SAFETY CONCEPT OF A SELF-SUSTAINING PEM HYDROGEN ELECTROLYZER SYSTEM

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ABSTRACT

Sustainable electricity generation is gaining importance across the globe against the backdrop of ever-diminishing resources and to achieve significant reductions in CO_2 emissions. One of the challenges is storing excess energy generated from wind and solar power. Siemens developed an electrolysis system based on proton exchange membrane (PEM) technology enabling large volumes of energy to be stored through the conversion of electrical energy into hydrogen.

In developing this new product range, Siemens worked intensively on safe operation with a special focus on safety measures (primary, secondary and tertiary). Indeed, hydrogen is not only a rapidly diffusing gas with a wide range of flammability but frequent lack of information leads to insecurity among the public. Siemens PEM water electrolyzer operates at a working pressure of 50 bar / 5 MPa. The current product generation is being used for demonstration purposes and fits into a 30 ft. / 9.14 m container. Further industrialized product lines up to double-digit medium voltage ranges will be available on the market short- and mid-term. The system is designed to operate self-sustaining. Therefore, special features such as back-up and fail-safe mode, supported by remote monitoring and access have been implemented.

This paper includes Siemens' approach to develop and implement a safety concept for the PEM water electrolyzer leading into the approval and certification by a Notified Body as well as the lessons learnt from test stand and field experience in this new application field

1.0 INTRODUCTION

As the amount of electricity obtained from renewable sources is subject to strong fluctuations, there is a clear need not only for the storage of excess electricity, but also for systems to be flexible and dynamic enough to meet future requirements: for example it has to respond to fluctuations in energy production and availability extremely quickly and reliably, so that energy can be used optimally while ensuring grid stability.

2.0 TECHNICAL CONCEPT

Siemens has therefore developed an electrolysis system offering a number of benefits over the conventional alkaline process: PEM electrolyzers are suitable for high current densities and can respond within seconds to large jumps in electricity production typical for wind and solar plants. A proton exchange membrane (PEM) in the electrolyzer separates the areas in which oxygen and hydrogen are generated. Electrodes, made of precious metal, are connected to the positive and negative terminals of the voltage source. Water splitting takes place there.

Thanks to their membrane technology, PEM electrolyzers can be operated efficiently and flexibly along production curves with frequent instant variations. Besides their highly dynamic response, the new electrolyzers further have the advantage not to have to be maintained at a specific operating temperature. They can indeed be switched off completely, and don't require a warm-up phase prior to being switched on. This is of great advantage as it eliminates stand-by costs and enables efficient and reliable operation. In addition, PEM electrolyzers produce hydrogen at pressures of up to 50 bar / 5 MPa. This eliminates additional investment costs for auxiliary pressurization equipment to further process or store the produced hydrogen. Finally, the PEM electrolyzer technology leads to minimized maintenance cost and efforts (no caustic potash solution, no leaching, no precipitation, no inert gas flushing and less corrosion) and more compact construction (higher current density).

The current product generation is being used for demonstration purposes and fits into a 30 ft. / 9.14 m container. This container is divided into three separate compartments: The 'electrolysis process compartment' including the cell stacks, the 'control room' and the 'water treatment compartment'. The H_2 storage is not in the scope of Siemen's PEM electrolyzer system, but safety measures are installed in the pipes connecting the electrolyzer to components such as storage tanks, to avoid impacts in both ways.

Siemens' PEM electrolyzer system mainly comprises two major parts: the electro-chemical part where the electrolysis process is taking place, and the electro-technical part, built on well-proven Siemens standard equipment. The PEM system is CE marked, indicating its conformance with the Pressure Equipment Directive 97/23/EC, the Low Voltage Directive 2006/95/EC, the ATEX Directive 94/9/EC, the Electromagnetic Compatibility Directive 2004/108/EC and the Machinery Directive 2006/42/EC. The Conformity Assessment was taken out following Module G (Unit verification). An authorized third party (Notified Body) was involved in the procedure.

3.0 DEFINITION OF EXTENDED SAFETY MEASURES

The terms 'primary', 'secondary' and 'tertiary' safety measures originate from the Explosion Protection and Prevention guidelines. Siemens decided to go beyond these requirements and enlarged these definitions, making them applicable to its complete PEM system and herewith adapting its design from the start toward a systematic risk limitation. Figure 1 shows a schematic representation of the applied risk reduction process leading to the overall safety concept for the complete system. The **Extended Primary, Secondary and Tertiary Safety Measures** are directly related to the risk reduction measures.

