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Significance of Air Cooled System Over a Gas Cooled System in Large Rotating Electrical Machines

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Short circuit generators are used to deliver the short circuit power in testing laboratories. During operation at the time of field excitation a large amount of heat is generated. The dissipation of this heat has to be evacuated to improve the generator efficiency and its reliability. The generator cooling goals are to minimize drag or Windage loss, keep generator internals clean, minimize electrical, mechanical and corrosion problems, and maximize generator output.

The purpose of the cooling is to dissipate generator thermal losses by forced circulation of coolant, may be gas, water or air in a closed circuit through the different parts of the generator. This paper explains the methodologies adopted to cool down the electrical machines like generators and to provide the safe working atmosphere to the personnel's working around it and also emphasizes on challenges to handle the gas cooling system compared to the normal air cooling system. In this paper the actual cooling system is also addressed, used in 1500 MVA Short Circuit Generator.

Keywords: *TEWAC System, OV System, Purging,Joule Heating, TNT.*

1.0 INTRODUCTION

The history of design, manufacture and development of electric generator has been a long and varied one. The designs have evolved from slow speed vertical shaft units to high-speed horizontal shaft. The designer is having great challenge to maintain mechanical, thermal and magnetic limits. The generator cooling can be achieved by using water, oil, air or gas but the use of gas as coolant in the rotor and the stator is introduced in 1937 at Dayton Ohio, in October by the Dayton light and power co [1]. Allowing an increase in specific utilization and 99.0 % efficiency.

2.0 WHY COOLING IS ESSENTIAL

There are three prime factors which contributes heating in stator and rotor

2.1 Joule heating or Ohmic heating:

When electric current through a conductor it releases heat. The amount of heat released (Q) is proportion to the square of the current (I) i.e.

$$Q = I^2R \qquad ....(1)$$

Where, R is the conductor resistance.

The joule heating in extreme cases can damage the generator winding. Figure 1 shows the different kind of failures due to Ohmic heating.

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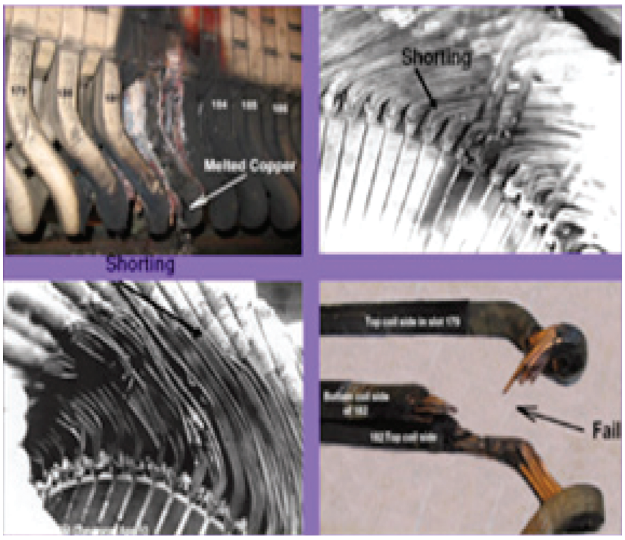

FIG. 1 EFFECT OF OHMIC HEATING

2.2 End bearings of the generator

When the generator runs at its rated speed lot of heat is generated in the bearing due to churning action in lube oil used for cooling the bearing. This heat is also added to the joule heating and the effect weakens the insulation and efficiency reduction.

2.3 Drag or windage

This is an aerodynamic friction caused by air or gas when it moves over a surface of rotor during rotation.

3.0 COOLING METHODOLOGY

The cooling can be obtained by gas, oil, water and air but the following methods are widely accepted.

3.1 Open ventilated (OV) cooling

The OV configuration draws air from the atmosphere to cool its active components, then exhaust air back in to the atmosphere.

