REVOLUTIONIZING NUCLEAR SIMULATION: EXPLORING THE LATEST TRENDS AND INNOVATIONS

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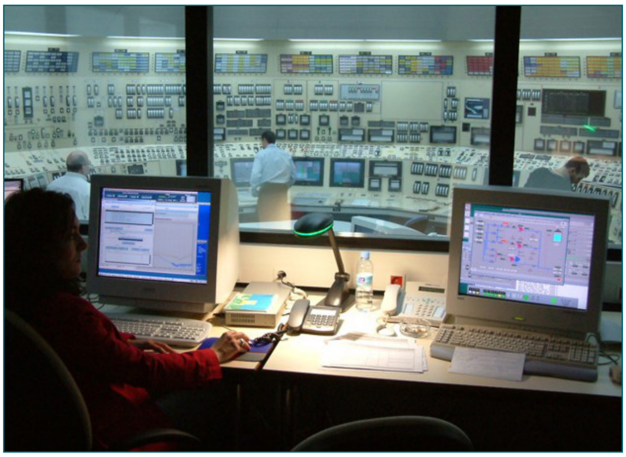
In the dynamic landscape of nuclear technology, simulation has emerged as a crucial force, reshaping the way we understand, predict, and improve nuclear processes. From virtual models of reactors that simulate intricate nuclear fission and fusion reactions, to sophisticated training platforms for nuclear operators, the world of nuclear simulators is undergoing a remarkable process of innovation. In this article we will explore the latest trends in nuclear simulation, discovering cutting-edge techniques, applications, and industries that are revolutionizing safety, efficiency, and advancements in this critical field.

A BIT OF HISTORY

Replica simulators have proven to be fundamental tools in the nuclear industry, playing a crucial role in the training, analysis, and optimization of plants. These simulation systems, of high technological complexity, accurately reproduce the behavior of a nuclear power plant in a replica environment of the control room and its instrumentation, including all the systems and components with presence in the control room, coupled and synchronized live. This allows operators to acquire theoretical and practical knowledge, as well as to train in emergency situations and abnormal events in a safe and controlled manner.

The historical evolution of replica simulators has been constant, accompanied by technological advances in the IT field, improving in terms of fidelity and capacity over time. Today, they feature sophisticated system models, immersive graphical interfaces, advanced visualization systems, and realistic control systems. These features allow operators to immerse themselves in virtual environments that realistically simulate the conditions of a nuclear power plant, providing them with a highly effective learning experience.



One of the highlights of replica simulators is their role in the analysis of transients in nuclear power plants. Simulators make it possible to simulate abnormal events and accidents, analyze their behavior, and evaluate response and mitigation measures. This capability contributes to improving the safety and responsiveness of nuclear power plants to emergency situations, thus ensuring the protection of the population and the environment. In addition, replica simulators are valuable tools in adjusting the performance of nuclear power plants and their control loops, as they allow detailed analysis of operations and optimization of operating parameters, to maximize the efficiency and energy production of the plant.

In the same vein, the use of simulators in the nuclear industry has become a fundamental tool for evaluating the safety of possible plant modifications before their implementation. Simulators are able accurately recreate the operation of plant systems, making it possible to carry out virtual tests and hypothetical scenarios without putting the integrity of the facility at risk. Engineers and technicians can adjust and evaluate modifications in the simulated environment, identifying potential risks and conflicts before making real changes to the plant. This advanced testing methodology offers an opportunity to improve security by ensuring that all modifications are rigorously evaluated and validated before being implemented. In the field of education and training, the contribution of replica simulators has proven to be invaluable. They allow operators to acquire practical skills and theoretical knowledge essential for the safe and efficient operation of nuclear power plants. In addition, replica simulators are an effective tool for assessing and improving staff competence and performance. It is important to highlight the collaboration between Tecnatom and the Spanish nuclear power plants in the application of replica simulators. This collaboration has allowed the development of global projects with high added value, ensuring that replica simulators are used optimally and that international quality standards are met.