Before starting the risk reduction process, the limits of the system had to be determined. Possible hazards during the entire lifecycle of the PEM electrolyzer were identified and their risk was estimated and evaluated. Based on the results of this analysis, the risk reduction process was started according to the procedure shown in Figure 1.

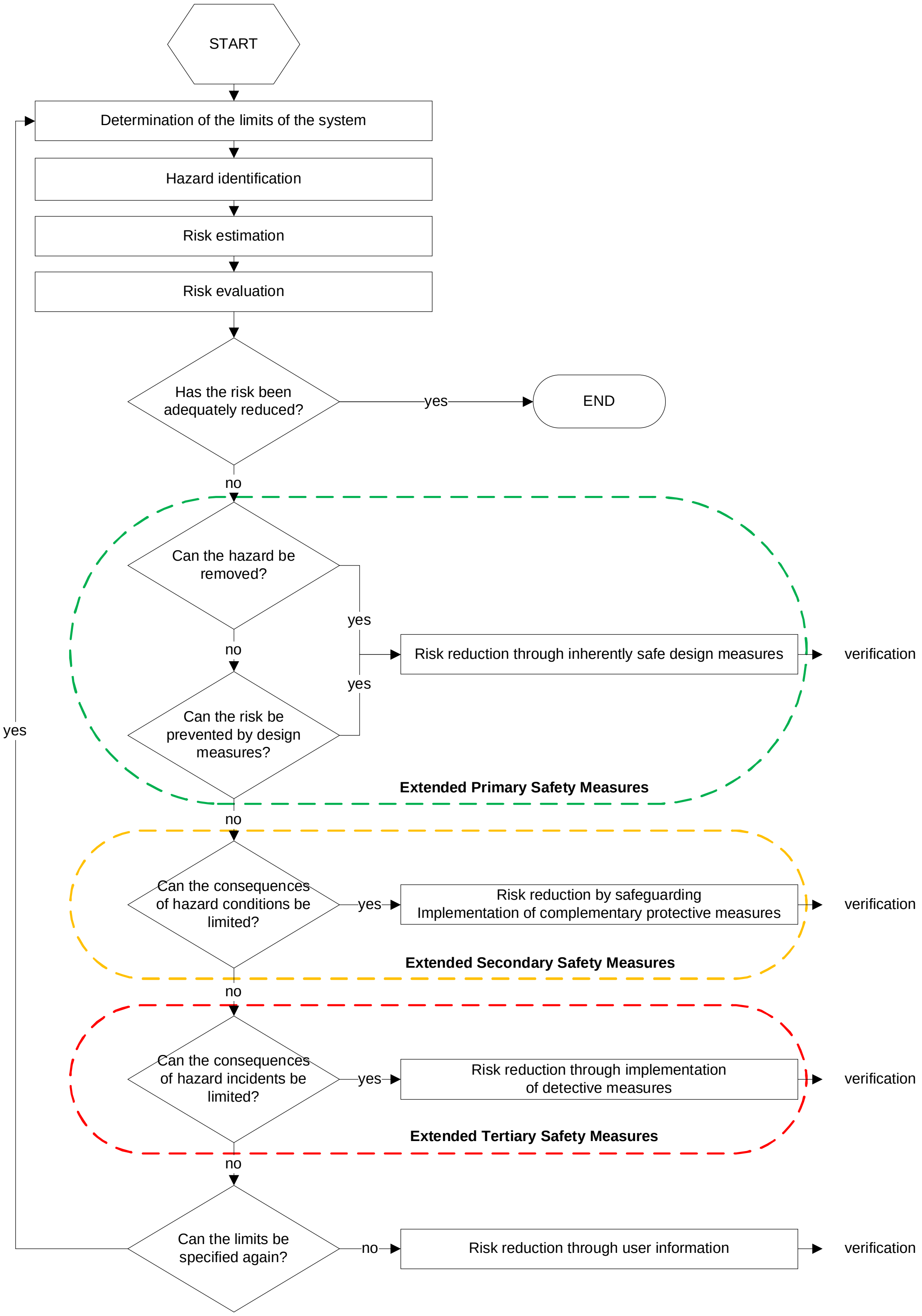

Figure 1: Schematic representation of risk reduction process including resulting safety measures according to ISO 12100 [1].

