Digital twin technology transforms hydrogen production

Loic Charbonneau explains how digital twin technology is helping to scale up industrial PEM electrolysis hydrogen production

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Hydrogen is emerging as the fuel of the future and a key enabler to achieve the objectives of the European Green Deal and Europe's clean energy transition. Hydrogen is an ideal clean energy source offering a high calorific value and energy density, and multiple transport and storage methods, but most importantly it produces virtually no greenhouse emissions when combusted with oxygen. Consequently, hydrogen's share of the energy mix in Europe is projected to rise from 2% to 14% by 2050. New infrastructure is required to meet this increased demand, including large-scale production plants.

The two most common methods for producing hydrogen are steam-methane reforming and electrolysis. Steam-methane reforming is currently the least expensive way to produce hydrogen, but at present, is mainly produced by reforming natural gas and this releases a lot of CO2. Electrolysis is a process that splits hydrogen from water using an electric current. Electrolysis produces zero emissions and when the source of energy for water splitting is renewable or low-carbon, the hydrogen produced is sometimes referred to as green hydrogen. The European Commission estimates that €13-15 billion will be invested in electrolysers to ramp up hydrogen production capacity to 40 GW by 2030.

There are two established industrialised electrolysis production technologies - alkaline water electrolysis and Proton Exchange Membrane (PEM) electrolysis. High-temperature solid oxide electrolysis (SOE), also known as steam electrolysis, presents an interesting alterative, but has yet to be demonstrated at a commercial scale. PEM electrolysis are evolving to overcome the issues inherent to alkaline electrolysers namely partial load capabilities, low current density, and low pressure operation. PEM electrolysers have emerged as a very good alternative, offering fast start-up, no corrosion and simpler maintenance.

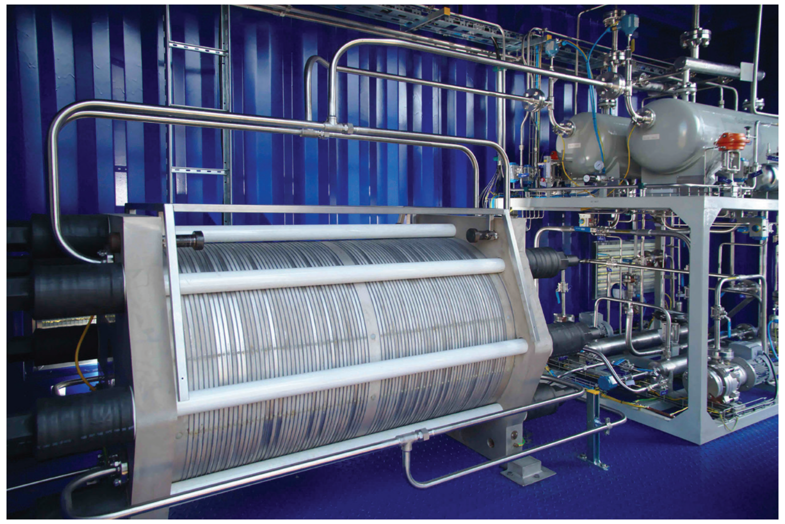
Scaling up to drive costs down

To meet the market demand, providers of electrolysis technology are looking at ways to scale up and improve their designs. For example, the Green Hydrogen Catapult initiative intends to scale up production 50-fold in the next six years with the aim to reduce costs to below $2 (€.65) per kilogram. Plant designs will need to handle higher current density and provide high efficiency over a longer lifetime. Technology providers also need to make their design ready for production-chain manufacturing, which will also lower the cost per kilogramme of hydrogen. There also needs to be a greater use of recycled materials to replace the rare and expensive materials traditionally used in PEM systems, while still guaranteeing the integrity of the system. The control and operational strategies for plants are very important. Operational setpoints need to be established and balance-of-plant (BoP) components and sub-systems must be developed, integrated and optimised.

Potential efficiency improvements of 3-5% in both water purification efficiency and hydrogen purification may be possible. Ever larger projects are underway to validate how to achieve higher efficiencies, with a 20 MW PEM electrolysis hydrogen production facility, the largest in the world, soon to become operational in Quebec, Canada. Market analysis by Imperial College shows that further process improvements are possible in numerous areas such as increased current density, improved water purification, BoP design, improved rectifiers with minimum current/voltage ripple, optimised start/stop procedures and others. Many of these large scale hydrogen plants will be built within existing industrial clusters such as refineries, ammonia plants, steel mills, harbour/ports or even offshore - safety is therefore paramount.

Digital twin technology

To this end, one solution that is proving to be a game-changer across many industries is digital twin technology. A digital twin is a software-based virtual replica of the complete physical assets of a production facility, including its process equipment, instrumentation and controls, as well as the production



HydrogenPro is a leader in large-scale green hydrogen plants

processes. Through this replica, the operation of these assets is modelled and simulated through their lifecycles.

A digital twin will usually represent a replica of the control system, operator displays, and alarms, along with process modelling and a real-time execution and integration solution for the automation systems. A digital twin is developed using process design information, including piping and instrumentation diagrams, process flow diagrams and other data governing the process. This information is then converted and developed into a software-based representation of the process using simulation software. As this software has a wide range of unit objects pre-configured, models can be developed efficiently to provide a highly accurate representation of the behaviour and dynamics of the process under consideration. The digital twin becomes an invaluable tool to analyse various `what if' design scenarios, such as different rectifiers or water purification systems, different BoP design improvement ideas and others. A digital twin can also validate the optimised control and safety schemes, including advanced control models and start/stop procedures.

Digital twin technology can also prove essential in the area of regulatory compliance and validation of proposed safety concept where the electrolysis facility will be integrated within existing industrial plants. Fundamentally, it enables cost-effective compliance and validation of the process control system, as well as operating procedures. When the plant is operational, the digital twin can provide data and insight into equipment and system health, helping plant management to optimise preventative maintenance practices and avoid costly unscheduled downtime. The accuracy of the digital twin can be constantly enhanced with data taken directly from the process as it becomes available. With many hydrogen electrolysis projects to be built in phases, this enables the digital twin to facilitate seamless integration of each phase.

Digital twins provide a platform to enable faster operator training and competency assessment. Running an exact digital replica in parallel with the live plant also creates a valuable means of training control room operators and technicians familiarising them with the control system and processes before start-up. Digital twins expose personnel to what they will experience in their actual control rooms, but in an offline and risk-free environment, thus making them better equipped to successfully control any process upsets or abnormal situations.

Conclusion

By providing a virtual environment where process control and operational solutions are designed and tested before being applied to the live plant, a digital twin reduces risk when upscaling electrolysis plant design. Digital twin technology can also help across the lifecycle of the plant, helping to bring it online quicker and safer, upskilling operators in a safe environment, and helping to maximise operational efficiencies for increased plant productivity and profitability.

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Digital twin solutions enable advanced testing of equipment and processes through dynamic simulation