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IMPROVED GENERATOR PERFORMANCE UTILIZING ONSITE HYDROGEN GENERATION AND CONTROL

DICKERSON GENERATING STATION – CASE STUDY

Authored and presented at 4th EPRI Steam Turbine-Generator Technology Transfer Workshop,
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Mirant's Dickerson Plant, Maryland, USA

INTRODUCTION

The high thermal conductivity of hydrogen remains a key advantage in its use as a cooling fluid in electric power generators. The density of hydrogen is also an advantage over that of air. Since hydrogen's density is 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. Like any critical resource required by the plant to produce electric power, the supply and use of hydrogen gas should not be taken lightly. Considerations need to be made to control costs, secure a reliable supply, insure the safety of the installation, and implement the most efficient way of operating the generator hydrogen system. Critical to the proper implementation of such a system is the supply of a continuous stable flow of high purity hydrogen from a trusted source.

The traditional mode of hydrogen supply differs from plant to plant depending on such things as distance from the central hydrogen supply or permit restrictions on the volume of stored hydrogen. There are a number of plants that utilize single cylinders or transportable cradles of six, twelve, or eighteen cylinders. Others utilize large bulk systems that are either stationary high or low pressure tanks or transportable high pressure tube trailers. How a plant implements a hydrogen supply mode also differs depending on how large the plant is or the permitting restrictions they need to adhere to. Whether a plant is utilizing a large volume of gas as a central supply or smaller volumes that are distributed throughout the plant, the goal should always be the same – maintain an uninterrupted supply of pure hydrogen to meet the OEM specified requirements for generator pressure, purity, and dew point.

This paper will present the problems identified by engineers at Dickerson Generating Station during a routine check of hydrogen gas dew point and how those initial findings led them to reconsider their whole approach to providing a safe and reliable source of hydrogen to the plant.

PROBLEMS IDENTIFIED

High Hydrogen Gas Dew Point

In August of 2002, the dew point in Dickerson Generating Station's unit 1 generator hydrogen cooling system was measured at greater than 43°F (6°C). Even though the hydrogen system on unit 1 was utilizing a hydrogen dryer to remove moisture, the dew point remained at extremely high levels with no signs of improvement. Plant engineers determined that the gas dryer in the hydrogen system was no longer operational and needed to be replaced.

The implications of operating an electric generator with high gas dew point can affect the overall reliability of the generator and should not be ignored. Water vapor contamination inside a generator has been shown to reduce the life of its components, and high humidity can induce stress corrosion cracking on its retaining rings and cause stator winding shorts. It is recommended that the hydrogen dew point be maintained below 0°F in most generators, but will vary depending on the generator's original equipment manufacturer (OEM), the size of the generator, and the hydrogen gas pressure. Studies have shown that generators that operate with high hydrogen gas dew point are much more susceptible to insulation degradation in windings that inevitably lead to disastrous shorts and major unplanned repair actions. It is well understood by power plant operators and recommended by generator OEMs that hydrogen gas dew point should be kept as low as possible to insure reliable operation of the generator. Mirant's Generator and High Voltage Systems Engineer advised Dickerson that all efforts should be made to keep the hydrogen dew point in the plant's generators below – 20°F (-28.9 °C).

The costs to a power generation plant for premature or unplanned shutdowns and repairs due to moisture-induced failures can be significant. In addition to hard costs of parts and labor, a generator repair of this type usually means an extended plant outage and significant lost revenue. It is estimated that the total cost to a plant for an unplanned outage of this type can easily be in the millions of dollars.

Low Hydrogen Gas Purity

Hydrogen gas purity within the generator casing was very inconsistent and was averaging 97% as a result of the purity purge process that the plant was employing. 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 75%. The primary function of purity monitoring systems has been to avoid this disastrous condition. Most plants will initiate a shutdown and automatic CO2 purge of the generator if the concentration falls below 85%. Dickerson Generating Station was not in any danger of operating their generator in an unsafe manner, but allowed hydrogen gas purities to degrade to 94-95% regularly before initiating a manual purge of the generator cavity.

Secondarily, hydrogen's purity within a generator correlates directly with windage friction losses associated with an increase in hydrogen gas density. As windage friction 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. The manual periodic gas purge employed by Dickerson was causing the generators to operate much less efficiently than designed and directly affected fuel consumption and emissions.

