Evaluation of Impurities in Hydrogen Cooling System and Their Influence on Power Generation Efficiency at Pelabuhan Ratu Power Plant

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Abstract*—Pelabuhan Ratu Steam Power Plant is located at Jalan Raya Cipatuguran Desa Jayanti, Citarik, Kecamatan Pelabuhanratu, Kabupaten Sukabumi, West Java, Indonesia, with a total capacity of approximately 3 X 350 megawatts (MW). Generators, especially those used in large power plants, require cooling as they produce heat as a by-product of energy conversion. The coolant used in the generators at Pelabuhan Ratu Steam Power Plant is water and hydrogen. Hydrogen is used as a cooling medium because it has good thermal properties and high thermal conductivity, so it can absorb heat efficiently. It is important to note that the use of hydrogen coolant in brushless generators requires appropriate processing and security systems to avoid the risk of hydrogen leakage which can cause fire or explosion hazards. It is also necessary to maintain the purity of hydrogen gas in the cooling system. The problem that occurs in the Pelabuhan Ratu Steam Power Plant is that the purity of hydrogen in the generator cooling system cannot be maximized. The methods used include comparative statistical analysis to compare the performance of hydrogen cooling generators with and without hydrogen drying equipment, to determine if there is a significant difference, or regression analysis to identify factors that affect generator temperature. This study aims to maintain the purity of hydrogen can last longer by using a hydrogen dryer and analyze the effect of hydrogen purity is maintained on the power output of the generator. The results obtained hydrogen dryer system is able to maximize the purity of hydrogen from 96.7% to 98.6%. Hydrogen temperature readings of the cold exciter and hot exciter generator side become lower from 37.5 ° C and 47.9 ° C with 328.0MW power to 33.3 ° C and 46.6 ° C with 332.1MW power. And the cold turbine and hot turbine side hydrogen generator temperature readings also decreased from 36.6 °C and 49.1 °C with 328.0MW power to 31.6 °C and 47.1 °C with 332.1MW power. Analytical research can provide a solid basis for better decision-making. By analyzing relevant data and information, researchers can identify problems or opportunities, evaluate options, and provide recommendations based on the evidence and findings found. This helps decision makers at Pelabuhan Ratu Steam Power Plant make more informed and fact-based decisions.

***Keywords*—Dryer, Generator, Hydrogen, Power Plant, Purity**

I. Introduction

A power generator is a device or machine that converts mechanical energy into electrical energy. The working principle of this generator is based on electromagnetic induction, which was first discovered by Michael Faraday in 1831 [1]. In general, a generator consists of a coil connected to a mechanical energy source such as a water turbine, internal combustion engine, wind turbine or steam engine [2]. When the mechanical energy source drives the coil, a changing magnetic field is generated in the coil. This change in magnetic field causes an electric current in the coil through the process of electromagnetic induction [3].

The electromagnetic field formed in a power generator can cause heating in the generator itself. When electric current flows through the coils in a generator, strong magnetic fields form around those coils [4]. These magnetic fields can cause friction and resistance forces to build up in the power generation materials, which in turn generate heat [5]. Heat generation in generators can come from several sources, such as: Wire resistance (The coils in the generator are made of copper or aluminum wire. Current flowing through this wire will generate resistance which causes heat to build up) [6]; Friction (The rotation of the rotor and stator in a generator can also cause friction between the components, this friction can generate heat) [7]; Inefficient heat transfer (If the cooling system in the generator is inefficient or compromised, the heat generated by the internal components of the generator may not be properly dissipated, and can cause excessive temperature increase) [8].

Excessive heating of the generator can be a serious problem as it can reduce operational efficiency and result in damage to generator components [9]. Therefore, it is important to design an efficient cooling system and control the temperature well to keep the generator operating at a safe temperature [10]. There are several cooling methods commonly used in generators, such as: Air Cooling (Air is used as a cooling medium by passing air through the generator to carry away the heat generated) [11]-[13]; Water Cooling (Water cooling uses a water circulation system to remove heat from the generator. Water is used as the cooling medium and pumped through channels that pass through generator components that require cooling) [Oil Cooling (Oil is used as a cooling medium to remove heat from generator components. Oil is flowed through cooling lines connected to components that require cooling) [16]-[17]; and Hydrogen Cooling (Hydrogen-cooled generators are a type of generator that uses hydrogen as a cooling medium to remove heat generated by the internal components of the generator) [18]-[20].

