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Use of Robotic and Automation Systems in Small Modular and Micro Reactor Development

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Abstract: ***This paper shares knowledge of robotic systems used in the nuclear industry and proposes using robotic and automation systems in advanced small modular reactor development. It has been seen in the era of advanced technology that the use of automation and robotic systems is becoming too frequent and increasing daily. There are plenty of areas that are still in the development stage. The nuclear industry is one of the developing fields for building advanced reactors through autonomous robotic systems. It has been observed that the nuclear industry still needs to utilize autonomous solutions in developments like manufacturing, inspection, operation, and maintenance. Developing automated robotic systems can help manufacture, inspect, operate, and maintain next-generation nuclear reactors, specifically small modular and micro nuclear reactors. Robotic systems can achieve benefits like inherent safety, reliability, efficiency, and accuracy in small modular reactors (SMR) or Micro Reactor (MR) development. This research can be extended to use robotics and automation systems from nuclear fuel fabrication facilities to nuclear waste disposal applications. This research can be used to design and implement intelligent autonomous nuclear reactor robotic and automation systems.***

Keywords: Robotic, Automation, Advanced Nuclear reactors, Small Modular Reactor (SMR), and Micro Reactor (MR)

1. Introduction

Nuclear power plants are of various types and generations. Recent developments have been made in the generation 3 type of nuclear reactors. With increasing demand to reduce carbon footprint, multiple organizations are approaching generation 4-based Small Modular and Micro Reactor development. Conventional Nuclear power plant manufacturing processes were labor-intensive and time-consuming tasks. The Process of fabrication, tooling, inspection, and assembly of complicated control systems, reactor vessels, steam generators, and Energy generators [1]. The application of robotics and automation aims to perform duplicate tasks with safety, precision, efficiency, and consistency.

Integrating this technology into manufacturing nuclear power plants will substantially improve the atomic industry. With the increasing high base power demand for safe, clean, consistent, and cost-compelling energy solutions, only small modular and microreactor manufacturing can use robotics and automation to facilitate and enhance high production, quality, and safety standards. The introduction of robotics and automation technology in the multinational power terrain and their possibility can revolutionize the nuclear power plant manufacturing process [2].

A. Robotics

Nuclear Power plant manufacturing has various stages in its production lines. With robotics, all production stages can be automated. Robots made for industries are equipped with sensors, tools, and actuators to perform critical tasks such as drilling, cutting, welding, and handling with high repeatability and precision. Advanced collaborative robots can work with workers in nuclear power plant manufacturing environments to enhance production ability [3]. Figure 1 shows the potential use of robotic systems for multiple applications

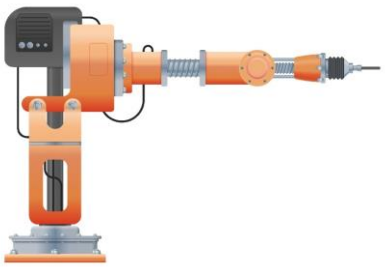

Figure 1: Robotic System for Multiple Applications.

B. Automation

Robotics integrated with Automation facilitate challenging production streams to reduce worker intervention. Autonomous systems consist of sensors, control systems, and robotics used to review, assess, and maintain regulatory standards. Computer-aided designs, software simulations, and analysis integration in the system can reduce production time and associated costs.

Using robotics and automation for nuclear power plant manufacturing has many benefits, including improved safety, precision, productivity, and cost reduction. Instead of several challenges, robotics and automation for Small Modular and Micro Reactor manufacturing seem promising. New

advancements in robotics with artificial intelligence or machine learning can further enhance manufacturing capacities. Adopting robotics and automation systems in the nuclear industry can satisfy the requirements of clean and sustainable energy [4].

C. Small Modular and Micro Reactor

Three types of Nuclear Power plants are available that can be divided into three categories which are shown in Figure 2 that are 1) Large-scale Scale, 2) Small modular, and 3) Micro reactors. Among all these three Micro Reactors are the only small-size reactor technology that can be manufactured in the factory [5].

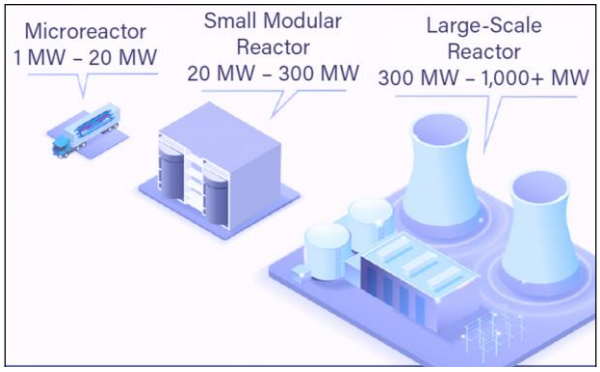

Figure 2: Nuclear Power Plant Categories

The Nuclear Industry widely uses Robotic systems for their product development, in the proposed research its application in Small Modular and Micro Reactor manufacturing is given for the understanding of the requirements for the development. The research also suggests its capability for manufacturing Micro Reactors with Autonomous robotic systems [6].

