Integrating Nuclear Power with High Temperature Industrial Processes



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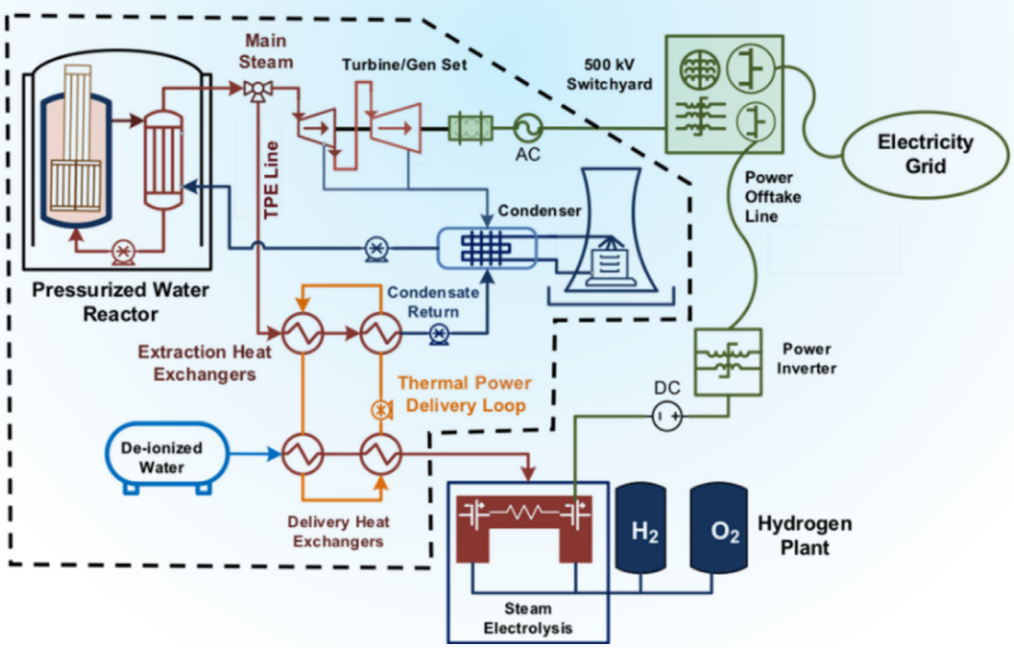
The LWRS Program is developing nuclear power plant simulators that directly couple nuclear plants to industrial processes, such as electrolysis for hydrogen generation and industries that use steam for heating and concentrating process streams. With electricity grid operations undergoing rapid and far-reaching changes, nuclear power plant owners and utility companies need to understand technical, operational, and human factors requirements for plant operations that involve switching between electricity production for the grid or directly providing thermal and electrical energy to an industrial partner. With flexible operation and generation, nuclear power plants may distribute energy to an industrial process in a dynamic manner optimizing revenue for nuclear power plant owners. Studies have shown nuclear power plants can competitively provide the energy required to produce hydrogen and other valuable chemicals and products [1]. Many nuclear power plants could be employed in this way [2].

Figure 7 illustrates how a nuclear power plant can supply thermal and electric power to an electrolysis plant that splits steam into hydrogen and oxygen. Nuclear power plant simulators that include dispatching thermal and electric power to dispatchable industrial processes provide key understanding of technical, operational, and human factors requirements that are needed to estimate the performance of the integrated system, as well as the associated installation and operating costs and potential revenues. These simulators are also valuable for addressing issues related to integrated system performance that may be used to support operating license amendments. In 2020, the LWRS Program modified a generic pressurized water

Figure 7. Thermal and electrical power dispatch to a high-temperature electrolysis plant.



