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Review Article

REVIEW OF PEM ELECTROLYSER AND ASSOCIATED BALANCE OF PLANT SYSTEM FOR GREEN HYDROGEN GENERATION

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A R T I C L E I N F O

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A B S T R A C T

The energy transition is continuing at an unprecedented pace and scale, calling for new low carbon technologies. Green hydrogen is one among them and is considered fuel of the future. In mid to long term, usage of hydrogen will help India meeting emission goals under the Paris agreement and will also reduce import bills from fossils fuel. In short term selection of right type of technology both at upstream and downstream needs to be matured. This paper considers review of Hydrogen generation through PEM electrolyser with emphasis on study of balance of plant equipment basic design, control concept & safety requirement. Balance of plant equipment which can be divided into subsystems, its optimisation saves on space, weight & auxiliary power consumption and ultimately adds to the enhanced efficiency of the hydrogen generator. Present practice at small and mid size hydrogen generator is to have BOP systems dedicated to individual hydrogen generator. As the scale of hydrogen generation is supposed to increase exponentially, a common BOP system with larger capacity and redundancy configuration feeding to various array of hydrogen generator is envisaged. Higher capacity BOP equipment / systems will provide window of opportunity for systems engineer for optimization, value engineering leading to overall efficiency improvement and operational flexibility for different combination of hydrogen generators.

INTRODUCTION

The Paris Climate Change Agreement has set in international law the objective of achieving a net zero carbon future for the planet, in the second half of the century. Although it doesn't clearly specify exactly when, climate change scientists tell us the trajectories to get there. These trajectories of emissions obviously relate to how fast we will reach to carbon budget of the atmosphere. Once we do, 100% of the emissions associated with the use of fossil fuel will have to be stopped completely. Reaching zero emissions is possible or not will depend what alternative we choose for meeting our future energy requirement. Hydrogen both as an energy source and as an energy carrier offers real hope in achieving zero emission.

There is paradigm shift in government policies to encourage green energy; development of National Hydrogen Mission is a firm step in bringing hydrogen into mainstream of energy. India is committed to the rapid expansion of the hydrogen economy, ensuring the cost-effective deployment of low carbon hydrogen technologies across the transport, industry, and power sectors by 2030.

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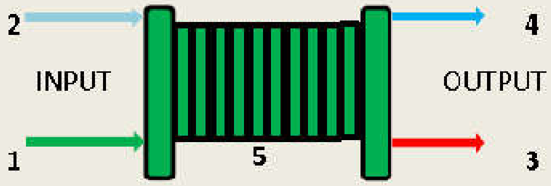
green hydrogen is seen as the next clean energy prize, which will require coordinated action from industry and government for India to capture the benefits. Early demand markets for hydrogen include fuel cells for trucking, balancing supply and demand in the power sector and replacing fossil fuels in industry. The potential scale of hydrogen use in India is huge; increasing between 3 and 10 times by 2050. Hydrogen can provide a supplementary role to renewables and batteries, in a transition to a carbon neutral economy. Hydrogen can be divided into ‘grey’ (produced from fossil fuels), ‘blue’ (produced from fossil fuels with carbon capture and storage) or ‘green’ (produced from renewable electricity). It is imperative to note that production of hydrogen by steam reforming is not the real challenge, but cost-effective production of the green hydrogen is the real challenge and in recent time PEM electrolysers using renewable energy power supply source are growing as prominent source of green hydrogen generation. Let’s explore more about PEM electrolysers and its BOP systems.

Figure1: **PEM ELECTROLYSER & BOP SYSTEM**



1 - Input DC Power from Renewable energy
2 - Input Deionised water
3- Out Put Green Hydrogen for purity processing
4- Output Oxygen
5- Stack

Processing of input deionised water, dc power and processing of output hydrogen and oxygen requires systems / equipment, consolidated processing systems are called BOP (Balance of Plant) system

Proton-exchange membrane or PEM water electrolysis

This is relatively technology that appeared in the seventies, when appropriate polymer electrolyte materials became commercially available. This solid polymer electrolyte or SPE-based PEM technology became an area of development for life-support systems. This was due to the purity of the oxygen produced, and the availability of hydrogen, suitable for a variety of applications such as life-support systems in submarines and spacecraft, or as small-scale hydrogen suppliers for gas chromatograph. Even in the early days, it was clear that PEM water electrolysis could offer higher current densities than that of alkaline electrolysis, resulting in lower capital costs and equipment size. This is due to the use of a thin proton-conducting membrane used as the 'solid' electrolyte that allows to achieve elevated current densities. On the other hand, because of the highly acidic environment found in these polymers, platinum group metal (PGM) electrocatalysts are required.