3.2 TEWAC cooling

A relatively recent innovation in electric generator cooling is Totally Enclosed, Water and Air Cooled generator (TEWAC) design. In a TEWAC generator, the generator and a connected air-to-water heat exchanger are a single, sealed, air-filled environment, and the enclosed volume of clean air is continuously recirculated through the generator and the heat exchanger. Instead of being a once-through system like an open air system, TEWAC systems use recirculated clean air to remove the winding heat and deliver that heat to the generator cooling water circuit. As compared to the open ventilated design, TEWAC machines have similar heat transfer and windage loss limitations due to the use of air as the working fluid. Because TEWAC systems are a sealed system, employing clean air, they keep the generator windings cleaner than an open system. TEWAC systems are simple to operate like open air cooled systems, and ensure cleaner windings than open air systems.

3.3 Hydrogen cooling

This method is also an alternative where the pressurized hydrogen atmosphere is maintained inside the stator housing to cool the generator windings. Another way to cool the generator is to use hydrogen gas circulated through the generator and around the rotor to cool things. Hydrogen is seven to ten times better at transferring heat than air. That is, hydrogen is much, much better at absorbing heat and then at giving up thatheat to another medium/area than air.

This means that for the same size generator, if it's cooled with hydrogen versus air that more current can flow in the stator and rotor windings which means that more power can be produced. In other words the same amount of power can be produced with a smaller generator cooled with hydrogen than one cooled with air. This is the typical reason for using hydrogen cooling; to reduce the physical size (and cost) of the generator. Figure 2 & 3 shows the view of the Generator.

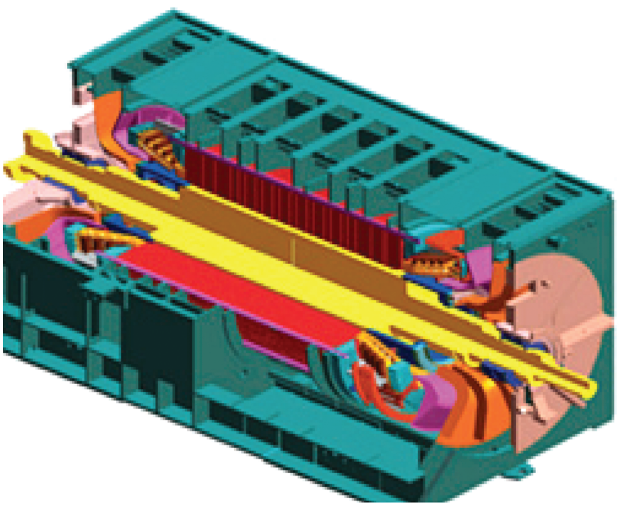

FIG. 2 SECTIONAL VIEW OF GENERATOR

FIG. 3 ACTUAL VIEW OF 1900 MVA SHORT CIRCUT GENERATOR

4.0 A BRIEF OVERVIEW OF AIR COOLED (TEWAC) SYSTEM AND GAS COOLED (H_2 COOLING) SYSTEM

4.1 Gas Cooled Generators

Operating an electric power generator produces large amounts of heat that must be removed to maintain efficiency. Air, water and oil have all been used for cooling. But hydrogen's low density, high specific heat and thermal conductivity make it a superior coolant for this application. Plus, it's abundant and therefore relatively inexpensive.

As shown in Figure 4 hydrogen cooled generators use a "closed" supply of pressurized hydrogen that is circulated continuously while the generator is turning. The hydrogen circulates in a continuous loop from the generator, through a fan mounted on the generator shaft, through a hydrogen dryer if one is present on the specific generator, through a shell and Tube hydrogen-to-water heat exchanger, and back to the generator. In a properly operating generator system, the recirculation loop is leak free, and no hydrogen is lost during the heat removal process.