NOW WHAT?

So far, we have talked about the traditional use of simulators, but what else is there? A pillar of innovation is to apply what is known beyond its customary uses, and simulation is no exception. We are at an inflection point, where new trends in simulators are taking this technology to an unprecedented level.

We will explore some of these emerging trends, from the use of conversational assistants to interact with the simulator to the integration of Virtual Reality to improve tasks in the field.

We will also examine how the democratization of simulators and their application in engineering are transforming the way challenges are met and growth is fostered in this industry.

ENGINEERING USES

The use of Simulation Assisted Engineering (SAE) is an invaluable resource in the field of nuclear engineering. Steps are already being taken to ensure that full-scope simulators are effectively integrated from the outset into the design process of a new installation or design modification. In the most advanced cases, the simulator's configuration control database is coupled with the plant's own BIM database. In this way, the evolution of the design feeds live to the simulator, which is updated almost automatically, and allows the design to be evaluated and fed back into it, years before the actual installation starts. The application of simulators in this area offers advantages because: it allows problems to be detected early and allows commissioning to be carried out virtually. This early detection philosophy not only optimizes the associated time and expenses, but also ensures a smoother and safer implementation of nuclear engineering projects. In short, simulators as an engineering support are opening up new perspectives in the industry, improving the efficiency and quality of design, construction and commissioning processes.

In the last 30 years, the first timid SAE have become standardized, to a point where it is now customary to use SAE in every design modification. At Tecnatom, we have a registered more than 100 SAE, covering everything from the replacement of large equipment (steam generators, for example), the installation of new distributed control systems (hardware or software in the loop), validation of human factors of new instrumentation, the analysis of unexpected events, the adjustment of control loops, etc. The use of full-scope simulators has been standardized, so a standard covering these activities is already under development (ANSI/ANS 3.5.1 – "Nuclear Power Plant Simulators for Use in Simulation-Assisted Engineering and Non-Operator Training").

Training in the nuclear industry is undergoing a radical transformation thanks to the democratization of simulators. The possibility of having operating environments adapted to each user profile (replica room or dynamic PI&D diagrams with tutored high-level controls, ...) allows other plant personnel to also benefit from their use. Engineers, technicians, and support staff can access it to improve their understanding of processes, gain skills, and support related to their roles (e.g., to optimize procedures to reduce zero-out lead times). This democratization expands knowledge and competence throughout the plant, strengthening the team as a whole and fostering a culture of safety and collaboration.

USES FOR TRAINING

In addition to the above, this democratization of simulators would be enhanced by the implementation of an integrative platform that allows instructors to have a complete view of what each student is doing in their individual load. This integrative platform can also employ artificial intelligence as a conversational assistant to assist the instructor. By analysing the situation and performance of students, artificial intelligence will offer suggestions and recommendations to improve the teaching and learning process. This same conversational assistant will help the instructor in the classic simulator environment to make it easier to generate the scenario required at any given time, as well as suggest actions based on previous training scenarios.

Simulation in a distributed environment is another key feature that would complement the democratization of simulators. This modality allows both students and instructors to interact virtually (in some of Tecnatom's experiences, training sessions have been held with an instructor located in Spain and students located in two different Latin American countries). The ability to train and learn in remote environments provides greater flexibility in training, allowing employees to adapt to their needs. In this context, virtual instructors will play a crucial role, guiding learners in real-time based on their performance. This immediate, personalized feedback will significantly enhance the learning experience, allowing participants to correct mistakes, refine techniques, and reach an optimal level of proficiency more efficiently.

Another element related to the democratization of training is what we call "training pills", understood as microsimulators on the web, with 24/7 access for basic training and with student support systems (electric cabin logics, PI control systems, basic thermohydraulics, fundamentals of neutronics, ...). The training pills have made it possible, for example, to reduce travel costs by 1/3 and unavailability for training electrical maintenance technicians at airports.

