EXPERIENCES OF STATOR CONDUCTOR OXIDATION BUILD UP FOR 500 MW GENERATORS

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ABSTRACT

Stator conductor oxidation build up has been a cause of concern for utilities. Uncontrolled build up results in partial blockage of hollow conductors, which may result in overheating and premature failures. Operational feedback on large size generators stator de-mineralized water cooling problems has been shared in this paper.

Authors have experienced high differential pressures across stator windings in few 500 MW units. The name plate details of the generators under discussions are 588 Mva, 0.85 p.f. (lagging), 21 kV, 50 Hz. The stator winding is directly cooled by demineralized water, which flows through hollow conductors of stator bars. The stator core and rotor are cooled by hydrogen gas. As per manufacturer’s guidelines, the stator water system of these units is required to operate in low oxygen regime to avoid oxidation build up in hollow conductors. The paper explains how the stator conductor oxidation build up results in partial blockages and high differential pressures across stator windings.

Oxygen regime is very important parameter and need to be regularly maintained to avoid corrosion/build up of the oxidation in generator stator hollow conductors. Flushing of the stator bars with H₂SO₄ and subsequent alkalization of stator water has been good experience for authors as compared to EDTA flushing without alkalization of the stator water. The operation of water-cooled generators whether high oxygen or low oxygen regime needs to be strictly maintained to avoid corrosion/build up of oxidation products in the stator hollow conductors. The controlled make up of stator water is considered equally important to prevent the disturbance in shift of the oxygen regime.

1.0 INTRODUCTION

The paper explains how the stator bars oxidation build up results in partial blockages and high differential pressure across stator windings of generators. In two cases mix up of materials in stator water system and in other cases the shift in oxygen regime resulted in build up of the oxidized deposits. The hollow conductors of stator bars are of copper wherever the problem of oxidation build up has been experienced. Authors have so far not experienced any problem wherever the hollow conductors are of stainless steel design. The units in which problems have been experienced were designed to operate in low oxygen regime. Different case studies have been discussed in detail where fluctuations in the oxygen regime and mixing of materials of stator water system were observed to be the main cause of oxidation build up.

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2.0 DESCRIPTION

Generator stator bars corrosion build up has been the cause of concern for the authors specifically for 500 MW units. The stator windings of the 500 MW units are water-cooled and designed to operate in low oxygen regime. The cross-sectional view of the stator-winding bar is shown in fig.1.

![Sectional view of stator bars](image1)

In many cases there are twenty hollow conductors in one stator bar and the bars are transposed at 540 degrees in the slot portion across the total length of the stator as shown in fig.2.

The corrosion of the hollow conductors in 500 MW units is inhibited by formation of passive layer of cuprous oxide (Cu₂O). Similarly water-cooled generators of 200 MW units are operated under high oxygen regime where formation of passive layer of cupric oxide (CuO) inhibits corrosion. Authors have not experienced any problem in 200 MW units whereas in 500 MW units the blockage of the stator bars were revealed due to increase in differential pressure across the stator winding. In one case the problem could not be identified at initial stage as the increase in differential pressure (DP) across stator winding which deviated the normal flow was considered to be due to operating frequency fluctuations. However, the gradual increase of differential pressure over the period raised the alarm, which subsequently revealed to be the partial blockage of the hollow conductors in stator winding.

![Trends of differential pressure across stator winding in different 500 MW units](image3)

The blockage in one unit (Station-I in fig.3) could be detected after 13600 operating hours with the primary water circuit operated in the neutral/low oxygen regime. Generator protections tripped this unit due to “Primary water flow rate low”. The copper corrosion products plugging the hollow strands were attributed to the ingress of oxygen into primary water circuit caused by feeding large quantities of fresh water into the
primary water circuits. The corrosion could be detected after isolation of the individual sample stator bar from teflon hoses and viewing the hollow conductors by boroscopic inspection.

