Hydrogen Measurement in Hydrogen-Cooled Turbo Generators

Introduction

Why use hydrogen for stator coolant purposes? The gas which fills any generator is also present in the generator's air gap, and due to high turbulence it develops a certain amount of friction loss; the so-called windage loss. This effect heats up the gas. The cooling gas is circulated in a closed loop to remove heat from the active parts, and is then cooled by gas-to-water heat exchangers on the stator frame. The working pressure is up to 6 bar. The best gas for this task should have:

- Low friction loss to avoid heating itself
- A high heat capacity to pick up heat with minimum temperature rise.

With its low viscosity and high specific heat, hydrogen is the best gas available and is therefore used in large generators where the cooling requirements are severe. Even then the low density of hydrogen is a disadvantage so it is always used at elevated pressure.

Stator Design and Cooling Systems

In general, three cooling approaches are used:

- For generators up to 300 MW, air cooling can be used
- Between 250-450 MW, hydrogen cooling is employed
- For the highest power generators, up to 1800 MW, hydrogen and water cooling is used. The stator winding are made of hollow copper tubes cooled with water circulating through them. The rotor is hydrogen-cooled.

Benefits of gaseous hydrogen cooling include:

- High specific heat, and highest thermal conductivity at 0.168 W/(m-K) of all gases.
- Hydrogen has a very low viscosity, a favorable property for reducing drag loss
- It is 7-10 times better as a coolant than air
- Hydrogen is easily detected with hydrogen sensors
- A hydrogen cooled generator can be significantly smaller, and therefore less expensive than air-cooled generators
- Easy to manage – not readily miscible with CO_2 purge gas
- Helium with thermal conductivity of 0.142 W/(m-K) was considered a coolant as well, however its high cost hinders its adoption despite its non-flammability.

Hydrogen Impurities Impact on Plant Efficiency

Hydrogen has very low viscosity, a favorable property for reducing drag loss in the rotor. These losses can be significant as the rotors have a large diameter and high rotational speed. Every reduction in the purity of the hydrogen coolant increases windage loss in the turbine. As air is 14 times denser than hydrogen, each 1% of air corresponds to about a 14% increase in density of the coolant and the associated increase of viscosity and drag. A purity drop from 97% to 95% in a large generator can increase windage loss by 32%, which is equal to 685 kW for a 907 MW generator. The windage losses also increase heat losses of the generator and associated cooling problems.

The absence of oxygen in the atmosphere significantly reduces the potential damage of the windings insulation by eventual corona discharges. These can be problematic as the generators typically operate at a high voltage, often 20 kV.

Air Contamination in the Gas Circuit

The bearings have to be leak-tight. A hermetic seal, usually a liquid, is employed; turbine oil at pressure higher than the hydrogen inside is typically used. A metal ring (e.g. brass), is pressed by springs onto the generator shaft and the oil is forced under pressure between the ring and the shaft. Part of the oil flows into the hydrogen side of the generator, another part to the air side. The oil entrains a small amount of air. As the oil is recirculated, some of the air is carried over into the generator. This causes a gradual air contamination buildup and requires maintaining and controlling hydrogen purity.

Scavenging systems are used for this purpose. Gas (a mixture of entrained air and hydrogen released from the oil) is collected in the holding tank for the sealing oil, and released into the atmosphere. The hydrogen losses have to be replenished, either from gas cylinders or from on-site hydrogen generators. Degradation of bearings leads to higher oil leaks, which increase the amount of air transferred into the generator. Increased oil consumption can be detected by a flow meter associated with each bearing.

Stator Maintenance and Purge Sequences

Requirements regarding gas cooling between normal operation and maintenance are different. During and after shutdown the generator enclosure is purged before opening it for maintenance, to avoid a highly explosive mixture of air and hydrogen. It requires the hydrogen loop to be purged using the following sequence:

1. Hydrogen is purged by an inert gas. Carbon dioxide (or nitrogen) is used for this purpose as it does not form high explosive mixtures with hydrogen and is inexpensive.
2. The inert gas is replaced by air. Gas purity sensors are used to indicate the end of the purge cycle, which shortens the startup and shutdown timers and reduces consumption of the purge gas. At the end, fresh air replaces all other gases allowing operators to work inside the generator. Carbon dioxide is favored as it is easily displaced by hydrogen due to a very high density difference.
3. After maintenance operations, air is replaced by the inert gas
4. The inert gas is replaced by hydrogen and the generator is ready for operation.

In the following table the measurement goal is described as well as the best suited ORBISPHERE system. As a global solution, H_2 and CO_2 measurements will fulfill the main analysis requirements.

Main Operation	Location	System	Goal of Measurement
Power generation	H_2 stator loop	510 H_2	H_2 purity up to 99%, generator efficiency
	H_2 stator loop	510 O_2	H_2 purity up to 99.99% (option)
	H_2O lop	510 H_2	H_2 leak control in the water loop
Maintenance			
CO_2 purge		510 CO_2	End purge indicator
Service in air	H_2 stator loop	510 CO_2	Operator safety
CO_2 purge		510 CO_2	End purge indicator
H_2 refill		510 H_2	Efficiency, H_2 purity

Security

The flammability limits (4 - 75% of hydrogen in air at normal temperature but greater at higher temperatures), its autoignition temperature at 571°C, its very low minimum ignition energy, and its tendency to form explosive mixtures with air require provisions to be made for maintaining the hydrogen content within the generator above the upper or below the flammability limit at all times and other hydrogen safety measures.

When filled with hydrogen, overpressure has to be maintained as the inlet of air into the generator could cause a dangerous explosion in a confined space.

Benefits

In summary, measuring hydrogen for stator coolant brings several benefits, including:

- Allows stability of high hydrogen purity to keep the generator at its highest efficiency
- Reduces risks of hydrogen leaks and unplanned outages
- Minimizes downtime during generator maintenance
- Improves operator and plant safety
- Reliable hydrogen sensing technology reducing risks of false alarms.

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