From Steam to Power: Using the GPWR Simulator to Strengthen Safety Culture in Turbine-Generator Operations

Ryuichi T. Kishimoto, Albert C. Dairo, Jaclyn F. Natividad, Mark Gino E. Aliperio, Ryan U. Olivares
Philippine Nuclear Research Institute
Commonwealth Avenue, Diliman, Quezon City, Philippines
rtkishimoto@pnri.dost.gov.ph, acdairo@pnri.dost.gov.ph, jfnatividad@pnri.dost.gov.ph, mgealiperio@pnri.dost.gov.ph, ruolivares@pnri.dost.gov.ph

ABSTRACT

Turbine-generator systems are a critical component of nuclear power plants, serving as the primary interface between thermal energy produced in the reactor and electrical power generation, while also supporting overall plant reliability and safety. These systems transfer thermal energy from the secondary side to mechanical shaft power, which is subsequently converted into electrical output. Effective turbine-generator operation requires operator situational awareness, accurate performance monitoring, and timely response to abnormalities to maintain stable plant conditions and prevent the escalation of transients that could challenge reactor safety. This paper examines how the Generic Pressurized Water Reactor (GPWR) simulator supports the strengthening of safety culture and knowledge management in turbine-generator operations through the simulation of realistic failure scenarios and the use of data-driven insights.

The GPWR simulator provides a controlled setting and safe environment where operators can practice handling turbine-generator failures such as loss of steam supply, pressure imbalances, and turbine trips. These scenarios provide high-pressure situations, giving the operators a safe way to practice handling the system faults without having the risks of real plant operations. The simulator allows operators to recognize alarm patterns, identify affected systems, and determine which components must be activated or controlled in accordance with established procedures, thereby strengthening system understanding and decision-making under abnormal conditions.

By collecting detailed data on operator actions and system responses, the simulator establishes a structured basis for knowledge development and performance assessment. These data support post-scenario analysis through event sequence review, parameter trend evaluation, and verification of procedural compliance, enabling plant personnel to examine operational responses, share insights, and strengthen safety protocols. Through systematic analysis of simulator outputs, operating procedures are refined, system reliability is enhanced, and continuous learning is integrated into routine practice. Operator performance is assessed based on adherence to established procedures, appropriateness of control actions, and effectiveness in maintaining stable plant conditions during abnormal and emergency scenarios.

The GPWR simulator incorporates detailed modelling of key secondary-side and balance-of-plant systems, including steam generator behaviour, turbine and condenser systems, feedwater control, steam admission and extraction processes, and turbine protection and trip logic. Integrating simulation results from these systems into training programs and operational reviews enhances knowledge transfer across the organization and reinforces consistent operational practices. Overall, the study demonstrates how simulator-based training supports the systematic integration of operational experience into turbine-generator operations, contributing to sustained improvements in safety culture, knowledge management, and long-term plant safety and reliability.

Keywords: *pressurized water reactor, simulator, turbine-generator, safety*

1 INTRODUCTION

Nuclear power plant safety depends not only on the reliability of engineered systems but also on the attitudes, competence, and behaviour of the people and organizations responsible for plant operation. The concept of safety culture has long been recognized as a fundamental principle in nuclear safety, emphasizing that safety must receive the attention warranted by its significance at both the organizational and individual levels [1]. More recent literature continues to show that human factors, communication, leadership, and organizational performance remain closely linked to the safe and dependable operation of nuclear facilities [5].

Within this context, simulator-based training has become an essential component of personnel development in nuclear power plants. The IAEA has documented that control room personnel in virtually all countries operating nuclear power plants receive simulator training for both initial and continuing training, with plant-specific full-scope simulators widely used to support realistic operational preparation [2]. In parallel, current IAEA safety guidance stresses that the recruitment, qualification, and training of plant personnel are central to maintaining a high level of competence and to fostering a strong safety culture in nuclear power plants [3]. These principles are particularly important during abnormal and infrequently encountered conditions, when operator judgment, procedural adherence, and accurate diagnosis are most critical.