Generator Hydrogen Gas Pressure Instability

Hydrogen gas pressure within the generator casing varied due to the "batch" method of maintaining hydrogen pressure employed at Dickerson. Plant operators were keeping the hydrogen supply cylinders isolated from the main hydrogen manifold and introducing hydrogen once a day to boost the hydrogen pressure that was lost to seal leakage. The chart below (Figure1) shows how the plant was operating unit 1 prior to the implementation of onsite hydrogen generation and a "continuous" hydrogen feed method.

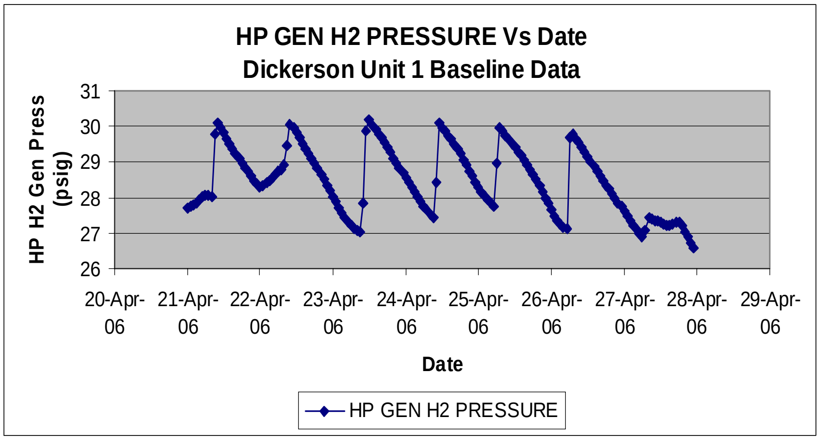

Figure 1

Maintaining a stable hydrogen pressure at the OEM specified level is critical to the ability of the hydrogen coolant gas to effectively remove heat from the generator. At increased pressures, hydrogen becomes denser, improving its capacity to absorb and remove heat. As a result, additional 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, while for pressure between

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Increasing hydrogen pressure also permits operation at normal load with the temperature of the water supplied to the gas cooler in excess of normal. An increase in cooling temperature of approximately 1°F may be obtained for every 1-psi increase in hydrogen pressure up to 15 psig, while for pressure between 15 and 30 psig, an increase in cooling water temperature of 0.5°F per psi of an increase in pressure may be obtained.

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. The ability to operate at maximum electric power capacity during peak demand periods can allow plants to sell all available power when electricity prices are at their highest, increasing the revenue to the plant.

Inefficient Use of Resources

The plant was also managing a very large inventory of gas cylinders (several hundred were kept on site at any one time) and utilizing a "batch" hydrogen feed process to maintain both pressure and purity in all six of its generators. The hydrogen supply method employed at Dickerson was both expensive and inefficient and there was a strong desire by plant operators to search for alternative methods to supply their generators with hydrogen.

The cost of hydrogen delivered in cylinders is more about the logistics (ordering, tracking, transporting, installing, renting) of getting the gas to the point of use than the actual cost of the gas molecule itself. The labor required to manage those logistics is seldom accounted for, but cannot be ignored. In today's power plant environment with fewer and fewer human resources available to perform value added tasks within the plant, the hours spent managing cylinders is a waste of valuable time.

SOLUTIONS PROPOSED

Hydrogen Dew Point and Purity Improvements

A search was conducted by plant personnel to find a suitable supplier for replacement dryers, which yielded several reputable manufacturers that proposed the replacement of all six hydrogen drying systems at the plant.

Sometime during the dryer evaluation process Proton Energy Systems, an OEM of onsite hydrogen solutions, contacted plant personnel to discuss the benefits of onsite hydrogen generation. Even though plant personnel were very interested in what was being proposed by Proton, it was understood that funding for the alternate hydrogen supply method would have to be used to purchase new dryers. Proton proposed utilizing an onsite generation system and a new hydrogen control method (Figure 2), as an alternate, to provide all of the required makeup hydrogen for the plant and also improve the quality of the coolant gas to meet OEM specifications without installing new dryers.

