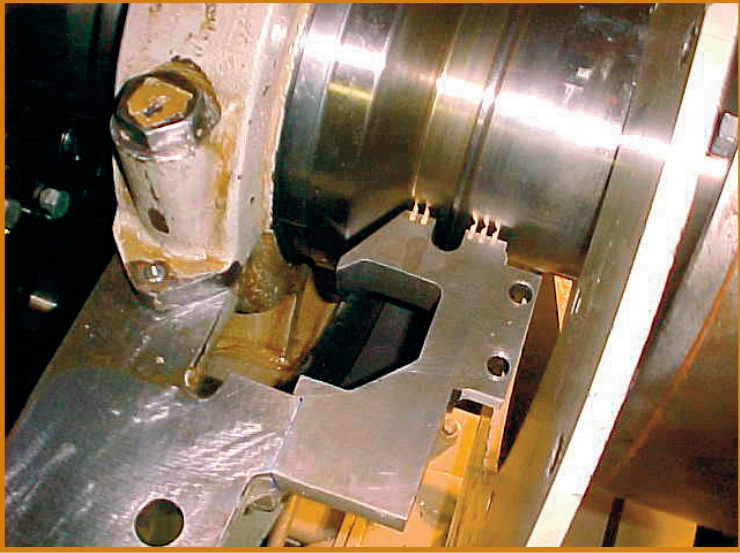
Degradation of the oil is also considered to be a contributing cause. Test results confirmed that EPG2's lubricating oil foaming properties had degraded over the years. The foam tendency (foam volume after five minutes of blowing as per ASTM D892, Sequence 1) for the EPG2 lubricating oil

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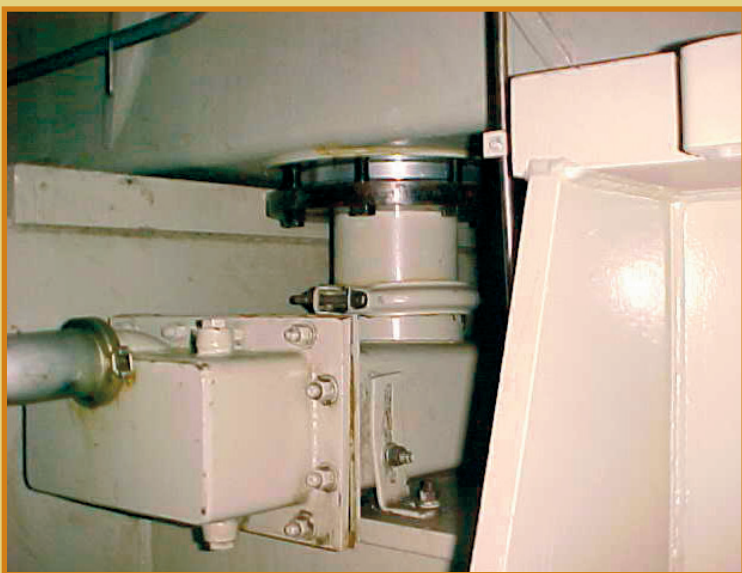
Figure 4. Simplified Lube Oil Schematic



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Figure 5. Gearbox bearing seal arrangement

sample was 260 ml. The new oil specification is a maximum foam volume of 60 ml. Higher foaming contributed to poor draining of the gearbox and explains why the EPG2 gearbox didn't flood during commissioning and during tests in previous years (the supply oil pressure had been set at 310 since commissioning). As a result of this finding, the predictive maintenance oil analysis program has been revised by adding oil foaming characteristic to the critical parameters of the

Figure 6. Oil drain arrangement from reduction gearbox

lubricating oil. The limit value for the foam tendency was set at 200 ml, while the foam stability at 0 ml.

It is interesting to note that the value of 260 ml is still well within the normal upper limit for turbine oils. However, the oil in these machines normally undergoes high levels of foaming/air entrainment due to the injection of pressurized air to the bearing oil seals. This requires that the oil maintain very good anti-foaming/air release values.

Furthermore, it took a combination of the high oil pressure and flow combined with the deteriorated antifoaming properties of the oil to cause this problem. The above testing proved that correction of the high oil pressure alone was sufficient to fix the problem. It is assumed that changing the oil and leaving the oil supply pressure as is would also have been sufficient.

CONCLUSION

The gearbox is not vented. The air carried by the foam into the drain tended to keep the pressure in the gearbox slightly negative. The air detraining from the oil draining into the large oil tank kept this tank slightly positive, so air flowed from the tank along the drain header to the gearbox in the opposite direction to the draining oil. The flow of heavily foamed oil would be restricted by a contrary airflow.

A vent line connecting the gearbox to the lubricating oil tank will be installed to ensure that high pressure in the oil tank due to air detrainment and slight vacuum in the gearbox doesn't cause inhibit draining. Furthermore, the oil level is expected to drop further after the modification is installed. This was confirmed during field tests when the gearbox was vented to the atmosphere and the oil level dropped by 0.5 inches. The lubricating oil for the EPG2 has since been replaced.

The oil pressure on the other EPG—EPG1 had always been set at ~241 kPa and two, successful, 24-hour test runs have been done on EPG1 since March 2002. EPG1, therefore, doesn't have the same problem with the lubricating oil system and the operability of EPG1 is not in question. The condition of the lubricating oil in the EPG1 also satisfies the upgraded oil specifications. <<