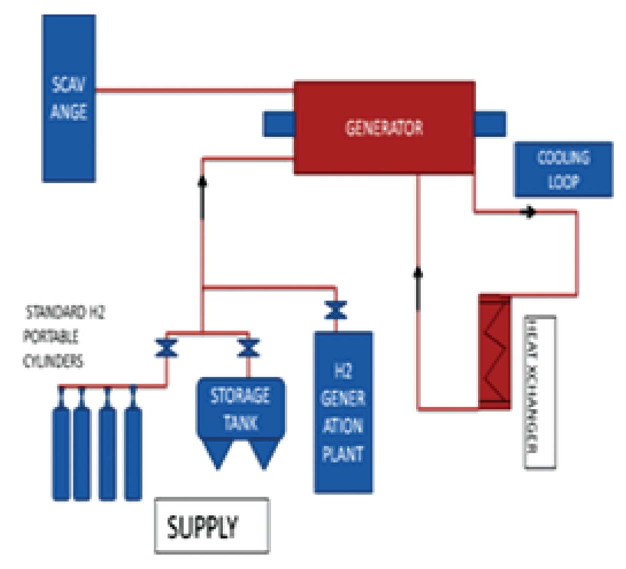

FIG. 4 HYDROGEN COOLING CYCLE

But the challenges to handle hydrogen are very crucial like:

4.1.1 *Maintaining low due point*

Dew point affects generator winding longevity. The insulation on the generator windings functions in a challenging environment of high temperatures, high electrical flux and high dynamic forces. Because the generator windings may be damaged over a time if water vapor is allowed to condense in the windings, it is good practice to ensure that the circulated hydrogen in the cooling system is dry enough to eliminate water condensation under operating and non-operating conditions. One or more of several techniques are used to prevent water from accumulating in the circulating hydrogen [2]:

- A vacuum seal oil system is used to pull dissolved gases such as air and water vapor from the seal oil to prevent introduction into the hydrogen.
- A hydrogen scavenging system can be employed to scavenge hydrogen with elevated water content and replace with dry hydrogen.
- A hydrogen dryer may be used to the circulating hydrogen in the cooler loop. The Figure 5 shows the stable flow of hydrogen by maintaining pressure and dew point.

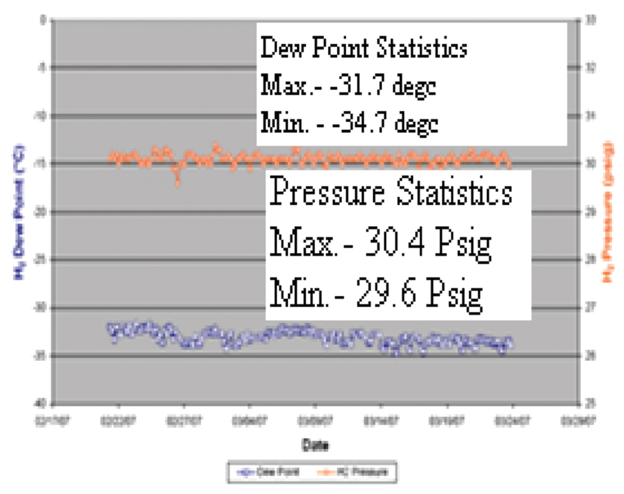

FIG. 5 DEMOSTRATE THE STABLE FLOW OF HYDROGEN

Effect: If the dew point is not maintained up to the specified value the hydrogen vapor will turn to droplets and deposit on surface of the winding. It penetrates and weakens the insulation, hence the Corrosion and oxidation of the conductor starts.

4.1.2 *Maintaining pressurized atmosphere*

As the stator housing is to be pressurized continuously during the operation of the generator the prime task is to see that it is higher than the outside atmospheric pressure, otherwise outside air may rush in, which can be catastrophic and Endangers the people working around the generator.

4.1.3 *Purging*

During periods of generator maintenance it may be necessary to displace the gas from the generator housing because hydrogen can be explosive when mixed with air. CO_2 gas is used to remove hydrogen which is also toxic. In order to fill the generator with hydrogen, the air must first be removed. CO_2 is admitted through the bottom of the generator. Because it is heavier than air, the air will be forced to the top where it is vented off. With the generator now full of CO_2, hydrogen may now be admitted. The hydrogen, being lighter than CO_2, is introduced from the top of the generator. When a reading of 95% hydrogen is achieved at the bottom of the generator, normal operation may begin. Should maintenance become necessary inside the generator, the hydrogen must be removed. To do this CO_2 is admitted to the bottom of the generator, forcing the hydrogen out of the vent, air can then be used to remove the CO_2 from the machine. Thus in case of emergency any kind of repair cannot be taken easily unless the whole hydrogen is removed from the stator.

