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Experience with CO_2 free Generator Operation

Uwe EICKELBECK
Siemens Energy Global GmbH & Co. KG
Germany
Uwe.Eickelbeck@siemens-energy.com

SUMMARY

Until now, it has been common practice to use Carbon Dioxide (CO_2) as an inert gas in industrial applications including turbo generators, but most recently the environmental impact of CO_2 comes more and more into focus. 67 countries have already committed to net-zero emissions in the near future and the pressure that governments are putting on companies to reduce carbon emissions is growing.

Siemens Energy has successfully developed a process to purge generators without any CO_2 emissions. This advanced purging process which uses argon as an alternative to the common practice of using CO_2 has multiple benefits for the operator in addition to the environmental impact. CO_2 is mostly supplied in liquid form and must then be converted to the gaseous state in a complex process. Argon is a noble gas with a very low critical temperature and can be applied at high pressure. The elimination of the conversion will lead to opportunities for reducing outage time during shutdown and start-up of the plant. Simplifying the system also has the advantage of fewer components to maintain, which leads to higher reliability, and improved safety.

A patented CO_2 free generator purging was at first validated in the generator test bed at a Siemens Energy factory, followed by practical tests successfully performed in commercially operating power plants. Currently there are several hundred units globally using this advanced technology. Some units have used argon right from the start of their operation, while other units were converted from CO_2 to argon purging. The earliest installations have accomplished more than two decades of successful operation and helped already many operators around the globe to reach their goals on the way to net-zero CO_2 emissions.

KEYWORDS

Turbo Generators – Hydrogen - CO_2 free - Net Zero Emissions - Purging - Argon - Safety

INTRODUCTION AND MOTIVATION TO APPLY CO_2 FREE GENERATOR OPERATION

At the 21. World Climate Conference in Paris (2015) countries aimed to reach global peaking of greenhouse gas emissions as soon as possible to achieve a climate neutral world by mid-century [1]. Therefore, it was agreed to limit global warming to well below 2 degrees Celsius, preferably to 1.5 degrees Celsius, compared to pre-industrial levels.

67 countries have already committed to net-zero emissions and the pressure that governments are putting on companies to reduce carbon emissions is growing [2].

Figure 1: Examples on commitments towards net zero emissions

Most recently the Glasgow Climate Change Conference took place (COP 26) and pending items that prevented the full implementation of the Paris Agreement on carbon markets and transparency have finally been approved [3]. In addition, it was stressed that more must be done at the national level in the course of this decade to limit global warming to 1.5 degrees Celsius.

Siemens Energy analyzed power plant products in respect to these ambitious targets towards net-zero emissions. One of the products where CO_2 is used in power plant applications is the purging of hydrogen cooled generators.

The need for purging, technical solutions, advantages and disadvantages and experience with CO_2 free generator operation are described in this paper.

GENERATOR PURGING PROCESS

Hydrogen is an ideal generator coolant for medium and large sized turbo generators, having advantageous heat transfer characteristics and low windage losses. But to maintain these advantages, the hydrogen must be handled safely and carefully.

Figure 2 gives an example for the typical design of a hydrogen cooled generator [4]. The casing, stator core, end zones, etc. are typically cooled by hydrogen gas, ventilated via internal fans, and re-cooled by hydrogen / water heat exchangers, which are integral part of the generator casing. The rotor, stator winding, parallel rings and bushings can be cooled with hydrogen too or by usage of alternative cooling methods like demineralized water depending on the specific configuration [5].