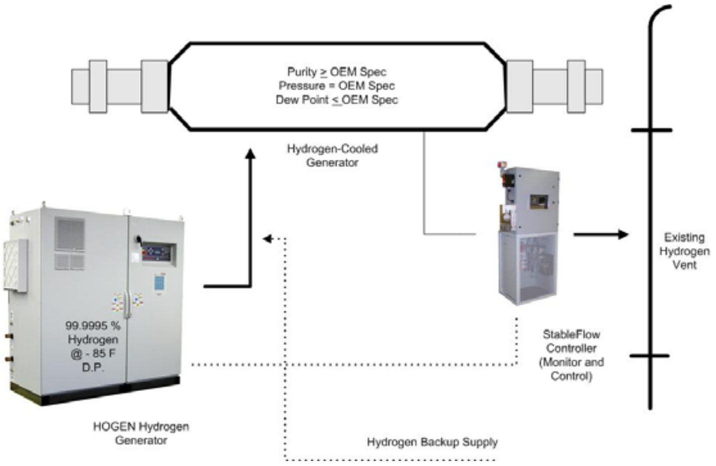

Figure 2

Pressure Stability and Safety

The implementation of a continuous feed hydrogen supply method versus the "batch" feed process that the plant was utilizing to stabilize the pressure within the generator casing was also proposed. It was not entirely understood why plant operators implemented the "batch" feed process, but the consensus was that it was most likely due to safety concerns related to a large gas volume "lined up" to the plant. The concern over large hydrogen gas volumes — 40,000 to 120,000 cubic feet in the case of a tube trailer, potentially feeding a huge undetected seal or casing leak — is a valid one. There is also the probability of pressure reducing regulator failures causing catastrophic generator failures due to high pressure hydrogen supply systems over pressurizing the generator casing as well. To reduce the risk of a catastrophic leak in a plant, "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 using the pressure decay over time method. The hydrogen seal leak rate can be determined if the pressure drop in the generator, temperature, and duration between fills is known.

The implementation of an onsite hydrogen generator addresses the safety concerns listed above by having a very low inventory of hydrogen gas while generating the gas required to meet the full demand of the process it is connected to. An onsite hydrogen generator is also limited to a set capacity and cannot produce more gas than its rated output. This allows plant operators to plan for “worst case” scenarios without the variability of a continuously changing tank volume. The hydrogen seal leak rate can also be tracked and trended by taking advantage of an onsite generator’s inherent ability to act as a volumetric flow meter.

Resource Management

The implementation of an onsite hydrogen generator eliminates the need to have hundreds of cylinders on the premises, which dramatically reduces the labor needed to track and account for the inventory as well as eliminates the monthly rental charges on the majority of the existing inventory. The hydrogen generator is located right at the point of use and does not need any operator interaction to provide the required gas output to the gas manifold. When the generator is used in conjunction with a “continuous” feed supply method the need for an operator to boost generator pressure on a shift or daily basis is eliminated. The on site inventory of stored gas is reduced to a small volume that can be used as a backup supply if needed.

Delivered hydrogen is relatively expensive when compared to onsite generation. Delivered gas prices fluctuate with the volatility associated with the 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 de-mineralized water and electricity to operate. An onsite hydrogen generator sized for an average power plant requires less than 20 gallons of water a day and 17kWh of electricity per 100 cubic feet of hydrogen produced. As these feedstock components — water and electricity—are a surplus to the power plant, they enable the plant to effectively source its own hydrogen supply for a small fraction of what is paid for delivered gas.

PHYSICS BEHIND THE SOLUTION

Effects of Cooling Gas Quality

The quality of the hydrogen cooling gas 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 components.

- The stability of the hydrogen gas pressure within the generator affects the maximum generating capacity of the electric power generator.

The density of the hydrogen gas within the generator casing has a physical affect on the windage loss of the generator and the thermal conductivity of the gas and its ability to remove heat.

Gas Density versus Windage Losses

Air is the most likely impurity to affect hydrogen density within the generator casing. Air is 14.4 times as dense as hydrogen, so even relatively low levels of air increase the density of the hydrogen-air mixture considerably.