4.1.4 *Drying*

Presence of water in hydrogen has to be avoided as it causes deterioration to hydrogen cooling properties, corrosion of the generator parts arching in HV windings, and it reduces the life time of the generator and hence, dryer has to be introduced in the gas circulation loop.

4.1.5 *Make-up*

TABLE 1

BLAST-WAVE IMPACT FROM AN EXPLOSION OF 1 kg OF TNT

At 1m Distance Maximum Pressure: 1,000 Kilopascals	At 2.7m Distance Maximum Pressure: 100 Kilopascals	At 11m Distance Maximum Pressure: 10 Kilopascals
It can cause severe damage to the body. Internal bleeding and prolonged loss of consciousness.	It can cause damage including fractures and prolonged loss of consciousness.	It can cause damage to the body and minor injuries

Hydrogen is often produced on sites using a plant consisting of arrays of electrolysis cells but the dominant method of production is steam reforming from hydrocarbonsbut the refilling, transportation and storage is very crucial."Hydrogen gas inventory becomes the chief safety concern because of the potential energy in hydrogen," standard portable cylinder filled with hydrogen at 2,400 psig is equivalent to 35 pounds of TNT in terms of explosion potential. Table 1 shows the damage caused by H_2 explosion equivalent to TNT explosion.

4.2 Air Cooled (TEWAC) Generators

Air-cooled generators are an ideal choice for power system applications that demand simplicity and flexibility of operation. Because of the absence of a pressurized atmosphere within the generator, its structural components are simple and easy to handle, which facilitates routine maintenance. Table 2 shows all the components that constitute the total air cooling system.

TABLE 2

GENERATOR AIR COOLING SYSTEM

Fan motor-Flow rate 20 m^3/secs. Speed 1480 rpm		Radiator-5 kW, 400 V, 3 ph, 50 Hz
Heat Exchanger Power dissipated 98 kW inlet temp. 86 °C. outlet temp: 44 °C.	Monitoring system Cu - Co thermo couples.	Filtration unit per unit 6 cartridge type-275 MIC 330.

Generator cooling system divided in to three segments

- Air Cooling System
- Lube Oil Cooling System
- Water Cooling System

4.2.1 *Air Cooling System:*

The purpose of this system is to provide sufficient cooling to the generator and transfer the heat carried by air, to water. System comprises of various components like blower, heat exchanger, filter and monitoring system as shown in Figure 6 and 7.

4.2.1.1 *Air Duct*

With all these features the loop or air duct is to be described. It is designed in such a way that the blow initiated by the fan should have enough velocity so as to reach to generator windings and should come back through return duct to the initiating point.

Factors influencing duct design:

- Air velocity: Air velocity in the duct should be enough to reach to the generator winding and should not be more than the specified limit i.e.700-900 ft/min. If it increases turbulence and noise is added.
- Length of the duct: Ongoing and return duct should be in such a way that the velocity and the pressure should be maintained.
- Material used: This duct is specially designed duct which is partially metallicand partially made up of concrete.

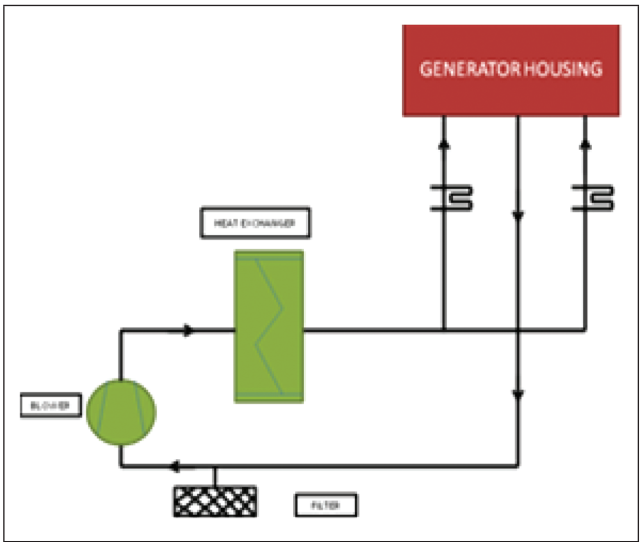

FIG. 6 COOLING CIRCUIT (CLOSE LOOP SYSTEM)