Fig 4. Cuprous-oxide deposits in teflon hoses

In another case condition of teflon hoses indicated large amounts of deposits as shown in fig.4. The deposits were tested to be predominantly cuprous oxide and in one sample the X-ray diffraction analysis also revealed presence of Fe₃O₄. Subsequent inspection of components of float valve in make up overhead tank were observed to be rusted as shown in fig.5, while the unit was under capital overhaul. This unit is presently being operated without float valve assembly. However increasing trend of higher differential pressure is being observed again and the unit is presently in operation under strict supervision.

In other case of 500 MW unit (Station 2 in fig.3) the mix up of material of stator water system was observed to be the main cause of high differential pressure across the winding. The rubber lining of the make up water system was subsequently observed to be dislodged at many locations which resulted in high ferrous content in the stator water leading to blockage of the hollow conductors. Calculating the normalized differential pressure (DP) as per the following formula can offset the variation of flow due to frequency fluctuations.

\[
\text{Normalized DP} = \frac{(\text{Rated Flow})^2 \times \text{DP}}{(\text{Actual Flow})^2}
\]

The above method takes care of the fluctuations in the flow due to variations in the operating frequency. The utilities can therefore have the correct picture of stator water flow and any rise in DP across the stator windings can be predicted accurately.

The high differential pressure (DP) across the stator windings results in partial blockage of the hollow conductors, which prevents proper cooling of the individual stator bars. In our case all the slots inside the generator stator are not wired for temperature monitoring. Therefore, if the blockage takes place in any individual conductor where there is no monitoring of slot temperature, the situation can be further aggravated. The high slot temperatures in these isolated individual stator bars can result in blocked flow and subsequent over heating, which may go unnoticed by the operators. The condition become very serious if uncontrolled and can lead to premature failure of stator bars, which can result in long unit forced outages. In subsequent units the revision in specifications have been undertaken so that temperature of each stator bar is monitored. This will ensure detection of hot-spot temperature at an early stage for preventing the subsequent failures. The monitoring of individual stator bars for temperature is necessary because the hot-spot temperature of partially blocked bar may not be detected due to average temperature rise which may be of the order of 2 to 3°C. Authors have experience of chemical cleaning of the stator bars with both H₂SO₄ and EDTA solutions. The cleaning with H₂SO₄ was one time process and repeat exercise was not considered necessary. However the generator which had been cleaned with EDTA solution was forced to go through the same process repeatedly as shown in Fig.6.
In the above figure whenever the DP of generator was reaching close to 3.5 kg/cm², the flushing used to be done with EDTA solution, maximum of three such flushings were attempted in one unit. Subsequently even after undertaking three flushings with EDTA solution, DP had rising tendency as shown in fig 6. Reverse hot water flushing was also carried out three times. The unit is presently being operated under strict supervision.

3.0 CAUSE OF OXIDATION

The main cause for partial blockage where cleaning was done with EDTA solutions were again attributed to be shift in operating regime of these units. The fluctuation of oxygen levels in stator water system has lead to corrosion problems in hollow conductors. Enough care was taken to maintain low oxygen content in stator water system however, fluctuations were caused during the make up of the lost stator water. The make up therefore, needs to be controlled in such a way so that abnormal shift in the oxygen regime can not take place. The sudden mix in the stator water system can raise the oxygen level and push the operating unit in highly corrosive environment. The operation can be further demonstrated as in fig 7.

It is clear from the above that if the fluctuation in the oxygen content takes place and pH of the stator winding system is also close to seven, the chances of corrosion of the hollow conductor becomes maximum. However if the pH content of the stator water system is increased by alkalizing as demonstrated in the above figure, the chances of corrosion are decreased to a considerable extent. Even if small fluctuation takes place during make up of the system the corrosion chances becomes minimal by increasing the pH of the stator winding system. This aspect was followed vigorously after cleaning of the winding with H₂SO₄ as shown in the arrangement (fig 8). Subsequently to maintain the corrosion rate minimum, it was ensured that the water system remained tight and stable.
The make up water taken from demineralized water system was considered safer as compared to turbine condensate extraction pump discharge. Turbine condensate discharge can be contemplated with the condenser leakage and during start up of the plant when oxides of iron and copper are usually present in excess of the control limits. However in case of demineralized water, enhancing of the pH to a reasonable level of 8 to 8.5 with the help of external dozing of the alkaline system (NaOH) was considered safer and better. The operating experience with this make up has therefore not given any trouble for the past twelve years. However, the issue can be debated further and experiences of other utilities can also be discussed for any conclusion in this regard.