For turbine-generator operations, the value of simulator training is especially significant because disturbances in secondary-side systems can challenge plant stability, affect operational continuity, and place additional demands on operator performance. Effective response requires not only technical knowledge of steam, feedwater, turbine, condenser, and protection systems, but also the ability to detect deviations promptly, interpret alarms correctly, communicate clearly, and execute control actions in accordance with approved procedures. IAEA guidance on conduct of operations highlights the importance of clear communication, proper recording of plant status and actions, and disciplined operational behaviour, particularly during abnormal situations [4].

Beyond immediate training benefits, simulator exercises also support knowledge management. The IAEA defines knowledge management in the nuclear field as an integrated and systematic approach to identifying, managing, and sharing organizational knowledge in order to achieve institutional objectives [4]. In a simulator environment, this can be realized through structured review of event sequences, analysis of plant parameter trends, examination of operator decisions, and discussion of lessons learned after each scenario. Such practices help convert individual experience into organizational knowledge, strengthen operational consistency, and reduce the risk of knowledge loss over time [4].

This paper therefore examines how the Generic Pressurized Water Reactor (GPWR) simulator can be used to strengthen safety culture and support knowledge management in turbine-generator operations. Specifically, it discusses how realistic failure scenarios in the GPWR simulator can be used to reinforce procedural compliance, improve operator understanding of system interactions, and provide a structured basis for post-scenario learning and continuous improvement. By linking simulator-based training with operational reflection and knowledge sharing, the study highlights the contribution of simulation to sustained improvements in plant safety and long-term reliability.

2 METHODOLOGY

2.1 Simulator-Based Scenario

This study used the GPWR simulator as the main platform for examining how simulator-based malfunction analysis can support safety culture and knowledge management in turbine-generator operations. The simulator was selected because it provides a controlled environment where abnormal plant conditions can be introduced and observed without the risks associated with actual plant operation. In this study, the simulator was not used only to illustrate technical plant response, but also to provide a structured setting for reviewing operational behaviour, protection logic, and event progression in a way that supports learning and reflection [2].

A representative malfunction scenario involving an inadvertent turbine trip initiated with a delay time of 10 seconds was used as the basis of the analysis. The scenario was observed through the plant overview display, turbine protection system, and engineered safety features (ESF) indications. Particular attention was given to the turbine trip setpoint, actuation signal, and the corresponding plant response after the delayed trip event. These displays were used because they provide essential information for understanding how the event developed and how important plant systems responded during the disturbance.

2.2 Safety Culture Perspective

The scenario was analysed from a safety culture perspective by observing the sequence of plant behaviour from the initial normal operating condition, through malfunction initiation, up to the stabilized plant condition. This approach made it possible to identify key alarms, protection responses, and changes in plant status following the inadvertent turbine trip. Within the context of this study, safety culture was reflected in the importance of maintaining awareness of plant conditions, understanding the significance of turbine protection signals, and recognizing abnormal events in a manner consistent with safe plant operation.

Rather than measuring safety culture through behavioural scoring or survey-based methods, the study highlighted it through the value of the scenario as a training and review exercise. The malfunction scenario provided an opportunity to reinforce procedural awareness and to emphasize the importance of disciplined observation of abnormal plant conditions. In this way, the simulator exercise supported safety-oriented thinking by showing how system disturbances and protection signals can be examined in a structured and meaningful way.

2.3 Knowledge Management Perspective

The same scenario was also examined from a knowledge management perspective by using simulator outputs as reviewable sources of operational knowledge. Event progression, trip and actuation signals, system status changes, and plant response indications were treated as information that could be analysed, discussed, documented, and reused for future learning. This made it possible to go beyond simple scenario execution and consider how simulator-based observations can contribute to organizational understanding of turbine-generator disturbances.

In this study, knowledge management was reflected in the use of simulator outputs to support event reconstruction, technical discussion, and the sharing of lessons derived from the scenario. The value of the simulator therefore lies not only in reproducing a malfunction condition, but also in making plant response visible in a form that can be reviewed for continuous improvement. Through this process, the simulator supports the conversion of scenario observations into useful operational knowledge that may strengthen future training and operational review activities [3].