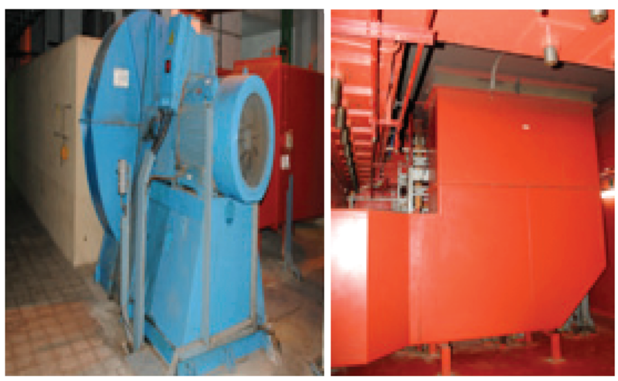

FIG. 7 BLOWER, INLET AND OUTLET DUCT

4.2.2 *Lube Oil Cooling System*

The purpose of this system is to provide cooling to the generator bearing and transfer the heat from lube-oil to the water as shown in the Figure 8 and 9. Table 3 shows all the components that constituted the Lube oil cooling system.

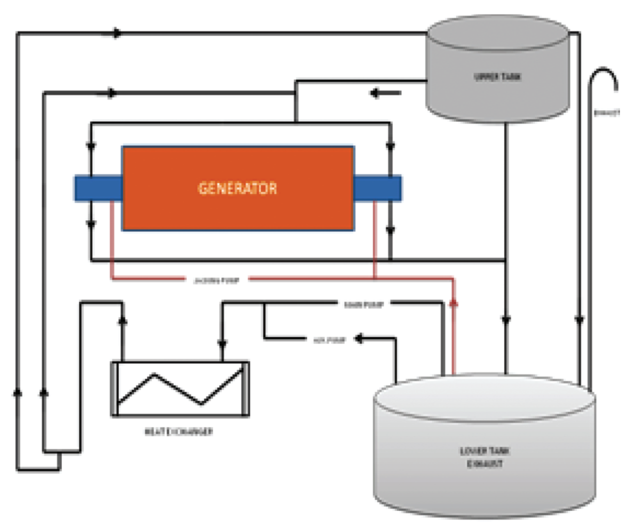

FIG. 8 OIL COOLING CIRCUIT (CLOSED LOOPSYSTEM)

FIG. 9 OIL RESERVOIR AND HEAT EXCHANGER

4.2.3 Water Cooling System

The purpose of the system is to provide the cooling to the water which is taking heat from the air and lube oil. It is made up of 4 main components as shown in the Figure 10.

i. Heat exchanger

ii. A water distributor

iii. A ventilation unit

iv. A water collecting tank

<table>
<tr><td colspan="3">TABLE 3</td></tr>
<tr><td colspan="3">LUBRICATING AND JACKING SYSTEM</td></tr>
<tr><td>Main oil tank
Capacity 10 Kl</td><td colspan="2">Upper oil tank
Capacity 3.8 m3</td></tr>
<tr><td>Main motor pump
15 kW, 500rpm, 415 V
50 Hz</td><td colspan="2">Auxiliary motor pump
15 kW 1500 rpm 415 V
50 Hz</td></tr>
<tr><td>Jacking oil pump
11 kW, 415 V,
50 Hz, 1500 rpm</td><td rowspan="2">O-W Heat exchanger</td><td rowspan="2">Pressure regulator</td></tr>
<tr><td>Monitoring system</td></tr>
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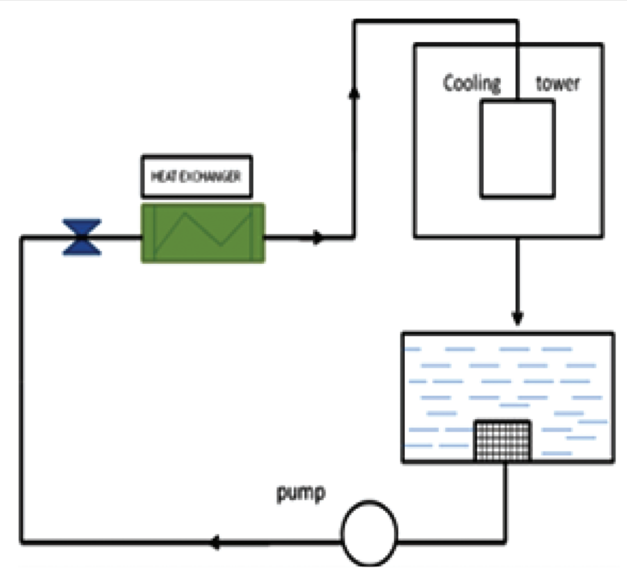