4.0 CORROSION OF IRON AND COPPER

In general, the amount of iron and copper oxides in the stator primary water will depend on the following main factors:

- Quantity and frequency of blow down.
- Quality and quantity of make up water.
- Concentration of dissolved oxygen.
- Quality and pressure of nitrogen gas in stator primary water tank; (if applicable).
- Operation of alkalizer system.
- Operation of stator water polishing unit.
- Primary stator water cooler leakage (ingress of impurities).

As mentioned earlier copper and stainless steel in stator primary water system have displaced the use of mild steel. Due to this reason, the quantity of iron in stator water should be minimum. In case the quantity is found to be more than normally maintained the reason must be investigated and corrective measures should be taken. Authors have also the experience of operating the generators with stainless steel hollow conductors and have not experienced any trouble for last seven years.

It must be ensured that the storage tanks and pipelines, handling demineralized water or condensate as make up to stator primary water system should be suitably lined. The inspection of lined surfaces should be carried out at periodic intervals and corrective measures be taken immediately on detection of any failure of lining.

The rate of corrosion is minimum when the primary stator water system is tight i.e. when neither water is lost from the system nor the make up is taken into the system. Practically, this is not possible as water is taken out for manual testing of the constituents and sometimes lost due to leakage. It is desirable that manual tests are carried out once a month, so that minimum water is taken out from the system. Operation staff should take the make up on certification of quality by station chemist. The reason for any abnormal increase in normal make up needs to be investigated. Nitrogen purging (wherever applicable) also needs to be simultaneously done when make up is being taken in the outer circuit of the stator windings. This practice will help in keeping dissolved oxygen within the operating range before it enters the main circuit.

Dissolved oxygen in primary stator water is considered to be the main reason for corrosion. In order to avoid dislodging of passive oxide layer from the surface, leading to the blockage of conductors, it is necessary to regulate the make up water flow in a manner that dissolved oxygen does not increase abruptly.
5.0 RECOMMENDATIONS

As per our experience alkalizing the low dissolved oxygen water (Fig 7) can largely reduce the severity of the corrosion attack. This system then becomes less susceptible to disturbances resulting from air leakage. The corrosion products in stator primary water when detached from the metal surface deposits on the tube ends and also on inlet and outlet hoses of water-cooled generator windings, resulting in flow rate restriction. In order to get timely indication of flow restriction, it is essential to provide individual pressure gauges at inlet and outlet of water flowing through stator windings. Also provision of differential pressure indicator gauges with suitable alarm setting will ensure proper attention of operation staff for corrective measures. It is also felt that a suitable on line dissolved oxygen monitor with recorder be provided for the system.

During capital overhauls the measurement of stator water flow in each teflon hose connecting top and bottom bars can be undertaken for problematic units. The modifications in the specifications in our case have also been undertaken for measurement of stator water temperature in each slot. The differential pressure across stator winding measurement is also considered very useful.

5.1 SCHEDULE OF MONITORING

Following monitoring schedule is also recommended.

- Differential Pressure and generator slots temperature rise should be closely monitored.
- Working in at intermediate oxygen zone needs to be prevented.
- Strainer deposits at the make up tank need periodical check up.
- Dissolved oxygen and conductivity of primary water system should not vary frequently.
- The sampling point for laboratory measurement of dissolved oxygen should be vertically placed in the primary stator water with a regulating valve.

6.0 CONCLUSIONS

The problem of corrosion of hollow conductors in water-cooled generators is of rare nature. The operating regime of stator water system whether high oxygen or low oxygen needs to be adhered strictly. The sampling frequency as well as controlled water make up is essential for trouble free operations. Authors for past seven years have experienced no problems wherever stainless steel hollow conductors have been provided. The pro and cons needs further discussions.

7.0 REFERENCES

4) The paper is also based on practical experiences as observed during operation of the units. This paper is presented as case history of different units and will serve as a useful feedback for manufacturing companies as well as operating utilities.