Of the several coolants used in generators hydrogen coolant has several advantages that make it considered one of the most effective coolants, especially for generators with high power and critical operations [21]. However, the use of hydrogen coolant also requires extra attention in terms of safety, as hydrogen is a flammable gas. Strict control and monitoring systems are required to avoid the risk of leaks and

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hazards associated with hydrogen. Hydrogen-cooled generators are usually equipped with pressure monitoring systems and sensitive hydrogen leak detectors. In addition, the design and construction materials of the generator should also consider compatibility with hydrogen, including resistance to hydrogen corrosion and adequate structural strength [22]. Hydrogen cooling approaches in generators are used primarily in critical applications that require high cooling efficiency and optimal safety. In addition, maintaining the purity of hydrogen used as a coolant in generators is also very important to maintain generator performance and safety.

To maintain the purity or purity of hydrogen can use a hydrogen dryer or hydrogen dryer. H2 Dryer is a tool used to produce hydrogen gas that has low humidity or also called dry hydrogen [23]. The main function of H2 Dryer is to remove moisture from hydrogen gas produced by electrolysis of water or other chemical reactions [24]. This aims to avoid corrosion of pipes and equipment or undesirable results in chemical processes. H2 Dryer uses desiccators or other drying materials to absorb moisture in hydrogen gas. In addition, the H2 Dryer is equipped with a filter to capture particles and other contaminants that can affect the quality of hydrogen gas. With the use of H2 Dryer, the quality of hydrogen gas produced can be maintained and meet the quality standards required for generator cooling systems [25].

The problem that occurs in the Pelabuhan Ratu Steam Power Plant is that the purity of hydrogen in the generator cooling system decreases rapidly. This study aims to maintain the purity of hydrogen can last longer by using a hydrogen dryer. And to determine the effect of maintaining hydrogen purity on generator power output.

II. Background and Related Work

A. Steam Power Plant

Steam Power Plant is a type of power plant that uses steam power as the main energy source. The basic principle of Steam Power Plant is to convert heat energy produced by burning fuel into mechanical energy, which is then converted into electrical energy. The Steam Power Plant work process begins with burning fuel, which is gene Steam Power Plant rally coal. The heat generated by the combustion is used to heat water in the steam generator boiler. This heated water turns into steam with high pressure and temperature [26].

The steam produced is then directed to a steam turbine. These turbines have rotating blades connected to a shaft. When steam flows through the turbine, the high pressure and temperature of the steam drives the turbine blades so that the turbine rotates rapidly. This rotational motion of the turbine converts heat energy into mechanical energy. Next, the mechanical energy from the turbine is transmitted to an electric generator. This generator converts mechanical energy into electrical energy. The electrical energy produced by the generator can then be channeled through the electricity transmission system to homes, buildings or to other places that need electricity [27].

B. Generator

Generators operate based on a basic principle discovered by Michael Faraday, namely electromagnetic induction. Generators consist of several important components, including a magnetic field, wire coils, slip rings and a voltage regulation system. The magnetic field, which can be generated by electromagnets or permanent magnets, provides a stable and consistent magnetic force. The wire coil, which is made of a conductor such as copper, is organized in a winding form around the magnetic field. When the magnetic field moves through the coil, there is a change in the magnetic flux around it. This change in flux results in an electromotive force being induced in the wire coil according to Faraday's law [28].

The importance of the relative motion between the magnetic field and the wire coil is achieved through the use of slip rings. The slip ring allows a continuous connection between the wire coil and the external load, so that the electric current can flow unhindered by the rotation of the coil. Thus, mechanical energy from a turbine or other power source can be converted into electrical energy [29].

In general, generators produce alternating voltage (AC) electric current. This happens because the direction of relative motion between the magnetic field and the coil changes periodically as the turbine or other energy source rotates. The AC output from the generator can then be channeled through the electricity transmission system to various intended uses. In addition, generators are also equipped with a voltage regulation system to keep the voltage produced stable. This system uses voltage regulation or other mechanisms to control the electrical output according to the needs and ensure that the supplied voltage remains within the desired range [30].

C. Hydrogen Refrigeration

The working principle of hydrogen cooling in generators involves using hydrogen as an efficient cooling medium to keep the generator temperature within safe and optimal limits. In a generator, hydrogen is pumped into the cooling system and flowed through special pipelines designed to distribute hydrogen to the hot parts of the generator that require cooling, such as the stator coils, rotor coils and iron core. As the hydrogen flows through these pipelines, it plays a role in the conduction cooling process. Hydrogen has excellent thermal conductivity properties, so when it comes into direct contact with the surface of the hot parts of the generator, it picks up heat from those components and carries it away from the areas that need cooling. In this process, heat from the stator coils, rotor coils and iron core is transferred to the hydrogen [31].