2.4 Methodological Contribution

Through this methodology, the study demonstrates a practical way of linking a turbine-generator malfunction scenario to the broader themes of safety culture and knowledge management. The inadvertent turbine trip scenario served as a focused example through which plant response, protection system behaviour, and simulator-generated information could be examined in a meaningful and organized way. This made it possible to show that the GPWR simulator can serve not only as a technical training platform, but also as a tool for reinforcing safety-oriented practice and supporting knowledge capture in nuclear operations [2], [3].

3 RESULTS AND DISCUSSION

3.1 Plant Response During the Inadvertent Turbine Trip

The simulator run began under normal operating conditions, as shown in Figure 1, and then proceeded to the inadvertent turbine trip scenario, as shown in Figure 2. At a simulation time of 5 minutes, the plant was in a shutdown state, with both the reactor and turbine indicated as TRIPPED. At the same time, electrical power and generator power were both 0.0 MW, indicating loss of power generation following the turbine trip. The display also showed SG-1 Total flow = 0.0 kg/s and SG-2 Total flow = 0.0 kg/s, confirming that the event had already progressed beyond a simple turbine disturbance and had affected overall plant operating status.

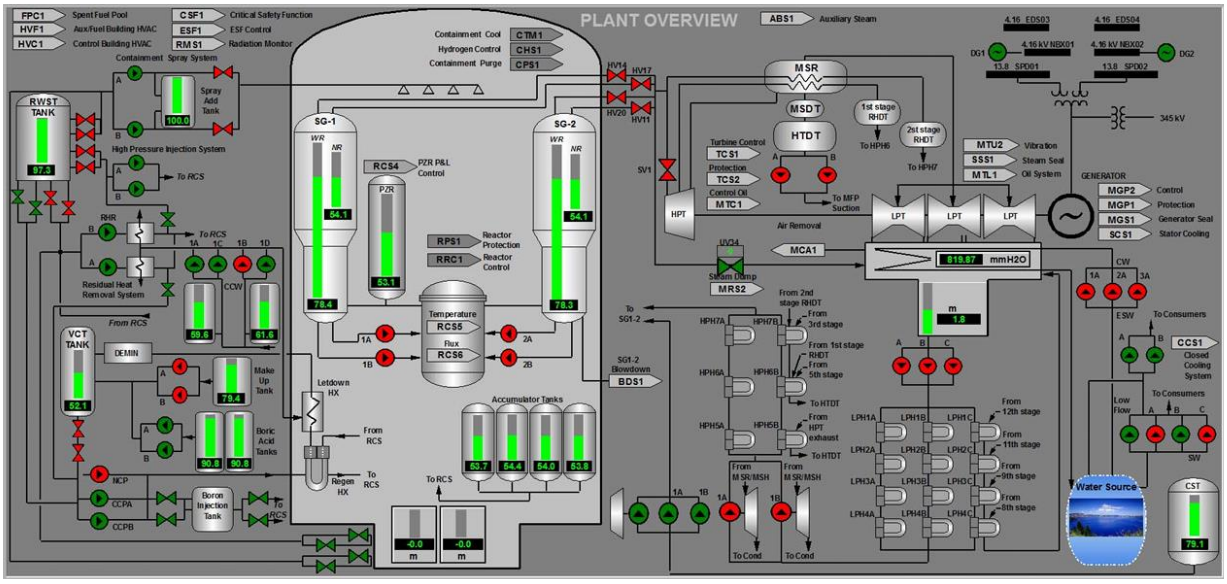

Figure 1: Plant Overview at Initial Condition (Normal Operation)