The combination of the democratization of simulators and simulation in a distributed environment with virtual instructors represents a paradigm shift in the training of the nuclear industry. This combination of advanced technologies not only increases the efficiency and effectiveness of the learning process, but also lays a solid foundation for the continuous development of plant personnel. In a field where safety and accuracy are essential, these training innovations promise to strengthen equipment readiness and raise standards of excellence.

OPERATOR ASSISTANCE

Also noteworthy is the implementation of advanced simulators that offer different aids to the operator. For example, generating a digital twin allows a series of significant advantages to emerge that transform the way this critical infrastructure is operated and maintained. A digital twin is a virtual, up-to-date replica of the plant in near real-time, so workers can gain hands-on experience in a secure environment. In some of the applications developed at Tecnatom, the digital twin is automatically updated (at the request of the engineer) to the latest data from the plant, performs a set of virtual tests to monitor performance under normal and accidental conditions, and warns of deviations in the results that warn of incipient failures and degradations. Decision-making is also optimized, as operators can simulate different scenarios and evaluate the impact of their actions before implementing them in the real system. Ultimately, the digital twin stands as an indispensable tool for improving operational efficiency, increasing safety, and ensuring more reliable and sustainable nuclear energy production.

All of this requires gateways that link the simulator configuration databases with the plant databases, allowing alignment with the real state of the plant. As a result, operators can rehearse complex manoeuvres, test different scenarios and carry out pre-jobs safely and effectively. This real-time data integration gives operators the opportunity to improve their skills, refine their decision-making, and optimize overall plant performance. In an environment where safety and efficiency are crucial, these simulation tools are proving to be a fundamental pillar for the future of the nuclear industry.

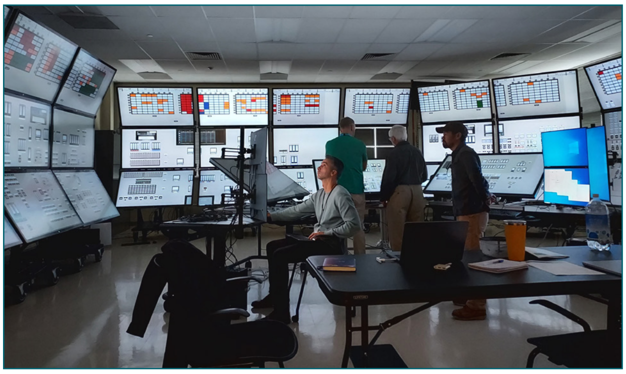
As mentioned above, the incursion of conversational assistants into the field of nuclear simulators represents a revolutionary advance in instructor-simulator interaction. However, there is another aspect of this and that is the use of conversational assistants by the operator himself, allowing them to interact naturally and fluidly with the system, for example, to follow complex procedures or analyze transients in the plant parameters. Thanks to the integration of natural language processing technology, these assistants can interpret verbal commands and answer operator questions accurately and in a timely manner. In addition, these attendees also find applications in the development of new simulators, where they optimize processes, such as the execution of acceptance tests. This combination of capabilities provides a powerful tool to improve the efficiency and usability of simulators, paving the way to a more sophisticated and safer future in the nuclear industry.

Another promising trend in the nuclear industry is the adoption of Virtual Reality (VR) to improve the execution of tasks in the field through prior immersive practice. VR offers nuclear plant workers the opportunity to simulate complex operations and procedures in a virtual environment, before facing real-world situations. As an example, we can mention the model of a refueling machine in PHWR technology combined with a VR for visualization of the cavity itself and a refueling machine. By allowing workers to practice and hone their skills in a secure virtual environment, VR significantly reduces the risk of errors and accidents during real-world execution. The benefits of this technology extend to areas such as maintenance, repair, and inspection of critical equipment, as well as training new operators. VR is emerging as an essential tool to increase the confidence, dexterity and readiness of personnel, raising the standards of safety and efficiency in the nuclear industry.