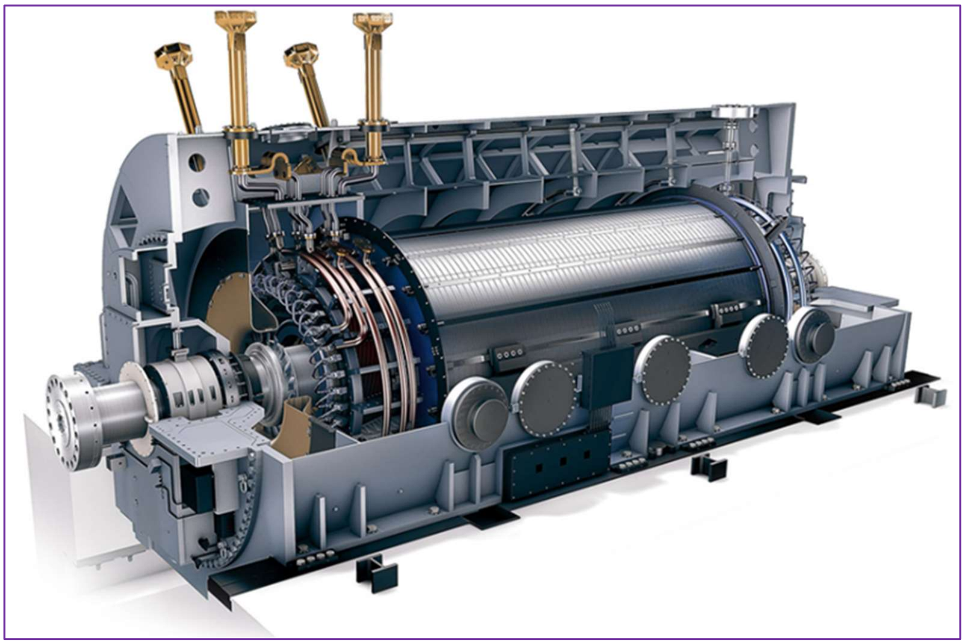

Figure 2: Typical design of a hydrogen cooled generator

In respect to plant safety and reliability, the hydrogen filling and venting process of the generator plays a very important role in the prevention of possible explosive atmospheres. In accordance with safety regulations and international standards like IEC60034-3 [6] or IEEE C 50.13 [7], it is not permitted to directly displace air with hydrogen or hydrogen with air in hydrogen cooled turbo generators and it is mandatory to maintain the hydrogen purity at safe level. To avoid this hazardous mixture, the so-called inert gas purging process must be performed. The purging process describes the explosion protection procedure to prevent the creation of an explosive atmosphere by using an inert gas, which does not undergo a chemical reaction e.g., with hydrogen.

During commissioning of a generator e.g., for initial startup or after an outage, the air must be removed with an inert gas and will be replaced with hydrogen for operation, like shown in

Figure 3. During the decommissioning steps the hydrogen will be replaced by an inert gas and the inert gas by air to allow accessibility e.g., for maintenance activities.

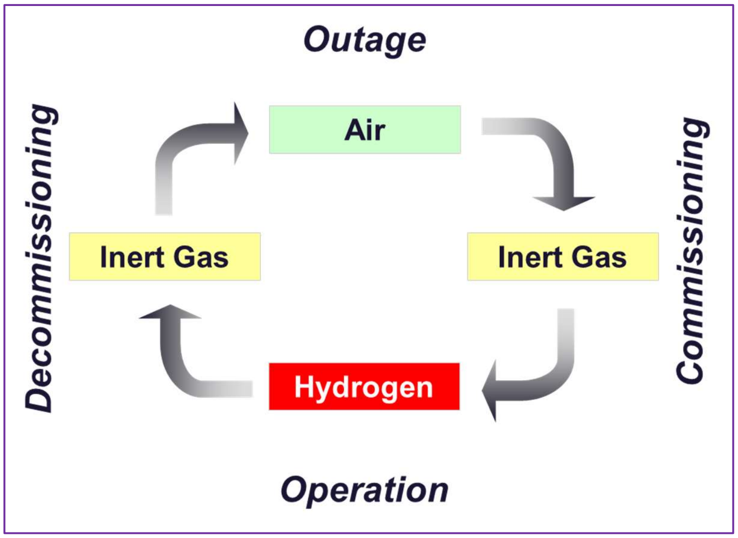

Figure 3: Generator gas purging cycle

Until now, it has been common practice to use Carbon Dioxide (CO_2) as an inert gas in industrial applications, but most recently the environmental impact of CO_2 becomes more and more into focus. But there are technical solutions available to avoid CO_2 and enable CO_2 free generator operation.

TECHNICAL ASPECTS AND SOLUTIONS TOWARDS CO_2 FREE GENERATOR OPERATION

Purging generators by using CO_2 is a common practice, well known and established since around hundred years. The first electrical generators which used hydrogen as a cooling media were built in the early 1920s as test generators, and the first commercial generators went into service in the late 1930s in the US. The reasons to use CO_2 as an inert gas to purge generators is that the density of CO_2 is quite different to the density of air and hydrogen and the usage of CO_2 is already known from other applications e.g., fire extinguishing systems.

In regard to continuous product improvement, operation simplifications and providing customer benefits, Siemens Energy successfully developed a process to purge generators with argon as an inert gas. This solution is safe, reliable, and cost effective without any CO_2 emissions. It has already been successfully implemented in several hundred units around the globe and has already helped many operators globally to affordably reach their goals on the way to net-zero CO_2 emissions.