This is shown as:

$$G_{dens} = (H_{pur} \times 1) + (A_{bal} \times 14.4)$$

Where:

G_{dens} = Increase in Gas Density (%)
H_{pur} = Purity of Hydrogen in Generator Casing (%)
A_{bal} = Balance of Impurity (air) in Generator Casing (%)

Example:

Hydrogen with a purity level of 97.0% and the balance of impurity being air at 3% will have the following affect on gas density.

$$[(0.97 \times 1) + (0.03 \times 14.4)] \times 100 = 140.2 \text{ \% change}$$

The relationship between hydrogen gas purity and gas density is illustrated in the chart below (Figure 3)

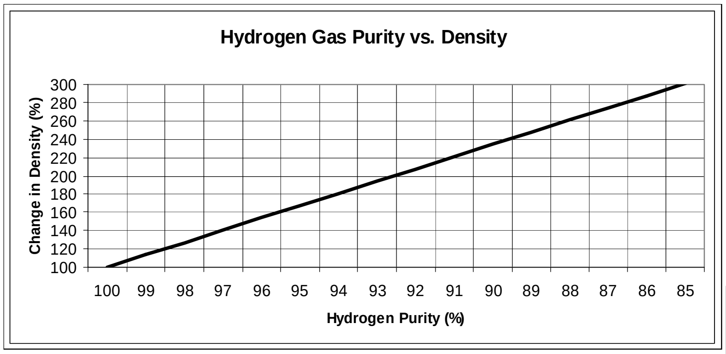

Figure 3

The change in gas density will have a negative affect on the windage loss of the generator. Windage losses are typically stated at nominal pressure above atmospheric pressure and at some nominal purity. The losses can be adjusted for actual operating conditions by some simple calculations.

This is shown as:

$$G_{loss} = G_{wind}\ x(D_{act}/\ D_{base})x(P_{act}+14.7)/(\ P_{spec}+ 14.7)$$

Where:

G_{loss} = Total Generator Electrical Losses due to Windage (kW)
G_{wind} = Baseline Generator Windage Loss (kW)
G_{net} = Net windage loss associated with hydrogen purity (kW)
D_{act} = Actual Gas Density due to Impurities (%)
D_{base} = Gas Density Baseline (%)
P_{act} = Actual Generator Operating Pressure (psig)
P_{spec} = Generator Operating Pressure Specification (psig)

Example:

A generator has an OEM specified windage loss of 1000 kW at 98.5% purity and a rated operating pressure of 60 psig. If the actual site conditions are 92% hydrogen gas purity and a 57.5 psig actual operating pressure the generator windage loss would be:

$$G_{loss} = 1000x(210/120)x(57.5+14.7)/(60 + 14.7) = 1691$$

The OEM specified baseline windage loss is subtracted from the total to get the net windage loss associated with hydrogen gas purity.

$$G_{net} = 1691 - 1000$$
$$= 691 \text{ kW}$$

So, an additional 691 kW is lost due to operating the generator with a hydrogen gas purity of 92%.

Gas Density versus Heat Removal

The improvement in the thermal capability of the generator is proportional to the square root of the absolute pressure increase in the generator casing.

This is shown as:

$$G_{cap} = \sqrt{\left(\frac{P_{spec} + 14.695}{P_{low} + 14.695}\right)} - 1$$

Where:

G_{cap} = Increase in Generator Capacity (%)
P_{low} = Pressure below OEM Max Specification
P_{spec}= Pressure at OEM Max Specification

Example:

An increase in H2 pressure of 2 psi (from 28 psig to 30 psig) would increase generator capacity capability by 2.3%.

The increased capacity is due to better heat removal from the copper windings associated with the higher density of the hydrogen gas. The higher density also has a small effect on the windage loss of the generator, but this is minimal in comparison to the gain in overall generating capacity.

THE RESULTS

Dew Point and Purity Improvements

Although plant personnel were initially skeptical of the claims made by Proton engineers, they agreed to a 90 day evaluation to test the theory of the innovative approach to maintaining purity and dew point within the generator casing. On February 17, 2004 a hydrogen generator was installed to supply ultra high purity hydrogen to unit 1 at Dickerson and the StableFlow^{TM} continuous purge method was initiated. Illustrated below (Figure 4) is a summary of the dew point improvement results during the first 90 days of operation. Keep in mind that the dew point prior to installing the proposed solution was extremely high and it was determined that greater than 90 days would be required to achieve the plant's desired dew point. It was agreed that if the initial results were significant and the trend was one of improvement, the plant would purchase the system and continue to monitor the results.

