HOGEN® HYDROGEN GENERATION AND STABLE FLOW™ CONTINUOUS HYDROGEN INJECTION IMPROVE PERFORMANCE IN ELECTRIC POWER GENERATORS

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Proton Energy Systems designs, manufactures and installs HOGEN® hydrogen generation systems for industrial and government customers worldwide.

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Introduction

The high thermal conductivity of hydrogen has proven to be a key advantage in its use as a coolant in electric power generators. The use of hydrogen instead of air permits a reduction of nearly 20% in the amount of active material required in the construction of a generator of given output and for a given temperature rise of the windings. The low density of hydrogen is also an advantage over that of air. Since hydrogen's density is approximately one-fourteenth the density of air at a given temperature and pressure, the use of hydrogen reduces the windage friction losses within a generator to a small fraction of the losses encountered when the generator is cooled by air.

Critical to the proper implementation of a hydrogen cooled generator is the supply of a continuous stable flow of high purity hydrogen from a trusted source. The list of traditional sources of hydrogen includes delivered cylinders, tube trailers, and liquid tanks. Onsite hydrogen generation systems were once only deployed to remote, hard to reach locations around the globe. In recent years however, onsite hydrogen generation systems have been adopted by an increasing number of power plants as a preferred supply method for a variety of reasons. Furthermore, when continuous hydrogen replenishment is coupled with the implementation of onsite hydrogen generation, advantages of lower hydrogen cost, improved plant operations, and increased safety are realized. Payback can be very rapid due to increased purity, lower dew point and stable pressure within the electric generator.

The Effect of Hydrogen Quality on Generator Operation and Performance

The quality of hydrogen coolant gas in the electric generator casing has an impact on the overall operation of an electric power generator in three principal ways:

- Hydrogen purity directly affects the operating efficiency of the generator.
- Hydrogen's moisture content affects the longevity of the generator's internal windings.
- The stability of the hydrogen gas pressure within the generator affects the maximum generating capacity of the electric power generator.

Mirant's Dickerson Plant, Maryland, USA

Purity

The purity of hydrogen within a generator casing is important for several reasons. First and foremost is safety. An explosive atmosphere exists when the hydrogen over air concentration in a generator falls below 74%. The primary function of purity monitoring systems has been to avoid this disastrous condition. Most plants will initiate a shutdown and automatic carbon dioxide (CO_2) purge of the generator if the concentration falls below 85%. Secondarily, hydrogen's purity within a generator correlates with windage friction losses associated with an increase in density. As windage losses increase due to impurities, the financial loss to the power plant correspondingly increases. While the small percentage decrease in purity within the generator casing may not present a safety concern, the impact on the plant's bottom line is dramatic. For example, as illustrated in Figure 1, an 800MW unit with a 1% increase in hydrogen purity will realize a corresponding 366kW increase in power output. Therefore, a 3% increase in hydrogen purity translates to an additional 1MW output without any increase in fuel consumption. Based on an electricity selling price of $.04/kWh, a 3% purity increase can enable savings of $320,000 per year (based on 8000 operating hours).

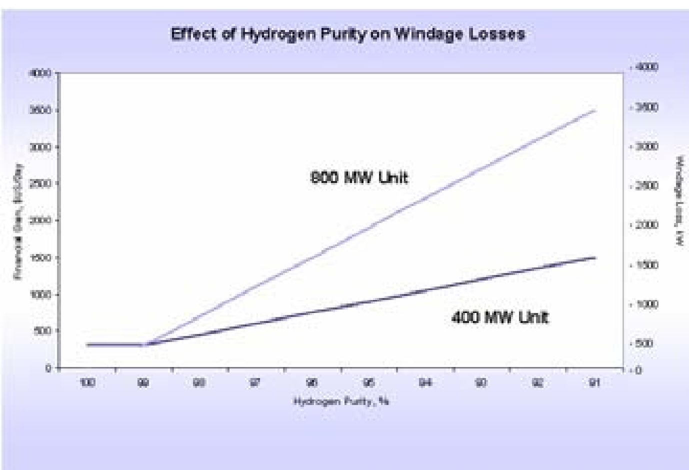

Figure 1

Dew Point

When the hydrogen gas coolant in the generator casing is high in water content, there are additional problems besides windage loss. Water vapor contamination has been shown to reduce the life of generator components, and high humidity can induce stress corrosion cracking on retaining rings and cause stator winding shorts. It is recommended that the hydrogen dew point be maintained below +32°F in most generators. Studies have shown that generators that operate with high hydrogen gas dew points are more susceptible to insulation degradation in windings that can lead to shorts and unplanned downtime.