Among the advantages of PEM electrolysers, we can highlight that as the concentration of the electrolyte is fixed and the electrolyte is not mobile, there is no need for corrosive and leaking electrolytes, which allows a safer operation. Moreover, as we have said, it is possible to operate it at elevated current densities and therefore the electrolysers are more compact. It is also possible to operate it safely at elevated pressure with high differential pressures. Additionally, PEM electrolysers are well-adapted to operation with transient power load. This is why they have aroused great interest for application with renewables because they can work in feed-in regimes of up to only 5 % of their nominal capacity. Finally, in this type of systems, there is no possibility of acid carryover into the effluent gas and their use results in a minimum power requirement per unit of gas generated. On the other hand, there are also some disadvantages. One of the most important is that, compared to the alkaline process, PEM technology is more expensive. This extra cost is partly due to expensive materials of the polymer electrolyte, the catalysts, or other cell components. In addition this extra cost is also due to the fact that because the electrolyte is confined in the polymeric membrane, tolerance of cell component dimensions is more demanding and it requires sophisticated mechanical tools.

In PEM cells, there is no liquid electrolyte as such, and only deionized water circulates. The central component of the cell is a thin membrane of a proton-conduction polymer electrolyte. It is around 0.2 mm thick. The membrane is used for the double purpose:i) Carrying ionic charges, which in this case are solvated protons& ii) Separating electrolysis products, thus preventing their spontaneous exothermic recombination into water.

Figure2: **PEM ELECTROLYTIC CELL**

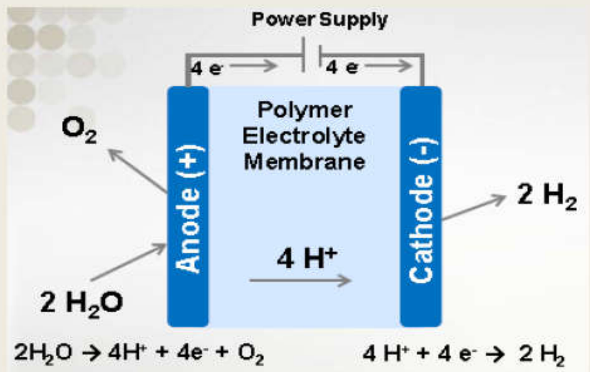
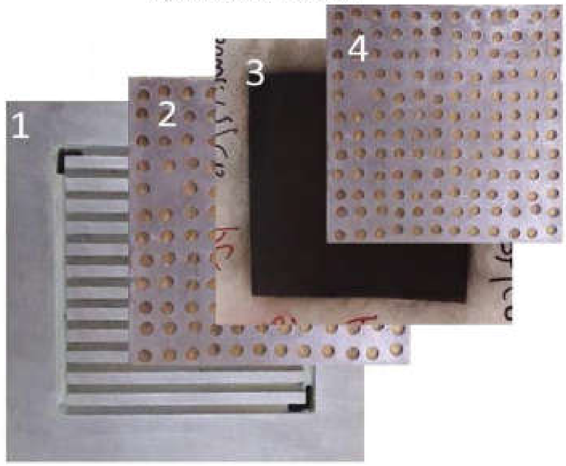


Fig 3 CELL COMPONENTS



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1) Bipolar Plate; 2) Anode current collector; 3) Membrane Electrode Assembly; 4) Cathode Current collector

The heart of the electrolysis cell is MEA (Membrane Electrode Assembly) which separates the cell in to twohalf cells (anode and cathode). The major PEM water electrolysis cell components are MEAs, current collectors (gas diffusionlayers), and separator plates. The most popular material used as solid polymer electrolyte (SPE) in these cells is a sulphonated tetrafluoroethylene-based fluoropolymer-copolymer. As we can see in the figure 3, on both side of the membrane, two porous catalytic layers are coated. Further they are connected to an external DC power source that provides electrical works for the reaction. During water electrolysis, the shown (figure 2) half-cell reactions take place. On the anodic side, DC current is used to split liquid water into gaseous oxygen and protons at the anode. The flow of water across the cell is called the electro-osmosic drag. In response to the electrical field set across the cell, solvated protons migrate down to the cathode where they are de-solvated and reduced into molecular hydrogen

Balance of Plant (BOP) - Processing of input deionised water, dc power and processing of output hydrogen and oxygen requires systems / equipment. A consolidated process of sub systems are called BOP (Balance of Plant) system. The PEM water electrolysis cell or stack requires a controlled environment for effective operation. By controlled environment, we mean adequate water purity, consistent dc power supply and adequate cooling of stack. On the output end adequate Hydrogen purity needs to be ensured. BOP of PEM electrolysers can be broadly segregated in following four subsystems:

1. Power Supply Subsystem
2. Water Purity Subsystem
3. Hydrogen Conditioning Subsystem
4. Cooling Subsystem

Figure 4 covers flow diagram of BOP subsystems. To understand it more, one by one each subsystems - description are covered.