There are two types of generator cooling with hydrogen, namely indirect cooling (conventional hydrogen cooled machine) and direct cooling (inner cooled machine). Indirect hydrogen cooling means that hydrogen is not in direct contact with the conductor or core, because of the insulation, especially on the stator. Direct hydrogen cooling means that hydrogen is in direct contact with the conductor without any separator. Direct hydrogen-cooled generators have hollow conductors so that hydrogen gas flows inside the conductor. Cooling the generator with water can only be done to the stator, while as cooling on the rotor usually uses hydrogen gas. Water used as a generator coolant is pure water (H2O) with conductivity close to zero. The advantages of hydrogen gas compared to other gases or fluids can be seen in the following table [32]:

Table 1. Generator Coolant Comparison

Cooling Type	Specific Heat	Density	Heat Conductivity	Heat Transfer Coefficient
Air	1.0	1.0	1.0	1.0
Nitrogen	1.0	0.966	1.08	1.03
Carbon Dioxide	1.27	0.64	0.64	1.13

Cooling Type	Specific Heat	Density	Heat Conductivity	Heat Transfer Coefficient
Helium	5.25	6.4	6.4	1.18
Hydrogen At:				
1.0 bar	14.35	0.14	6.69	2.65
2.0 bar		0.22		3.65
4.0 bar		0.375		4.65
Oil	2.09	848	5.45	21
Water	4.16	1000	2.1	50

III. Research Methods

A. Research Flow Chart

Analytical research methodology refers to the set of steps and procedures used to collect, analyze and interpret data in order to answer research questions or achieve established research objectives. Analytical research methodology involves selecting appropriate analytical techniques, collecting accurate data and using appropriate analytical tools. The following is a flowchart of the analytical research methodology used in this study:

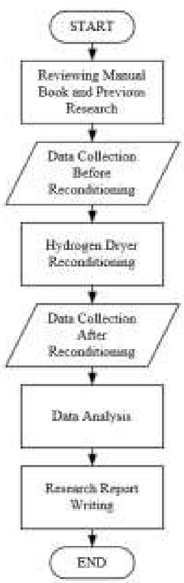

Figure. 1. Research Method Flowchart

B. Research Subject

The subjects in this study were the Hydrogen refrigeration system and the generator. The methods used include comparative statistical analysis to compare the performance of hydrogen refrigeration generators with and without Hydrogen drying equipment, to determine if there is a significant difference, or regression analysis to identify factors that affect the generator temperature.

The data collection techniques used in this research are quantitative data collection techniques to collect information that can be measured in the form of numbers or numerical data. In the context of this research using sensor data. Sensor data is usually translated into numbers that can be processed and analyzed. The following is the sensor data that will be used:

- Humidity Sensor, The humidity sensor data taken is the humidity before and after passing through the hydrogen dryer.
- Temperature Sensor, Temperature sensor data taken includes generator temperature, hydrogen temperature before and after entering the generator and temperature in the hydrogen drying tower.
- Hydrogen Purity Sensor, Retrieval of hydrogen purity sensor data in the hydrogen cooling system.
- Sensor Pressure, Retrieval of hydrogen pressure sensor data in the generator and in the hydrogen dryer system.
- Generator Power Output, Sensor data collection of power output readings generated by the generator.

IV. Results And Discussion

A. Hydrogen Dryer

H2 is the chemical formula of the hydrogen molecule. A hydrogen molecule consists of two covalently bonded hydrogen atoms. Under standard conditions, H2 is a colorless, odorless, and tasteless gas. Hydrogen molecules (H2) are often referred to as "molecular hydrogen" or "gaseous hydrogen". Gaseous hydrogen (H2) can become liquid at very low temperatures and fairly high pressures. The process of converting gas to liquid at low temperatures is referred to as condensation. Therefore, hydrogen dryers are required in generator cooling systems with hydrogen gas.

Dryers or dryers in hydrogen cooling systems for generators are used to remove moisture (water content) from the hydrogen gas used as a coolant. Removing moisture is very important because the presence of water in the hydrogen cooling system can cause corrosion of generator components and reduce their efficiency and operational life.

Dryers use desiccant or adsorbent materials, such as zeolite molecules or silica gel, which are capable of absorbing water molecules in the hydrogen gas. For the hydrogen dryer used in the Pelabuhan Ratu Steam Power Plant, the Adsorption Hydrogen Dryer (XQS-D). The XQS series adsorption hydrogen dryer is a double tower dryer. The two towers absorb and regenerate alternately and remove moisture continuously. This dryer can be used to dry hydrogen for generator units of 200~1000MW capacity [33].