A common source of moisture contamination in the hydrogen coolant gas is water that becomes mixed with the hydrogen seal oil. Water content in seal oil should be maintained below 100ppm to achieve a dew point below +32°F. Seal oil moisture of less than 50ppm will be needed if the desired dew point is below +15°F, and less than 10ppm if sub zero dew points are desired. In general, the lower the dewpoint maintained, the better.

Plants that still operate with old braze joint materials in their stator windings, hydrogen gas coolers, and other generator internal components will be affected by the production of conductive lead carbonate when high dew points are present. While there is always residual carbon dioxide present within a generator, the reaction between lead from the braze material and CO_2 that forms lead carbonate is enhanced by the presence of water. In a high moisture environment, lead carbonate is transported throughout the internal environment of the generator and will eventually find its way into exposed and less protected areas of the generator. Conductive lead carbonate will affect the longevity of internal components of a generator through induced shorts.

Stator windings are directly affected by the combination of moisture and lead carbonate. A generator's gas cooled stator windings have high voltage copper exposed at each end of the stator bars. This design feature necessitates long electrical creepage paths to prevent high voltage phase-to-phase or phase-to-ground faults. Operators of hydrogen-cooled generators have found that moisture degrades the electrical creepage strength of a surface. When moisture migrates to the end turn area of a generator's rotor windings, it attacks the interturn insulation and results in shorted rotor end winding turns.

The costs to a power generation plant for premature or unplanned shutdowns and repairs due to moisture-induced failures are significant. In addition to hard costs of parts and labor, a generator repair of this type usually means an extended unplanned plant outage and significant lost revenues. The total cost to a plant for an unplanned outage can exceed $1 million.

Pressure

At increased pressure, hydrogen becomes more dense, improving its capacity to absorb and remove heat. As a result, additional electrical load may be carried with no increase in the temperature rise of the windings. An increase in kilovolt-ampere output of about 1 percent may be obtained for every 1-psi increase in hydrogen pressure up to 15 psig, with an increase in electrical output of about 1/2 percent per psi of an increase in pressure for casing pressure between 15 and 30 psig. Increasing hydrogen pressure also permits operation at normal load with the temperature of the water supplied to the gas cooler in excess of normal. This increase in kilovolt-amperes due to maintaining a constant hydrogen pressure at the OEM's specifications translates directly to a plant's ability to operate at maximum electric power capacity.

Many power plants knowingly sacrifice potential capacity due primarily to hydrogen safety concerns. There is valid concern over large hydrogen gas supplies — 60,000+ cubic feet in the case of a tube trailer, potentially feeding a huge undetected seal or casing leak. There have also been cases of pressure reducing gas regulator failures causing catastrophic generator failures due to excess pressure in hydrogen supply systems.

To reduce risk, batch feed hydrogen supply methods are often employed to maintain the generator pressure manually. This manual batch feed system is also used to track seal wear by tracking the hydrogen leak rate. The hydrogen seal leak rate can be determined if the pressure drop in the generator, temperature, and duration between fills is known.

When a power plant is able to manage hydrogen safety issues while increasing hydrogen pressure and purity under a continuous hydrogen replenishment system, the resulting increases in capacity can provide dramatic economic benefits. For example, a 100MW generator operated with a continuous hydrogen supply maintaining a constant 30psi versus a batch supply method that pressure cycles 2 or 3psi over the course of the day will gain the capacity to produce an additional 8000MWh per year. That means an additional $400,000 in revenue (based on a .94 power factor, 8000 hours of availability annually, and an electricity sales price of $0.05/kWh).