Extended Primary Safety Measures

Those measures target the removal of hazards or prevention of risks and hazard conditions by inherently safe design measures. Such risks include the development of potentially explosive atmosphere, increase of pressure or increase of temperature. Primary Safety Measures also decrease the inspection and maintenance needs.

Extended Secondary Safety Measures

Those measures limit the consequences of hazard conditions by safeguarding and implementation of complementary protective measures. This includes but is not limited to the ignition of hazardous explosive atmosphere or bursting of pipes.

Extended Tertiary Safety Measures

Finally, those measures limit the consequences of hazard incidents. This can be realized by detective devices or sensors such as a fire detection system.

In case the risks occurring during the lifecycle of the PEM electrolyzer system can't be reduced through primary, secondary or tertiary safety measures and the limits of the system can't be specified again, the risk reduction has to be realized by user information.

4.0 SAFETY CONCEPT

To prepare the optimized safety strategy, all relevant Regulations, Codes and Standards were identified and taken into account. For a later safe operation of the system, national regulations such as "BetrSichV" ("Betriebssicherheitsverordnung" or industrial safety regulations) and UVVs ("Unfallverhütungsvorschriften" or Accident Prevention & Insurance Association safety prevention regulations) were furthermore considered at an early stage.

The overall safety concept for the complete PEM-system consists of but is not limited to the following Extended Primary, Secondary and Tertiary Safety Measures [2], [3], [4], [5], as shown in Figure 2:

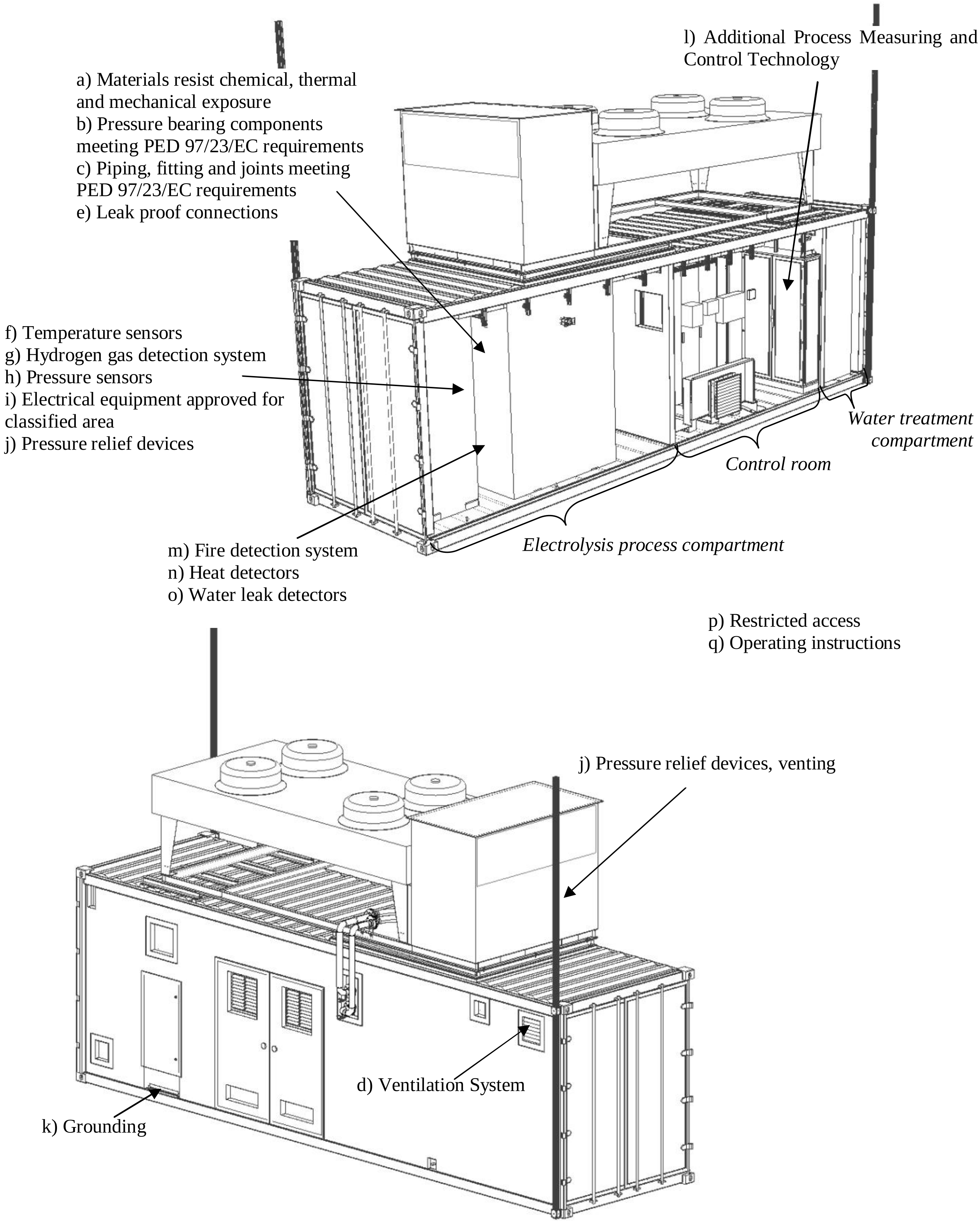

Figure 2: Extended Primary, Secondary and Tertiary Safety Measures for the electrolyzer system.

4.1 Extended Primary Safety Measures

Risk reduction by inherently safe design measures

Primary Safety Measures should be the first choice in developing a safe PEM electrolyzer system when the hazard can't be removed. Their objective is to prevent critical stages to occur, which could lead to hazardous incidents for third parties.

In the Siemens PEM electrolyzer, several extended primary safety measures were taken:

a) Materials selected to resist chemical, thermal and mechanical exposure

All the materials used in the PEM electrolyzer system were designed to resist the expected thermal, mechanical and chemical exposures. For the critical parts, additional material test certificates were requested from the suppliers.

b) Pressure bearing components meeting the Pressure Equipment Directive PED 97/23/EC requirements

A safe enclosure of hydrogen in the system is ensured by design measures and the usage of adequate materials. Therefore, the pressure bearing components in the PEM electrolyzer system are designed according to the Pressure Equipment Directive 97/23/EC. In order to secure a safe operation under pressure, Siemens furthermore conducted external design examination and final inspection through a third party. Finally the operating manual includes the necessary information as defined in the directive.

c) Piping, fitting and joints meeting the PED 97/23/EC requirements

Piping, fitting and joints as well as pressure-bearing instrumentation are designed to withstand the occurring maximum pressures and temperatures and to prevent wear and corrosion. The components selected meet the requirements of the Pressure Equipment Directive.

d) Ventilation system in the enclosure

The ventilation concept in the system is based on the analysis of hypothetic accidental releases, leakage and bursting of pipes during hydrogen production and during idle-time (on-, stand-by and off-time).

- The ventilation rate is sufficient to maintain an air exchange rate of approx. 15 times per hour.
- The forced air circulation concept is based on an opening located at the bottom of the container and an outlet on the opposite side, allowing appropriate air flow. Herewith hydrogen can be diluted and blown out very quickly.
- Following a warning through the gas leak detector, the ventilator automatically switches to full-speed.
- The ventilation system operation is assured through airflow monitoring and error protected traction unit supervision.
- Since the ventilator is an integral part of the explosion protection concept, it is connected to a UPS to secure ventilation in case of power outages.
- Failure of ventilation leads to a shutdown of gas production.

e) Prevention of accumulation of explosive atmosphere by leak proof connections

Leak tightness has to be guaranteed over the entire system lifetime. Welded connections have been preferred for the piping system; the number of joints and fitted connections is minimized. Before final acceptance and start-up of the PEM electrolyzer system, a leakage test is performed using Helium at maximum operating pressure for 30 min.

4.2 Extended Secondary Safety Measures

Risk reduction by safeguarding and implementation of complementary safety measures

In case the occurrence of potentially unsafe conditions can't be avoided, secondary safety measures have to be installed to limit the consequences. Therefore, protective measures are installed.