Figure. 2. Hirogen Dryer Working System

Its working system is divided into 2 stages, namely:

- Water Adsorption: When hydrogen gas passes through a dryer, the water molecules in the gas are adsorbed by the drying material. This adsorption process reduces the moisture in the hydrogen gas, resulting in a drier hydrogen gas.

- Regeneration: The adsorbent in the dryer needs to be regenerated or cleaned periodically due to saturation of the adsorbent by water. The regeneration process involves increasing the temperature or using hot gas to remove the water adsorbed on the drying material. Once regenerated, the dryer can be used again to absorb moisture in hydrogen gas.

The use of a dryer is usually placed in the hydrogen gas flow path within the generator cooling system. Dryers are often positioned after water separator components or other dehumidifiers to remove residual moisture that may still be present in the hydrogen gas. The advantage of using a dryer in a hydrogen cooling system helps maintain the quality of the hydrogen gas by removing moisture that can cause corrosion and damage to generator components. By reducing the moisture in the hydrogen gas, the dryer helps maintain the temperature stability and operational efficiency of the generator.

It is important to properly design the hydrogen cooling system, including the use of an appropriate dryer, to ensure adequate hydrogen gas quality to maintain generator performance and operational life. Also, maintenance and replacement of the adsorbent in the dryer needs to be done regularly according to the manufacturer's guidelines to maintain its effectiveness.

B. Hydrogen Moisture Content

The results obtained before entering the dryer system hydrogen moisture value at 61.7%. After going through the absorption process in the hydrogen dryer, the moisture value drops to 43.8%.

Figure 3. Hydrogen Humidity Before Dryer

Figure 4. Hydrogen Humidity After Dryer

C. Hydrogen Purity and Pressure

Initial data before the use of hydrogen dryers obtained maximum purity levels at 96.7% with maximum pressure at 334.9Kpa. As for the minimum purity and pressure levels before the addition of hydrogen at 96.0% for purity and 318.8Kpa for hydrogen pressure. The maximum data was taken on June 7, 2023 and the minimum data was taken on June 10, 2023.

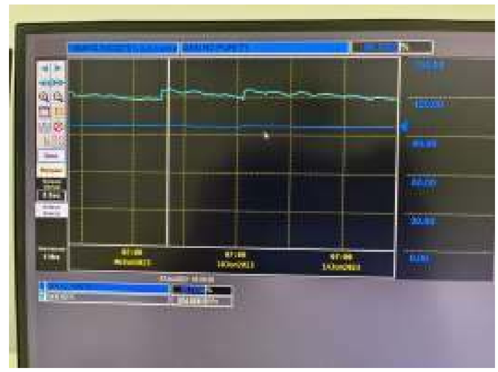

Figure 5. Maximum Hydrogen Purity and Pressure Before Use Hydrogen Dryer

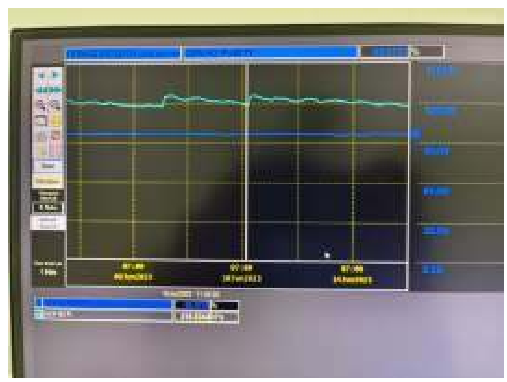

Figure 6. Minimum Hydrogen Purity and Pressure Before Use Hydrogen Dryer

After the use of hydrogen dryers, data for maximum purity levels were obtained at 98.6% with maximum pressure at 328.1Kpa. As for the minimum purity and pressure levels before the addition of hydrogen at 96.4% for purity and 310.6Kpa for hydrogen pressure. The maximum data was taken on July 31, 2023 and the minimum data was taken on August 4, 2023.