- On February 17, the dew point measured on unit 1 was 37 °F (2.8°C)
- By March 4, the dew point was down to about 30.8 °F (-0. 7°C)
- By May 18, the dew point was between 12 and 15 °F (-11 and -9°C)

Figure 4 below illustrates the steady decline in hydrogen gas dew point over a two week period during the evaluation period.

Hydrogen gas purity was measured above 99% following the first full week of operation with the proposed solution and did not drop during the evaluation period. It is important to note that the hydrogen purity monitor at the plant does not have sufficient resolution to detect hydrogen gas dew points that are beyond the OEM specified limits. Dew point monitors are recommended to perform the function of providing an accurate measurement of hydrogen gas dew point in the electric generator.

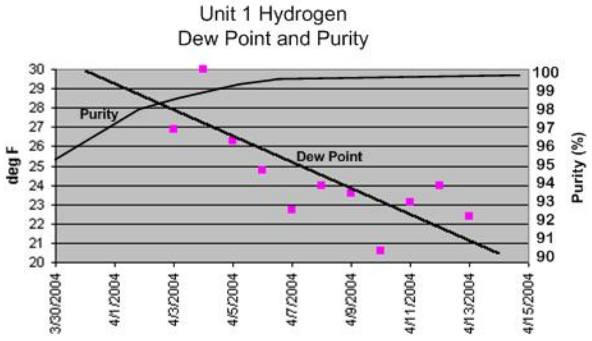

Figure 4

Dickerson decided to purchase the hydrogen generator after the evaluation period and canceled the order they had placed for six replacement dryers. Dickerson followed up with an order for 2 additional hydrogen generators to service the entire plant. The proposed solution of onsite hydrogen generation and the implementation of the StableFlow™ process at Dickerson eliminated the need for hydrogen dryers, saving the plant close to $300,000, and provided the plant with the ability to meet the required hydrogen makeup for the entire plant from surplus water and electricity.

StableFlow™ Hydrogen Control System Installation

Dickerson plant personnel still had a strong desire to automate the continuous purge process and in May of 2006 they installed a StableFlow™ Hydrogen Control System to automate the monitor and control process of the hydrogen system on unit 1 (Figure 5a and 5b). The StableFlow™ Hydrogen Control System was initially operated for two weeks in monitor mode only and the plant reverted back to their “batch” hydrogen feed process to gather some baseline data. The StableFlow™ Hydrogen Control System was then initiated and took full control over the monitoring and control function of the hydrogen system. The system quickly made initial improvements to the purity and dew point and controlled the purge rate to optimize the hydrogen usage.

Figure 5a

HOGEN® S Series
Hydrogen Generator

Figure 5b

StableFlow™
Hydrogen Control System

The chart (Figure 6) pictured below illustrates the effect the hydrogen “batch” feed process has on hydrogen gas dew point while operating in that gas delivery mode. The gas dew point will continue to rise, undetected at many power plants, to levels that far exceed the OEM specified levels. The chart shows that within hours of operating under full control of the StableFlow™ Hydrogen Control System the dew point begins to drop and settles out at the desired set point.