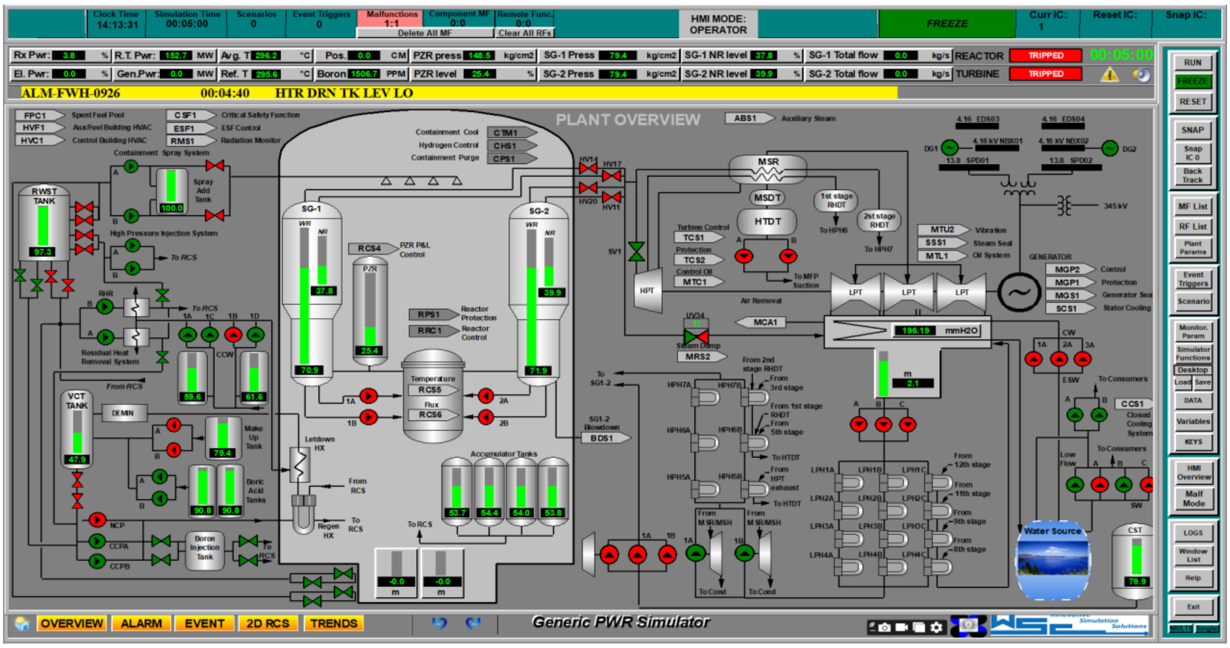

Figure 2: Plant Overview at Abnormal Condition (Inadvertent Turbine Trip Scenatio)

Compared with the initial normal operating condition, the event-time display shows a clear transition to an abnormal plant state. During the transient, the pressurizer pressure was displayed at 148.5 kg/cm², while the pressurizer level had decreased to 25.4%. Steam-generator pressures were shown at 79.4 kg/cm² for both SG-1 and SG-2, while SG-1 narrow-range level and SG-2 narrow-range level were displayed at 37.8% and 39.9%, respectively. These observations indicate that the malfunction produced a measurable transient in key plant parameters and resulted in a broader change in overall plant operating condition.

The ESF control screen as shown in Figure 3, provides the logic context for interpreting this condition. Its layout explicitly includes the pathways for reactor trip, trip main turbine, feedwater isolation signal, and auxiliary feedwater actuation, which are relevant to the transient under study. With the convention used in your simulator that red indicates actuated, the ESF display becomes useful for identifying which protection and support-system responses are involved in the event sequence. In addition, the event log shows that the simulator records detailed component-level status changes, including auxiliary feedwater pump controls and steam generator auxiliary feedwater control valve actions, giving the scenario a traceable operational record that supports later review.