The big disadvantage of the common practice is its liquid form at normal ambient conditions. The below Table 1 gives an overview about the relevant gas data and their relation in respect to generator purging This means that liquid CO_2 must be converted to the gaseous state before feeding into the generator. The processes to achieve this are complex and time consuming e.g., by an evaporation process via atmospheric heat exchangers, heating elements with additional auxiliary power or simple conversion with the disadvantage of component and pipe freezing and longer lasting conversion processes.

Due to the importance of being able to purge the generator at any time, even in emergency cases, the evaporation process must be possible immediately and fast. Therefore e.g., flash evaporators need to be connected to an electrical power supply with the highest availability. This could be, for example, an emergency power supply feed from a battery or a diesel-driven generator. By using an inert gas, which is already gaseous this additional steps, additional power supply and complexity is eliminated.

Purging with argon can be done without any additional auxiliary power, because its much lower critical temperature allow that it is already available in gaseous form and no complex and conversion from liquid to gaseous is needed.

Gas Data					
	Hydrogen (H_2)	**Air**	**Argon (Ar)**	**Carbon Dioxide (CO_2)**	**Nitrogen (N_2)**
critical temperature	-239.9 °C	-140.73 °C	-122.43 °C	+31.0 °C	-146.9 °C
density, gaseous at 0°C and 1.013 bar	0.08988 kg/m^3	1.293 kg/m3	1.784 kg/m3	1.977 kg/m3	1.250 kg/m3
density ratio to air at 0°C and 1.013 bar	0.0695	1	1.38	1.53	0.97
thermal conductivity at 25°C and 1 bar	1861*10^{-4} W/mK	260*10^{-4} W/mK	178.2*10-4 W/mK	164.0*10-4 W/mK	258.3*10-4 W/mK

Table 1: Gas data

The density and thermal conductivity of argon are comparable to the appropriate CO_2 values. As both gases are heavier than air, the proven principle of gas stacking is maintained during the purge process. This means the heavier gas is fed from the bottom, where the lighter gas is removed from the top and vice versa.

In some power plants nitrogen is used to purge generators and due to its low critical temperature, it also allows direct gaseous purging to remove the hydrogen from the generator. The disadvantage of nitrogen purging can be seen in the small density difference between air and nitrogen (see Table 1). Due to this small density difference of around 3 percent the amount of gas and time is higher than purging with argon.

A comparison of the general layout for CO_2 purging systems and Argon purging systems shows that more components are required for CO_2 systems (Figure 4). These number of components and their characteristic can be seen as a bottle neck. For purging with argon no electrical components, and no auxiliary energy are needed. This means as well less maintenance activities, less failure opportunities, higher reliability, and improved safety.

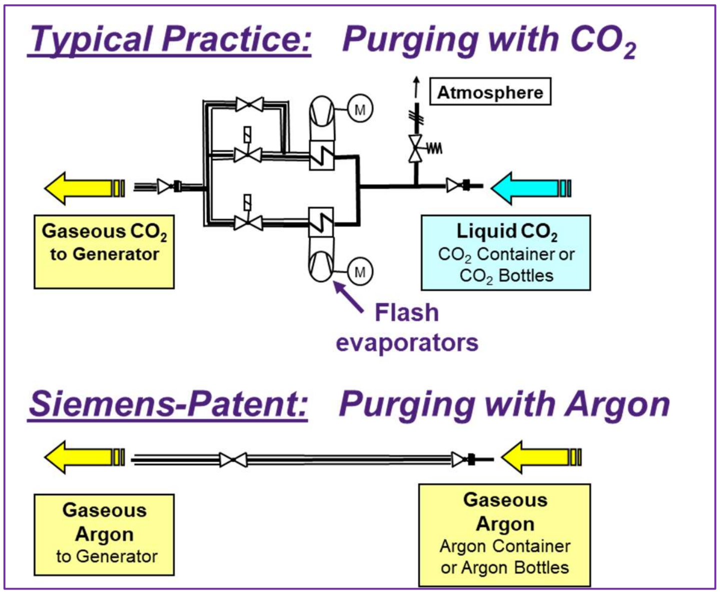

Figure 4: Simplified overview of CO2 and Argon purging

Since no additional evaporation process is necessary for purging a generator with argon, the system can be simplified. Therefore, faster inerting without time consuming pre-heating is possible. This will lead to opportunities for reducing outage time during shutdown and start-up of the plant.