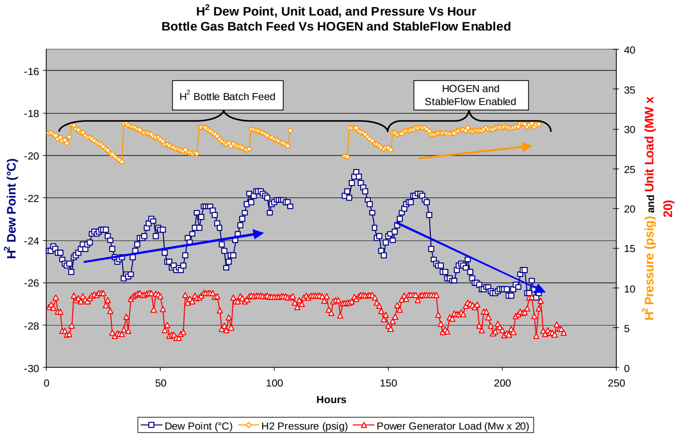

Figure 6

Figure 7 pictured below illustrates the affect the “batch” feed process has on pressure stability, but also illustrates that hydrogen gas purity is also affected by the periodic pressure decay and re-pressurization cycles. Hydrogen gas purity will drop as the pressure in the generator decreases and immediately responds positively as “new” gas is introduced into the casing to re-pressurize. As this trend continues the decrease in purity also continues to accumulate and will never fully recover until a significant purge of gas from the generator takes place under this process scenario. This cumulative negative effect on hydrogen casing purity takes a few days or a few weeks to get to the point where a purge needs to take place to correct the problem. The StableFlow™ Hydrogen Control

System automatically and continuously maintains the casing purity above OEM specified levels.

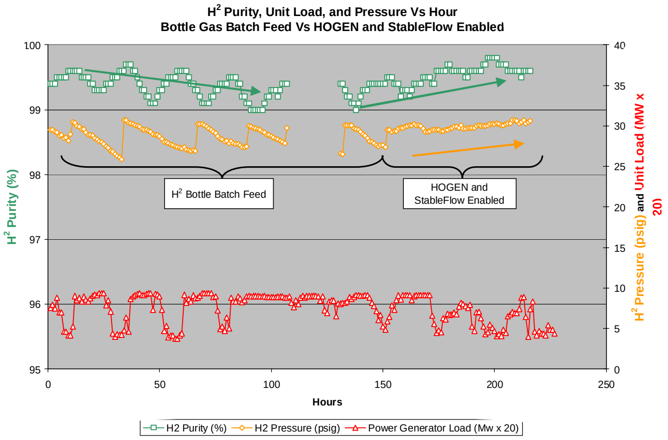

Figure 7

Hydrogen Gas Pressure Stability and Safety

Plant operators at Dickerson Generating Station were utilizing a "batch" feed hydrogen supply method and it was negatively affecting the ability for the plant to deliver power at full rated capacity at acceptable operating temperatures. Figure 1 represents the pressure profile for unit 1 prior to implementation of onsite generation and StableFlow^{TM} Hydrogen Control. Dickerson has implemented onsite generation and continuous feed on the balance of the generators at the plant and is in the process of selecting new pressure regulators capable of controlling generator casing pressure at 30 psig +/- 1psi.

Dickerson plant engineer, Larry Dusold, ran a calculation with 2005 generation data and found that on average, Dickerson's units operated at loads over 190 MW 558 hours per year (~6%) and over 191 MW for 66 hours per year (~1%). However, during those times, electricity was worth an average of $115.19 per MW/hr. Assuming that operating over 190 MW is pushing the limit of the unit's generating capability, then 1 additional MW is worth an additional $64,000 annually per electric generator.

Implementing onsite hydrogen generation has also increased plant safety by reducing the amount of stored hydrogen on the plant premises. Onsite hydrogen generation has allowed the plant to feed makeup hydrogen to the electric generators without the concern of a major hydrogen leak creating a hazardous environment. The ability of an onsite hydrogen generator to produce hydrogen with very little stored inventory requirements and the inherent ability to limit capacity makes it the safest form of hydrogen supply for generator cooling applications.

SUMMARY

A safe and reliable supply of hydrogen gas is critical to the operation of a power plant. Hydrogen gas used in the power industry should not be viewed as a commodity. Many power plants have made serious compromises to the way they utilize hydrogen to cool their generators and have negatively affected their performance. Traditional sources of hydrogen gas do not allow the plant to enhance the performance of their generators due to cost and safety concerns. Onsite hydrogen generators that utilize water electrolysis have been proven to provide the power plant with a safe and reliable source of hydrogen makeup gas. Hydrogen gas, when generated on site by electrolysis and controlled to provide a continuous purge through the electric generator has been proven to increase the operating efficiency and generating capacity of the generator.

Mirant's Dickerson Generating Station identified some critical issues with their hydrogen supply and control methods that were affecting the performance of their electric generators. Plant engineers made a bold move to evaluate onsite hydrogen generation as an alternate supply method and were pleased to learn that the benefits of onsite generation far exceeded their expectations. Dickerson also implemented an innovative technique to continuously purge their generator, which dramatically improved the gas quality in the generator casing. The improved gas quality has resulted in very low dew point in the casing as well as increased generator efficiency and capacity. These improvements have all impacted the performance of the electric generator and will ultimately impact the plant's bottom line.