Extended secondary safety measures implemented in the Siemens PEM system are:

f) Temperature sensors

To ensure a stable and safe operation of the PEM electrolyzer, several temperature sensors are installed in the system. Thermocouples are located in the cell stacks, in the peripheral devices, in the three compartments as well as in the control units. A shut-down of the system is automatically triggered in case pre-defined temperatures are exceeded.

g) Hydrogen gas detection system

The hydrogen sensors are systematically positioned above a potential leakage area where hydrogen may accumulate. Two redundant hydrogen sensors are installed in the electrolysis compartment of the container. In case the hydrogen concentration in the container is greater than 10% of the lower explosion limit (LEL, corresponding to 0.4% H_2 in air), an automatic emergency routine is triggered. Automatic emergency shut-off is initiated if the hydrogen concentration in the container reaches 25% of the LEL (corresponds to 1% H_2 in air) [6]. In such a case, gas production is automatically stopped.

h) Pressure sensors

The pressure in the system is controlled with redundant pressure sensors and monitored at all times. Should pre-set pressure be exceeded, an automatic shut-off of the system takes place.

i) Electrical equipment approved for classified areas

The classification of hazardous areas was realized taking into account the existence probability of potentially explosive atmosphere [6]. The selection of electrical equipment for use in the classified areas took place in line with the relevant standards. The whole electrolysis process compartment is classified as ATEX zone 2. The control room and the water treatment department are not classified as ATEX zone, as no accumulation of potentially explosive atmosphere can occur at any time.

j) Pressure relief devices

According to the Pressure Equipment Directive 97/23/EC, all pressurized systems have to be protected from overpressure. Siemens uses a spring-loaded pressure relief valve (HPRV). Relieved hydrogen and oxygen is vented outside the container.

k) Grounding

The PEM electrolyzer system is grounded according to the relevant VDE standards (German Association for Electrical, Electronic & Information Technologies). Grounding of the cell stacks is technically not possible as a safe and reliable operation of the process can't be realized otherwise. Nevertheless, they are also protected to prevent electric shock according to relevant standards.

l) Additional Process Measuring and Control Technology

The PEM electrolyzer system is equipped with a remote control system designed to guarantee a safe, reliable and self-sustaining operation of the system. This concept ensures that a single failure of a safety control circuit component does not lead to a hazardous situation. Programmable electronic equipment is used for monitoring and complies with design principles as fail-safe mode, redundancy and self-diagnosis. Safety components are UPS-buffered.

4.3 Extended Tertiary Safety Measures

Risk reduction by implementation of detective measures

In case neither one of the previous safety measures can be implemented, limitation of consequences of hazardous incidents has to be assured. This can be realized by devices able to detect such incidents.

Extended Tertiary Safety Measures realized in the Siemens PEM electrolyzer system:

m) Fire detection system

A fire detection system is installed in the container with sensors placed in each of the three compartments. This system is linked to the control system of the PEM electrolyzer. Automatic actions take place in case of fire alarm. The alarm signals can also be sent to the local fire department.

n) Heat detectors

Infrared heat detectors are installed to detect hydrogen flames. The response of the sensors automatically leads to emergency actions managed by the control system.

o) Water leak detectors

In case of a cooling or process water leakage, water leak detectors are installed to protect the system from further damages. Protective measures are automatically taking place triggered by the control system.

p) Restricted access

Access to the operating room as well as the electrolysis system is strictly restricted. Qualified personnel only are allowed to enter the various compartments for service and maintenance. In case the operating room has to be entered, the gas generation has to be stopped and the entire system has to be in a safe condition.

q) Operating instructions

Remaining risks which can't be reduced by extended primary or secondary safety measures are described in the operating manual to protect workers from harm and the system from damages. This manual also includes further Environment, Health and Safety (EHS) guidelines.

5.0 CONCLUSION

Since the deployment of an integrated safety concept is an iterative method and since primary safety measures leading to hazard removal and design measures are to be preferred, Siemens' experience in other industries demonstrated that such a process has to be embedded at an early stage in the design-development of the system. To further limit the risks and increase the operation safety, Siemens also decided, in addition to the risk analysis, to conduct a FMEA (Failure Mode and Effect Analysis) for the PEM system to identify potential failures, their causes and their influences.

The success of the innovative PEM electrolyzer technology and the potential role of hydrogen in the future energy landscape depend to a great extent on high public acceptance. Therefore, a third party (Notified Body) was involved during the entire development and production process. Regulations, Codes and Standards were interpreted in a very conservative and overcautious way to ensure a high reliability, stability and, most of all, safety of the PEM hydrogen electrolyzer system. The safe generation and use of hydrogen is Siemens' primary goal.

6.0 REFERENCES

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