The disadvantage of argon is that in some regions of the world it is slightly more expensive than CO_2. Considering the amount of inert gas needed and the specific gas cost, the extra cost is in a range of few hundred Euro per purging cycle [8]. However, this minor disadvantage is over compensated, because of systems simplification, less components, less complex parts to maintain, less spare parts and no need for emergency power supply to enable evaporation during normal and abnormal operation conditions.

This overall benefit was widely seen and leads to the fact that not only new units were installed with this advanced purging process, but as well several operators removed their existing CO_2 systems and converted to argon.

EXPERIENCE AND APPLICABILITY

A patented CO_2 free purging of a generator was at first validated in the generator test bed at a Siemens Energy factory, followed by practical tests successfully performed in commercially operating power plants. Since the first application, several hundred units globally were installed and operated with the advanced purging technology. The implementation has been performed either right from the start of their operation or existing units were converted from CO_2 to argon purging. The earliest installations accomplished more than two decades of successful operation.

Figure 5: Typical impression from a power plant implementation

The conversion from CO_2 purging to argon purging is rather simple because there are no modifications required on the generator proper, but special attention must be given on the auxiliaries. Depending on the operator´s preferred argon container, bundles or bulk supply can be used (see Figure 5).

Implementation and successful operation took place in many countries all over the world, including USA, Austria, Belgium, Czech Republic, Finland, France, Germany, Hungary, Netherlands, Norway, Poland, Portugal, Russia, Slovakia, Spain, Turkey, United Kingdom, Abu Dhabi, Bahrain, Egypt, Iran, Iraq, Israel, Oman, Bangladesh, Korea, Malaysia, Pakistan, Singapore.

In regard to avoidance of CO_2 emissions, Figure 6 indicates the trend of global benefit by the increasing numbers of generators operated without CO_2. More than thousand tons of CO_2 have already been avoided since the first installation and the number is increasing with every new installation or conversion.

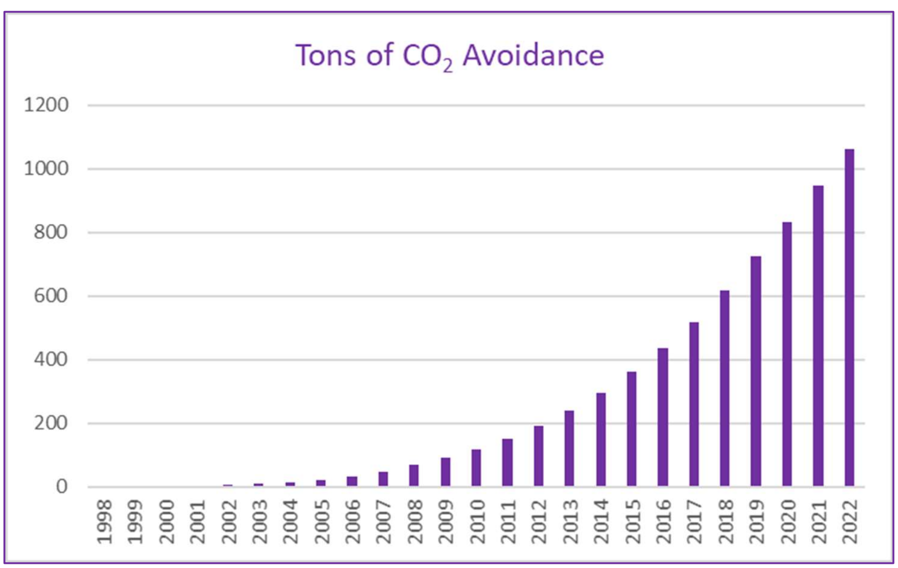

Figure 6: Trend of CO2 avoidance by CO2 free generator operation

Some of the main motivations for customers to apply argon right from the beginning or to convert existing units from CO_2 to argon include, but are not limited to safety aspects, overall cost considerations, system simplification and decarbonization strategies.

The application of argon or conversion from CO_2 or nitrogen to argon is not limited by the type of generator or OEM of the generator.

The generators are not the biggest source of emissions in power plants but reducing their emissions towards zero can easy show the right signal that these goals are taken seriously, and concrete measures are in place towards the goal achievement. The sooner the application is considered in new installations and conversion, the faster the ultimate goal can be reached.

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