FIG. 10 WATER COOLING CIRCUIT

5.0 O & M, AN OVERVIEW

So for we have seen the intricacy of H_2 cooled system and the ease of air cooled system. Table 4 shows an overview of operation and maintenance part of the system.

TABLE 4

O & M: AN OVERVIEW

S.No	H_2 Cooled System	TEWAC System
1	Even a routine maintenance if required, cannot be taken unless whole H_2 is purged and fresh air is forced inside the Generator. It is long duration process resulting outage of Generator for longer period.	No restriction of taking shutdown any time, if required and repair can be taken without losing much time.
2	Outside ambient plays a vital role on the characteristics of hydrogen gas as coolant. Hence intensive monitoring is most desirable, especially low dew point. This directly effects the insulation.	Outside ambient does not affect the system as it is a close loop air circuit.
3	Operation of H_2 cooled system in general more specific than the air cooled because lot of instrumentation and expertise is involved	Operation of the system is easy and understandable with less monitoring devices.
4	Supply and refilling of hydrogen has to be under intensive monitoring by experts otherwise leakage can be catastrophic.	Make up air drawn from the clean atmosphere through the high quality filters provided in air circuit.
5	By nature hydrogen is colorless, odorless which leads to ignorance of hydrogen available in the air. Small spark from slip ring carbon brushes may ignite and blast.	No such risk is involved.

5.1 Best O&M practices adopted in CPRI for TEWAC system

CPRI has adopted state of the art best maintenance practices of its kind for their 1500MVA short circuit station for TEWAC system. "Walking-the -beat" approach keeps the plant performance enhanced and all time availability.Pre-defined inspections of Heat-Exchangers and Cooling Tower are primarily addressed for removal of lime scale which hinders the plant operation. The above system is functional very well and always under monitoring [3].

Despite of so much care taken for safe production and handling of H_2, many accidents have been taken place but some of the plant failures/ accidents reported so far:

- **i.** January 2007 in U.S. hydrogen explosion at Muskingum river power plant leads to significant damage to several buildings including injuries and deaths. Reason: Hydrogen relief device failed during supply
- **ii.** April 2011- an internal investigation has shown that hydrogen gas which had not been fully purged from the generator during unit maintenance at the coal fired L.V.Sutton steam electric plant in New Hanover County(N.C) ignited and caused an explosion lead to death of an employee.
- **iii.** 11th March 2011, the explosions that happened recently at the Fukushima Daiichi nuclear plant was hydrogen explosions.
- **iv.** 23rd Oct 2001, Australia, Liddell Power station explosion due to hydrogen leakage.
- **v.** 1995 Australia, in a chemical plant hydrogen explosion took place.
- **vi.** 1986 Chernobyl Hydro power plant accident in Russia.

6.0 CONCLUSION

Hydrogen safety covers the safe production, handling and use of hydrogen. Hydrogen posses unique challenges due to its ease of leaking, low energy ignition, wide range of combustible fuel air mixture, buoyancy and its ability to embrittling metals that must be accounted for to ensure safe operation where as TEWAC method of cooling is utmost safe and reliable.

Hence the adoption of the technology/methodology is not merely the progress of mankind but also should be eco friendly and harmless to the human being.

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