Continuous hydrogen replenishment

A hydrogen supply system designed to continuously replenish hydrogen within a generator with a controlled flow rate of high purity gas (while an equal amount of impure gas is vented) has been proven to be an effective means of increasing hydrogen purity in the generator casing. The vent flow rate is controlled according to the desired purity level in the generator. As the purity in the generator decreases, the vent flow is increased until it reaches the desired purity set point. In most cases, just a small continuous "bleed" of the cooling gas can make a dramatic change in overall hydrogen purity and dew point.

Continuous hydrogen purge may not be practical with delivered gas cylinders and tube trailers. The operating cost of such a system can be substantial if the price of delivered hydrogen is even a few dollars per 100 cubic feet. Also, there are safety concerns associated with implementing a continuous feed gas supply method with bulk storage. Onsite hydrogen generation systems are a safe and economical alternative to bulk systems when implementing continuous hydrogen replenishment.

Delivered hydrogen versus onsite hydrogen generation

Delivered hydrogen is relatively expensive when compared to onsite generation. Delivered gas prices rise constantly with issues of gas supply, transportation, and increased security concerns over bulk hydrogen. Onsite generation, especially when employed at a power plant, offers the plant operator a fixed cost of hydrogen supply. An electrolysis-based onsite hydrogen generator requires a small amount of deionized water and electricity to operate. An on-site hydrogen electrolyzer sized for an average power plant requires less than 20 gallons of water per day and 17kWh of electricity per 100 cubic feet of hydrogen produced. Hydrogen is produced for under $1.00 per 100 scf.

Hydrogen gas cylinder changes can introduce particulate impurities and introduce air gases if not purged. Purity varies from cylinder to cylinder depending upon the source of the gas and what the cylinder was used for in the past. In contrast, onsite hydrogen generation systems monitor the hydrogen product purity continuously to insure the gas that is being introduced to the generator is of the desired quality. The ability to trend and provide alarms is also available. Delivered hydrogen also presents siting, storage and occupational safety challenges. High-pressure cylinders require personnel to monitor supply, manage delivery schedules to prevent unnecessary downtime, monitor the cylinders' condition and gas purity, and store cylinders in accordance with a facility's safety protocols. The alternative, onsite generation systems, carry low gas volume and less than 100scf of stored hydrogen while delivering gas on demand to the process. The maximum flow rate from an onsite generator will never exceed its maximum capacity, which is important when performing "worst case" safety analysis.

Onsite hydrogen generation systems are designed to stay online and feed a continuous supply of hydrogen as required by the process. An onsite hydrogen generator has the inherent ability to meter the flow rate of hydrogen used. This flow metering function can be used to alarm operators of a sudden demand for hydrogen in the case of a catastrophic component failure, while tracking seal wear over time to aid in preventative maintenance.

Power plant operators can reduce the destructive presence of water vapor and air within their hydrogen-cooled generators with a constant flow of dry hydrogen gas. Continuous hydrogen replenishment is a technique that can keep generators free of moisture, oxygen, and other contaminants that can prematurely degrade equipment, maintain hydrogen pressure at a level that supports an increased load, and supply hydrogen on demand at the rate it is required by the electric generator. These benefits are in addition to providing seal leakage makeup gas at a fraction of the cost of delivered gas.

Hydrogen Gas Analyzers

Purity and dew point analyzers are essential for monitoring the quality of the coolant gas within a generator. Older purity analyzers are good at detecting the percentage of hydrogen gas with a balance of air, primarily used for safety monitoring. However, if the impurity is something other than air, the readings are less reliable. Readings can fluctuate based on ambient humidity in the plant, the generator's operational status, and where the drying system is located. This is not the case with newer analyzer models that employ the latest sensor technology. New analyzer systems allow the plant to detect and display the percentage of hydrogen in air, CO_2 in hydrogen, and hydrogen in CO_2.