Further, this Robotic systems-based development will require further research to maintain the international safety standards for Nuclear power plant manufacturing.

2. Challenges

Many unusual challenges are faced in Small Modular and Micro Reactor manufacturing, including complicated designs, rigid safety requirements, and cost restrictions. Integrating robotics and automation in reactor manufacturing has several benefits but challenges in enhancing productivity [5].

A. Safety: Safety is a preliminary aspect of nuclear power plant manufacturing. The development of robotics and automation highlights the potential errors, malfunctions, and failures that can compromise safety. All systems must be tested and verified rigorously to take necessary steps in an emergency [6].

B. Radiation Resistance: All robotics and automation systems in harsh radiation environments can lead to potential damage to electronic components or material degradation. The developed systems should be radiation-resistant and can withstand harsh radiation environments without compromising their performance.

C. Task Complexity: Nuclear power plant manufacturing has a variety of complex tasks that require safe, reliable, precise, and efficient operation. Developing robotic and automation systems should be able to perform inspection and maintenance tasks precisely and autonomously in a challenging radiation environment [2][3].

D. Remote Operation: A nuclear power plant has many areas in the reactor core, and containment buildings during the operation have high radiation exposure, so radiation workers need to operate from a distance. Robotics and automation can perform remote operations in these environments reliably and efficiently.

E. Robot-Worker Collaboration: Workers play a crucial role in seeing and operating things. Besides designing and implementing robotics and automation systems, many tasks require human intervention for critical operations for safe, reliable, and efficient power plant operations.

Regulatory Compliance: To demonstrate the performance of robotics and automation in small modular and microreactor development, regulations must comply with approval from local and international regulatory agencies. Safety, Safeguards, and Security requirements are essential to using these systems for the work. If needed, suggestions from local and international agencies for any change should be incorporated into the development to implement the systems effectively.

F. Cybersecurity: Autonomous nuclear reactor operation is sensible for cyber threats and attacks. Developing Autonomous systems will demand safeguards and security to prevent unauthorized system access or process manipulation in nuclear power plant operations. To shield systems from potential sabotage in vulnerable scenarios, additional safeguards must be incorporated with robotics and automation systems against cyber-attacks.

G. Cost: Integrating robotics and automation systems requires Initial investment in research, design, development, and implementation. Only the Long-term use of robotic and automation systems can accommodate the cost of such systems in nuclear power plant manufacturing. These systems' manufacturing and production line costs can be quickly capitalized for Small Modular and Micro Reactor development.

H. Training and Education: Nuclear power plant development requires nuclear professionals and workers who require technological training to operate robotics and automation systems. Comprehensive programs allow professionals and workers to upgrade their proficiency with these systems for crucial operations [1].

3. Improvements

A. Design and Simulation

A Unique Computer-Aided Design of the autonomous robotics system with advanced features integration that can be used today or in the future for various nuclear reactor tasks,

specifically Small Modular or Micro Reactor development. Recent artificial intelligence and Machine learning models are to be used for their potential improvements in harsh radiation scenarios. Advanced software simulations and tools allow extensive testing of the systems under different scenarios to know their behavior for enhancing operations [7][8].

B. Manufacturing and Construction

Nuclear Power Plant manufacturing is a labor-intensive task that Robots can replace to improve work abilities in the reactor production lines. Robotics and Automation systems can precisely fabricate and assemble various reactor components to ensure uniqueness for Small Modular or Micro Reactor development. These system integrations for manufacturing can reduce human error, time, and associated costs to ramp up the manufacturing process [7].

C. Installation and Commissioning

Installation and commission of the nuclear power plant can be performed using robotics and automation systems in the dynamic environment to increase its inherent safety. Specialised Installation tasks are accommodated in the design to reactor commissioning in short intervals. Autonomous systems are tested to maintain the integrity of the nuclear power plants, and component redundancy in dynamic reactor environments is verified before functioning. In the case of Micro Reactor, the system is prefabricated and validated and is only pending for burnup and grid connection [9].

D. Operation

Robotics and automation systems are continuously observed and adjusted per the functional parameters to maintain performance in dynamic nuclear environments. Large-scale atomic power plants have operated for decades and require routine maintenance. In contrast, small modular or microreactor technology requires in-line maintenance procedures for predictive maintenance. Implementing artificial intelligence and machine learning models for predictive maintenance in these systems can anticipate possible failures before they appear to reduce downtime and boost the lifespan of nuclear reactors.

E. Decommissioning

autonomous robotic systems are equipped with special-purpose tools used in decommissioning tasks to address high-radiation core components and disassemble tasks in low spaces. As per the regulatory agencies, systems will automate the various intensive radiation tasks of nuclear waste handling, processing, and transportation to ensure adequate safety [10].

F. Safety Enhancements

Emergency Robotic Response systems can be developed for incidents or accidents. In such emergency system failure scenarios, automatic reactor shutdown can be performed to contain the component damages in critical contaminated areas for inspection and maintenance. Ongoing research in learning and developing systems equipped with artificial intelligence leads to manufacturers evolving autonomous systems for effective utilization [11].

