Artificial Intelligence Based Post-Hazard Condition Assessment of Nuclear Piping-Equipment Systems

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Abstract

Nuclear safety systems, such as equipment-piping systems, undergo aging and subsequent degradation due to flow-accelerated erosion and corrosion. It is not practical to implement the standard non-destructive techniques during plant outages to scan the vast equipment systems in their entirety. Any undetected degraded locations can cause failure, leakage and accidents at the power plant. Therefore, substantial resources are allocated for their maintenance and safety. In the case of an external event such as a major earthquake, nuclear plants are typically shut down and a very detailed assessment of the plant's safety systems is performed before it can be cleared for restart. In most cases, such an assessment spans several months. An artificial intelligence (AI) based post hazard assessment of such systems would result in lowering the maintenance costs along with extending the operating lifetime for a nuclear power plant. It may also help to reduce nuclear power plant outage time periods.

Existing health monitoring approaches propose the use of AI to detect major damage in structures such as buildings, bridges, etc. These approaches are not applicable to vast distributed equipment-piping systems because of the additional complexity offered by various modes contributing to the behavior of the system at different locations. Furthermore, major damage in a nuclear system is representative of fractures and leaks which would lead to an emergency situation. Therefore, the proposed post hazard condition assessment framework should be able to detect minor damage, such as the degradation caused due to aging effects in nuclear facilities.

In this research, a novel approach to conduct data-driven post hazard condition assessment in nuclear equipment and systems with the aid of AI is presented. A simple equipment-piping system subjected to an external hazard, such as an earthquake, is selected as an application case study. A proof-of-concept is presented wherein the proposed framework utilizes data collected from sensors to generate a machine learning data repository. The role of power spectral density as a robust degradation-diagnostic tool is explored with the implementation of proposed feature extraction approaches. Instead of damage indices, a vector of damage-sensitive quantities is extracted for training the ANN model. Uncertainty in the degradation severity is also incorporated in the design of the post hazard assessment framework. The effectiveness of the proposed framework is demonstrated on a realistic primary safety system of a two-loop reactor plant. The proposed framework is able to detect degraded locations as well as the degradation severity with high degree of accuracy.