AVOIDING OBSOLESCENCE

Due to the long lifespan of nuclear power plants, their control rooms and simulators face the challenge of withstanding long years of heavy use, which can lead to parts' supply problems and long-term obsolescence. Rapid technological advancement can make certain components hard to come by or even obsolete, threatening the operability and optimal performance of these critical systems. This situation can increase maintenance and replacement costs, and ultimately affect the safety and efficiency of nuclear power plants.

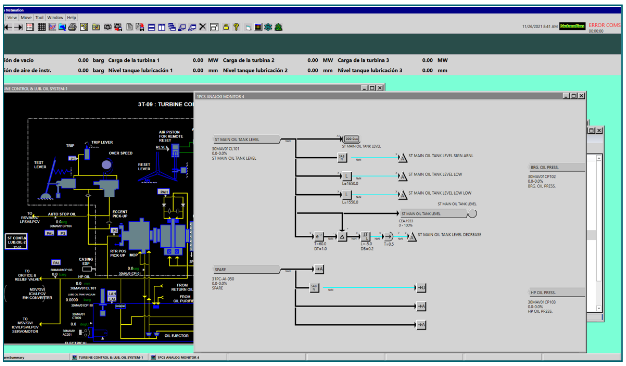
A promising solution to overcome these challenges is the implementation of virtual control rooms ("Glasstop simulator" concept). Because they are virtual instrumentation and dashboards, upgrades can be implemented quickly, without the need to replace physical components or make costly changes to existing infrastructure. Moreover, it enables the



possibility of carrying out "what if" analyses like the one INL is recently carrying out to couple a hydrogen production plant (high-temperature technology) to a nuclear power plant through a "behind the meter" electricity supply and a new steam supply system. This allows nuclear power plants to stay at the forefront of the latest innovations, optimising their performance and ensuring operational safety over time. The flexibility and agility provided by virtual control rooms become an effective strategy for extending the life and optimal operation of nuclear power plants, while ensuring efficient and safe operation in the context of the ever-changing technological landscape.

SIMULATOR DEVELOPMENT AND O&M OPTIMIZATION

Linked to the previous idea, in the development of new simulators and in the optimization of operation and maintenance, cost savings are one of the pillars. For example, the use of intelligent model development and intelligent management of initial conditions in simulators to save costs and improve efficiency. By leveraging advanced data analysis and machine learning techniques, operators can improve the fidelity and accuracy of simulation models, while reducing computational resources. Intelligent model developments enable a more accurate representation of complex nuclear process-



es, resulting in better predictive capability and more realistic training scenarios. Not only does this improve the training experience for operators, but it also allows for the identification of optimization opportunities in the plant operation.

In addition to intelligent model development, intelligent initial condition management (IC) represents a significant advantage in training, as this task often requires a considerable number of resources. However, it is critical to create realistic and effective scenarios in simulators. The key is to ensure that these initial conditions are generated autonomously through intelligent developments based on previous data. By using machine learning techniques and advanced data analysis, it is possible to derive accurate and relevant initial conditions from plant maintenance and historical databases.

CONCLUSIONS

In conclusion, simulation emerges as a crucial force in the nuclear industry, reshaping the way we understand, train, and optimize nuclear processes. Replica simulators play an essential role, providing operators with practical knowledge and safe training in virtual environments. Its historical evolution, driven by technological advances, has led modern simulators towards advanced analysis capabilities, improving the safety and efficiency of nuclear power plants.

The development of digital twins will be a significant advantage, allowing the accurate and continuous simulation of plant behavior, facilitating the early detection of errors, and optimizing decision-making. The integration of artificial intelligence and conversational assistants will further enhance these advancements, improving operational efficiency and instructor-simulator interaction.

The adoption of Virtual Reality (VR) to improve the execution of tasks in the field is another promising trend, reducing the risk of errors and accidents.

Facing the challenge of obsolescence, virtual control rooms and simulators offer an effective solution, quickly adapting to technological advances without costly replacements of physical components.

To sum up, with advanced simulators and emerging technologies, the nuclear industry is positioned for safe, efficient, and sustainable growth. Innovation in this area is essential to ensure a promising future in nuclear power generation.