A dew point sensor should be considered for continuous vent gas monitoring to improve the efficiency and longevity of the generator. A dew point sensor that is placed in the vent stream of a continuously purged generator will provide valuable feedback to both the operator and hydrogen generation system. The dew point data can be used to trend moisture over time to help identify the sources of moisture ingress and can be used to alarm an operator in the case of an internal water leak.

The analyzer that is used to determine the purity level of hydrogen as well as the dew point of the hydrogen gas may be interfaced with an analog control valve for vent control. The valve opening is increased or decreased as part of a continuous control loop in reference to the desired level of casing gas purity.

Using PEM technology for onsite hydrogen generation

The most widely used onsite hydrogen generation technology at power plants in the U.S. is Proton Exchange Membrane (PEM) electrolysis. Onsite hydrogen generators that use PEM technology offer a cost-effective approach to ensure hydrogen purity and low dew point. PEM electrolysis allows 99.999+% pure hydrogen gas to be produced on demand at process pressure without mechanical compression and without caustic electrolytes.

Test Description/Units	Result	D.L.
Nitrogen (ppm vv/by MS	nd	4
Oxygen (ppm v/v by MS)	nd	4
Carbon Dioxide (ppm v/v by MS)	nd	4
Argon (ppm v/v by MS)	nd	4
Helium (ppm v/v by MS)	nd	10
Hydrogen (% v/v by MS)	99.9+	0.1
Total hydrocarbon (ppm v/v as CH4)	--	0.1
Water Vapor (ppm v/v by EDP)	nd	0.5

Sample of H2 gas @ 225 psi generated by a PEM electrolyzer

D.L. = report detection limit. **nd** = indicates the concentration is less than the report detection limit. **-** = test not performed. **%** = percent. **ppm** = parts per million. **ppb** = parts per billion. **v/v** = volume analyte/volume sample. **w/w** = weight analyte/weight sample. **Unit conversions:** 1 ppm v/v = 0.0001% v/v.

Using onsite hydrogen generators with continuous hydrogen replenishment

By using an onsite hydrogen generator combined with a continuous hydrogen replenishment technique, plants can minimize hydrogen inventory, while guaranteeing consistent purity, dryness and pressure.

As illustrated in Figure 2, hydrogen that is continually produced by the hydrogen generator flows through a hydrogen manifold and pressure reducing regulators, and through the electric generator at 15-75psig. The hydrogen is vented through a control valve, through a purity monitor, and escapes through the plant's existing hydrogen vent system.

An optimized hydrogen supply solution for the power plant exists with the implementation of an onsite PEM based hydrogen generator as part of a system that includes seal oil cleanup, hydrogen analyzers, a dew point monitor, and a control valve to enable plant operators to maintain their generators at the optimum operating condition.

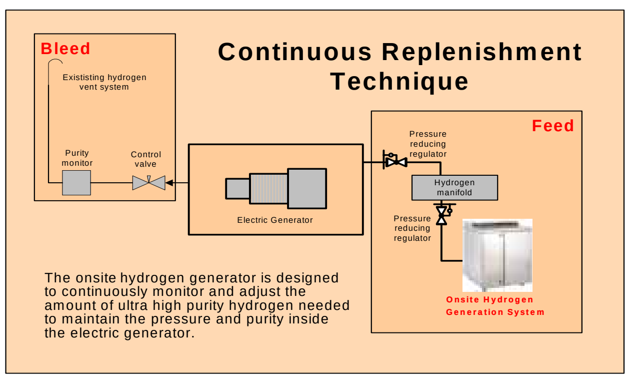

Figure 2—Stable Flow™ Continuous Hydrogen Injection

How Mirant Mid-Atlantic's Dickerson Power Station uses continuous hydrogen replenishment

Mirant's Dickerson, Md. plant employs three General Electric hydrogen cooled synchronous type ATB 4-pole, 3-phase 60-cycle generators, rated at 115,000 kilovolt-amperes at 1800 rpm and 13.8 kilovolts. They are designed for a power factor of 0.85, 30psig hydrogen cooling pressure and armature amperage of 4811 amps.