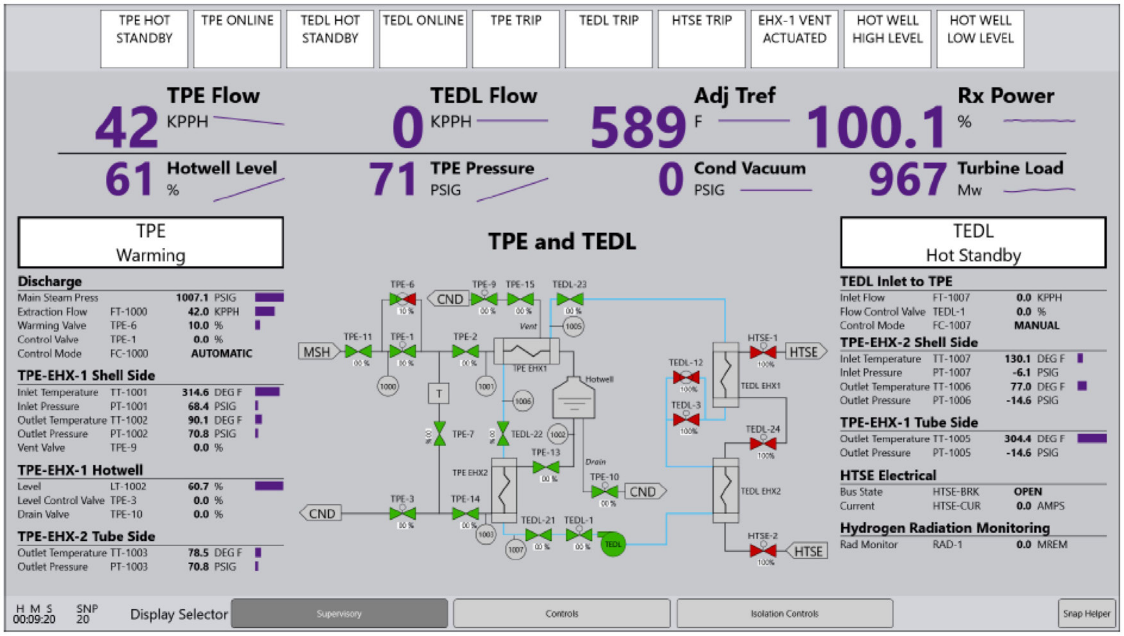


Figure 8. Supervisory screen of a prototype HSI for thermal and electrical power dispatch from a PWR.

reactor (PWR) simulator from GSE Systems® to include thermal power extraction and delivery to an industrial user [3]. The battery limits of the thermal power extraction simulator are shown by the dashed line in Figure 7. The simulation includes: (1) a thermal power extraction (TPE) line that extracts steam from the main steam line and passes the steam through "extraction heat exchangers" before returning the steam to the condenser; and (2) a thermal power delivery loop that circulates synthetic heat transfer oil between the extraction heat exchangers and a set of heat exchangers at the site of the industrial user, which may be as far as 1 km from the nuclear power plant. Rigorously simulating the modifications needed for electric power switching at the nuclear power plant switchyard and simulating the complex dynamic behavior of the industrial user will be pursued in 2021.

A prototype human system interface (HSI) was developed for the modified thermal power dispatch simulator. Simulator operating procedures were written to initiate, control, and terminate dispatching thermal and electric power to the hydrogen generation plant. Figure 8 displays the supervisory screen of the prototype HSI, which includes a combination of numerical and pictorial indicators for key systems and components, including the TPE line and the thermal energy delivery loop (TEDL), marked TPE and TEDL on the HSI control panel, respectively. Four former licensed nuclear power plant operators participated in human-in-the-loop studies of the modified thermal power dispatch simulator, the prototype HSI, and the operating procedures [4]. Each of the operators was successful in completing the tests, which included controlling, thermal and electrical power dispatch in a manner that could be realized in actual scenarios. The success of the tests confirmed the validity of the approach and identified areas for future research and improvements. For example, incorporation of electric power dispatch and the dynamic behavior of the industrial user in future simulators will enable more precise identification of technical and operating limitations and requirements, as well as human factors concerns. Coupling future simplified simulators to physical hardware during operator tests will assist in identifying hardware requirements to address associated with human factors, automated controls, and other issues.

References

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