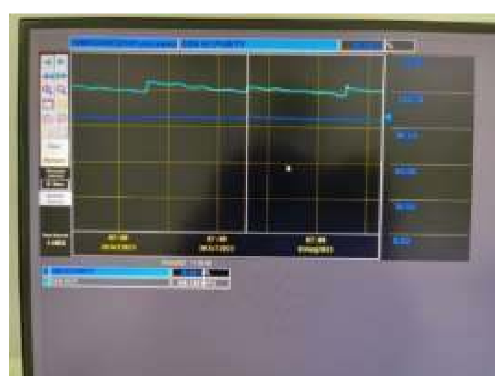

Figure 7. Maximum Hydrogen Purity and Pressure After Using Hydrogen Dryer

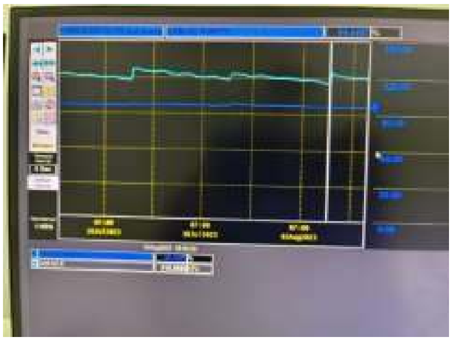

Figure 8. Minimum Hydrogen Purity and Pressure After Using Hydrogen Dryer

D. Generator Power and Temperature

Initial data before the use of the hydrogen dryer was obtained with a generator power of 328.0MW, the hydrogen temperature reading on the cold exiter side of the generator read 37.5 ° C and the hot exciter side read 47.9 ° C. Meanwhile, the hydrogen reading on the cold turbine side of the generator read 36.6 ° C and the hot exciter side read 49.1 ° C. Meanwhile, the hydrogen reading on the cold turbine side generator reads 36.6 ° C and the hot turbine side reads 49.1 ° C. Data was taken on June 10, 2023.

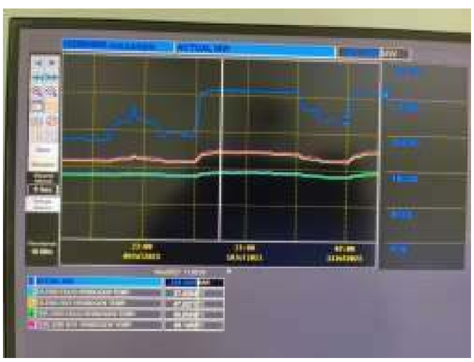

Figure 9. Hydrogen Generator Temperature Readings at Maximum Power Before Use of Hydrogen Dryer

After the use of the hydrogen dryer obtained data with a generator power of 332.1MW, the hydrogen temperature reading on the cold exciter side of the generator reads 33.3 ° C and the hot exciter side reads 46.6 ° C. Meanwhile, the hydrogen reading on the cold turbine side generator reads 31.6 ° C and the hot turbine side reads 47.1 ° C. Data taken on July 31, 2023.

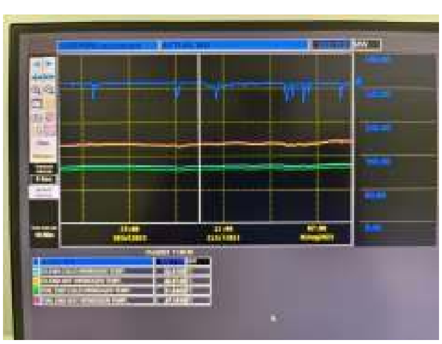

Figure 10. Hydrogen Generator Temperature Readings at Maximum PowerAfter Use of Hydrogen Dryer

V. Conclusion

The results of this study show that after using a hydrogen dryer there is a change in hydrogen moisture content in the hydrogen cooling system can decrease from 61.7% to 43.8%. In addition, the hydrogen dryer system is able to maximize hydrogen purity levels from 96.7% to 98.6% with lower pressure. And can maintain the minimum level of hydrogen from 96.0% to 96.4% with lower pressure.

In terms of temperature and power output after the operation of the hydrogen dryer, the temperature reading of the hydrogen generator on the cold exciter and hot exciter side becomes lower from 37.5 ° C and 47.9 ° C with 328.0MW power to 33.3 ° C and 46.6 ° C with 332.1MW power. And the cold turbine and hot turbine side generator hydrogen temperature readings also decreased from 36.6 °C and 49.1 °C with 328.0MW power to 31.6 °C 47.1 °C with 332.1MW power. This shows a decrease in generator temperature when operating with almost the same power output.

So, in order to improve the reliability of the generator hydrogen cooling system at Pelabuhan Ratu Steam Power Plant, our research has proven the effectiveness of using hydrogen dryers. As researchers, we confidently recommend the implementation of this hydrogen dryer system in all generating units of the Pelabuhan Ratu Steam Power Plant. The implementation of this recommendation is expected to have a positive impact in improving operational efficiency, reducing the risk of disruptions, and extending the service life of equipment throughout the plant, which will ultimately benefit the overall operation of the plant.

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