There are many system benefits in integrating robotics and automation into small modular or microreactor development. Still, a few things could be improved, like high capital costs and technical expertise for the operations. To address capital cost utilization, the operational timespan should be increased to achieve long-term savings. For technical expert requirements, awareness and knowledge transfer, education, and such interactive learning events and sessions must be enrolled in current education systems for robotics, automation, and nuclear engineering expertise [12].

4. Future Development

Several challenges will always be present in robotics and Small Modular or Micro Reactor development automation systems. Continuing advancement seems optimistic in developing advanced robotics and systems with artificial intelligence in nuclear power plant manufacturing, maintenance, and nuclear waste disposal. Ongoing research in these fields drives the exploration of widespread robotics and automation applications in the nuclear industry [13].

It aims to provide a safe, efficient, optimized system to reduce costs. The development explores these research areas and addresses opportunities to develop innovative autonomous or human-collaborative robotic systems The research can be also extended to the use of Artificial intelligence and Machine learning in the robotic systems for Nuclear power plant manufacturing, reactor core components manufacturing, operations, maintenance, and waste disposal [13].

5. Conclusion

Integrating robotics and automation systems in Small Modular and Micro Reactor development promises operational safety and efficiency with lower life-cycle costs. A small investment in the technology reduces radiological exposure in hazardous nuclear environments. Ongoing research on robotics and automation can accelerate the evolution toward a sustainable energy future to meet sustainable and clean global energy demand. The critical aspect of developing robotic and automation systems for the Small Modular and Micro Reactor was to illustrate insights into the potential use of these systems for safety, efficiency, and cost benefits. The transformative expansion of robotics and automation systems for Small Modular and Micro Reactor development will meet nuclear technological collaboration with regulatory agencies, providers, and manufacturers for clean and sustainable energy.

References

[1] Pioro, I., R. B. Duffey, P. L. Kirillov, and N. Dort-Goltz. "Current status of reactors deployment and small modular reactors development in the world." Journal of Nuclear Engineering and Radiation Science 6, no. 4 (2020): 044001.
[2] Seward, Derek W., and Mohamed J. Bakari. "The use of robotics and automation in nuclear decommissioning." In

22nd International Symposium on Automation and Robotics in Construction ISARC, pp. 11-14. 2005.

[3] Sayed, Mohammed E., Jamie O. Roberts, Karen Donaldson, Stephen T. Mahon, Faiz Iqbal, Boyang Li, Santiago Franco Aixela et al. "Modular robots for enabling operations in unstructured extreme environments." Advanced Intelligent Systems 4, no. 5 (2022): 2000227.

[4] Iborra, Andres, Juan A. Pastor, Barbara Alvarez, Carlos Fernandez, and Jose M. Fernandez Merono. "Robots in radioactive environments." IEEE Robotics & Automation Magazine 10, no. 4 (2003): 12-22.

[5] Vaya Soler, Antonio, Michel Berthelemy, Aditi Verma, Sama Bilbao y Leon, Gloria Kwong, Vladislav Sozoniuk, Andrew White, Veronique Rouyer, Kimberly Sexton Nick, and Ximena Vasquez-Maignan. "Small modular reactors: Challenges and opportunities." (2021).

[6] Hidayatullah, H., S. Susyadi, and M. Hadid Subki. "Design and technology development for small modular reactors–Safety expectations, prospects and impediments of their deployment." Progress in Nuclear Energy 79 (2015): 127-135.

[7] Black, Geoffrey, David Shropshire, and Kathleen Araújo. "Small modular reactor (SMR) adoption: Opportunities and challenges for emerging markets." Handbook of Small Modular Nuclear Reactors (2021): 557-593.

[8] Lu, Chao, Jiafei Lyu, Liming Zhang, Aicheng Gong, Yipeng Fan, Jiangpeng Yan, and Xiu Li. "Nuclear power plants with artificial intelligence in industry 4.0 era: Top-level design and current applications—A systemic review." IEEE Access 8 (2020): 194315-194332.

[9] Murakami, Tomoko, and Venkatachalam Anbumozhi. "Global Situation of Small Modular Reactor Development and Deployment." (2021).

[10] Aitken, Jonathan M., Sandor M. Veres, Affan Shaukat, Yang Gao, Elisa Cucco, Louise A. Dennis, Michael Fisher, Jeffrey A. Kuo, Thomas Robinson, and Paul E. Mort. "Autonomous nuclear waste management." IEEE Intelligent Systems 33, no. 6 (2018): 47-55.

[11] Playbell, Ioanna. "Economy, safety and applicability of small modular reactors." Proceedings of the Institution of Civil Engineers-Energy 170, no. 2 (2017): 67-79.

[12] Iqbal, Jamshed, Ahmad Mahmood Tahir, and Raza ul Islam. "Robotics for nuclear power plants—challenges and future perspectives." In 2012 2nd international conference on applied robotics for the power industry (CARPI), pp. 151-156. IEEE, 2012.

[13] Wood, Richard T., Belle R. Upadhyaya, and Dan C. Floyd. "An autonomous control framework for advanced reactors." Nuclear Engineering and Technology 49, no. 5 (2017): 896-904.