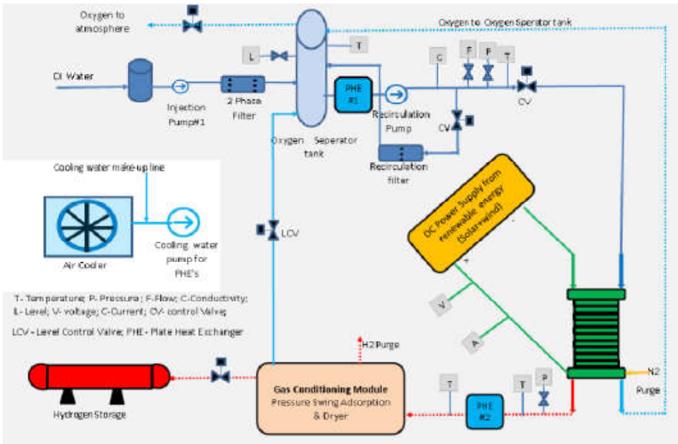

Figure4 - PEM Electrolyser Balance of Plant (BOP) - Subsystems

Power Supply Subsystem**:** In case of green hydrogen generation, the source of power supply subsystem to stack is from renewable energy, recent trend is from hybrid combination of wind and solar energy. Power supply subsystem function is to provide required direct current for initiation and sustenance of the core electrolysis process that produces hydrogen. This subsystem first uses an AC/AC transformer to adjust the voltage level of the main power source to the specific electrolysis plant requirements, and then an AC/DC rectifier to produce the appropriate direct current power source required by the electrolysis module. As PEM electrolyser works on high power and current densities, so provision of voltage and current measurements for monitoring and control purpose are considered. From safety point of view, a circuit breaker requirement is envisaged.

Water Purity Subsystem: The PEM electrolyser requires to maintain the level of water purity during operation and to recycle the flow of electroosmotic water, ensuring a longer stack life span. Water purity subsystem begins with accumulation of deionised (DI) water in the DI water storage tank, an injection pump injects DI water to the system through two phase water filter to the oxygen separator tank. The two-phase filter ensures that conductivity level of water is within stipulated limit of ASTM standard for Laboratory reagent water i.e. conductivity at the outlet of filer should be < 0.056 μScm^{-1}. The oxygen separator tank act as buffer to ensure adjustment of water flow to the circuit, as name suggests it separates oxygen from the water and also acts as sink that collects the waste-water generated during hydrogen gas conditioning. From the oxygen separator tank, recirculation pump feeds the DI water to the stack. There is provision of measurement of conductivity, flow, temperature and pressure at the outlet of recirculation pump. In case water conductivity is higher than the predefined value, the recirculation valve opens and allows water quality improvement through recirculation filter installed in the recirculation line. There is also provision of control valve at the inlet of the stack which ensures in coordination with flow measurement that always adequate amount of DI water is fed to the circuit.

Hydrogen Conditioning Subsystem: In the hydrogen conditioning subsystem basically generated hydrogen purity is ensured as per end user requirement. Hydrogen conditioning involves basically two steps liquid-gas separation and drying of separated clean hydrogen gas. It is based on pressure swing adsorption, a cyclic process that uses beds of solid adsorbent to removes impurities, moisture from the gas. The separation effect is based on the difference in binding forces to the adsorbent material. Hydrogen being highly volatile with low polarity are practically non-adsorbable as compared water vapours/ moisture. The captured moisture/ water is sent to oxygen separator tank through a level control valve.

Cooling Subsystem: The cooling subsystem consists of plate heat exchangers, which are located at the inlet of the recirculation pump in the input DI water circuit and at the outlet of the stack on the output hydrogen gas circuit. The cooling water circulation circuit is controlled by dedicated control valves which are interlinked with dedicated temperature measurement of the respectively. The cooling water of cooling subsystem once get heated by extracted heat from the primary fluid is cooled by an external air cooler, which has its own pump to guarantee water flow and pressure in the cooling line.

DISCUSSION

At present individual PEM electrolyser of MW scale are commercially available and operational, there is flexibility for various combination of module depending upon end user requirement. As the scale of hydrogen generation is supposed to increase exponentially, overall size of hydrogen plant with combination of electrolysers and associated BOP systems will increase as well. For e.g. an over all Green hydrogen generation project of 50 MW electrolysers input power can be divided into configuration of 5 units of 10 MW each. Further each unit of 10 MW can be further divided in 5 modules of 2 MW electrolysers each. In this case instead of having dedicated BOP system Module wise, a unitised BOP system can be considered. Unitised BOP system will seek proper equipment configuration selection with adequate redundancy say 2x100% injection pumps /cooling pumps/ PHE's or 3x50% injection pumps /cooling pumps/ PHE' configuration for reliable operation. Also these unitised BOP should have interconnection with inter-units for adding flexibility to overall project configuration. To coordinate these flexible unitised operations as well as individual module operation successfully, a smart controller is required.

CONCLUSION

Generation of green hydrogen is a step forward towards achievement of carbon free energy and with time scale of generation will increase exponentially, BOP system and associated equipment like pumps, plate heat exchangers, blowers, gas conditioning units, power modules are well proven and tested industrial products and it gives window of opportunity for core sector original equipment manufacturers to become part of greener energy chain. Further higher capacity BOP systems & associated equipment provides a right for systems engineer for optimization, value engineering leading to overall efficiency improvement and operational flexibility for different combination of green hydrogen generators.

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