Objectives

Managers at the Dickerson plant needed solutions to help them meet two goals. First, they wanted to reduce the storage, transport and manual operations required to manage hydrogen cylinders. At the same time they sought to decrease operating costs, decrease the dew point level in their generators, and improve generation capacity and efficiency by increasing the purity and pressure of the hydrogen circulating within the generators.

The plant's original intent was to reduce the hydrogen dew point by upgrading the existing dryers. During their investigation, Dickerson's management learned that an onsite hydrogen generation system could provide dry hydrogen in excess of their rate of consumption, allowing the plant to continually purge the generator with pure, dry hydrogen.

Dickerson's managers first reviewed the costs and benefits of purchasing an onsite hydrogen drying system that would be used with their current delivered hydrogen supply on three generators. Dickerson's costs for delivered hydrogen, plus the cost of adding six dryers, power for the dryer blower and heater, and for the hydrogen discharge purge cycle would have totaled approximately $325,000 in the first year of operation.

Next, Dickerson evaluated costs of using onsite hydrogen generation systems to continuously replace hydrogen within the three generators. Dickerson's managers determined that the installed cost of three hydrogen generators, electricity to power the generators, and required maintenance was less than $225,000, or 70% of the cost of the six driers that would have been installed. In addition, the hydrogen generators could provide hydrogen to both the plant's high and low pressure generators.

One of the hydrogen generators attached to the hydrogen manifold of one of the GE hydrogen-cooled generators at Mirant Mid-Atlantic's Dickerson, Md. power plant.

Dickerson placed the first hydrogen generator on its Unit 1 generator on February 17, 2004. On February 17, the dew point of the hydrogen coolant in the low-pressure generator measured 37 F. On March 4, the dew point was down to about 30.8 F. By May 18, the dew point was between 12 and 15 F. Presently the dew point remains between 12 F and 15 F. Based on results with its first system, Dickerson purchased two additional hydrogen generators for installation on its other two units.

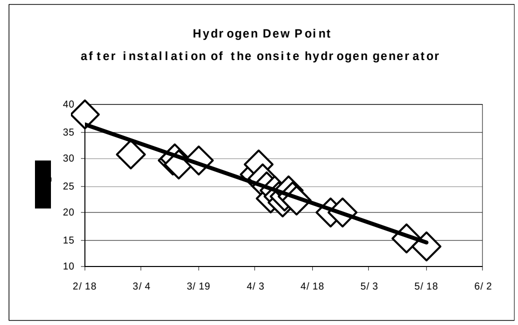

Table A

Additional economic benefits

In addition to operating the generators with a higher level of purity and lower dew point, Dickerson's generators have had increases in pressure stability as well. The generators typically operate on cycling load rather than continuous full load. GE's guidelines for the generators at Dickerson project a 1/2 percent increase in kilovolt-amperes output for each 1-psi increase in hydrogen pressure within the generator.

Dickerson projects that the stability increase in hydrogen pressure within its electric generators since introducing the continuous replenishment systems can produce 900 kilowatts of additional generation capacity. As an example, based on an estimated 5000 operating hours annually and an average electricity selling price of 5 cents per kilowatt-hour, an additional $225,000 in revenue can be realized from each of the three generators. When full load demands occur, Local Market Pricing (LMP) policies allow Dickerson to further increase revenue from operating the generators at maximum capacity.

Dickerson maintenance group leader Michael Bennett is satisfied with how their generators reduce dew point and increase purity by using continuous hydrogen replenishment. Among the benefits that the plant is experiencing, continually purging Dickerson's generators with pure, dry hydrogen produced by a hydrogen generator has reduced both the plant's dependence on hydrogen cylinders and the rental cost of keeping these cylinders on site.

With multiple generation systems in place and on line, a small number of cylinders are kept on site as backup while other hydrogen cylinders will only need to be brought on site to re-gas the generator after an outage where the generator is degassed. When maintenance of one of the hydrogen generators is required, the excess hydrogen from the other units can be used to maintain the supply of hydrogen to the unit with its hydrogen generator out of service.

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