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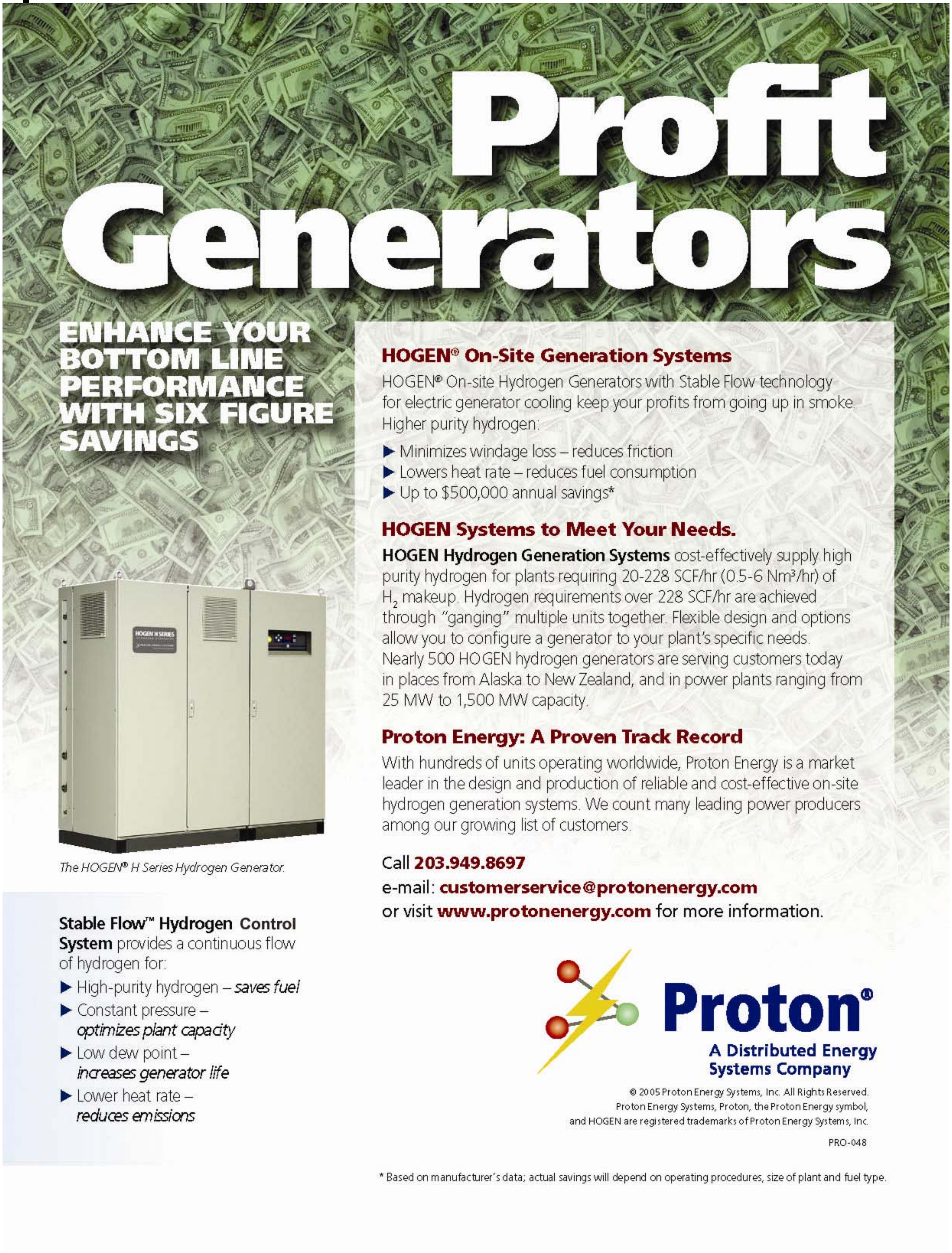

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* Based on manufacturer's data; actual savings will depend on operating procedures, size of plant and fuel type.