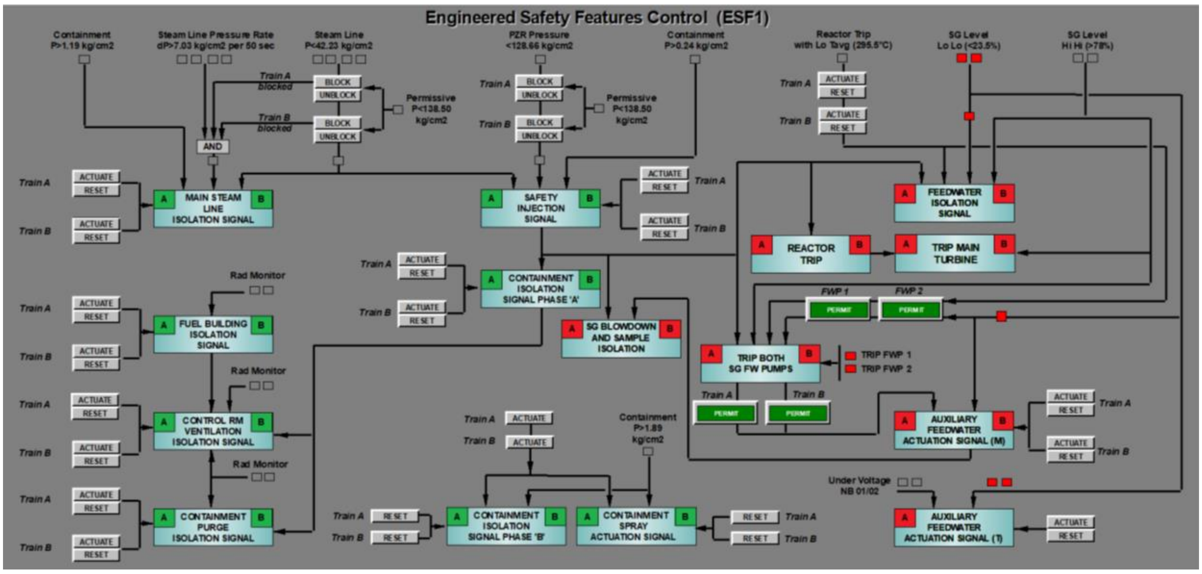

Figure 3: Engineered Safety Features Control System

3.2 Discussion from a Safety Culture Perspective

From a safety culture perspective, the scenario demonstrates the importance of recognizing how a turbine-generator malfunction can propagate into broader plant consequences. Rather than treating the event as a single equipment upset, the operator must interpret a sequence of conditions that includes turbine trip, loss of generation, alarm development, and protective system response. This is closely aligned with INSAG-4, which frames safety culture as the set of organizational and individual characteristics and attitudes that ensure safety issues receive the attention warranted by their significance [1].

The simulation results support this principle in a practical way. The plant overview requires the observer to connect multiple indications at once: the trip status of the reactor and turbine, the loss of electric and generator power, the reduction of key operating margins, and the appearance of alarms. This encourages disciplined attention to plant status and to the significance of protection-related information, which is central to a safety-culture-oriented mode of operation. Recent literature also continues to emphasize that human factors and safety culture are deeply tied to both organizational and individual performance in nuclear facilities, and the current scenario reflects that relationship because correct understanding depends on how effectively the event is interpreted, not simply on whether a signal change its color [2].

This interpretation is also consistent with IAEA guidance on simulator training. The IAEA notes that simulator training is used to develop and reinforce knowledge of plant systems and their relationships, improve the application of procedures, and prepare personnel for accident and infrequently encountered plant evolutions [2]. The present scenario fits that role well: it gives a controlled setting in which an operator can observe how an inadvertently initiated turbine trip evolves into a larger plant event that requires broad system awareness and safety-oriented interpretation.

3.3 Discussion from a Knowledge Management Perspective

The same simulator evidence is also valuable from a knowledge management perspective. The combination of the plant overview, ESF logic display, and event log produces a reviewable set of operational information that can be discussed, documented, and reused. The IAEA's guidance on knowledge management in nuclear organizations describes this as a systematic approach to identifying, managing, and sharing knowledge needed to support organizational objectives [3]. In the present study, the simulator outputs function in exactly this way by turning a transient event into an analysable and communicable body of operational knowledge.

The updated plant overview is particularly useful because it captures the plant at a meaningful point in the transient, when the trip condition and its operational consequences are already visible. The ESF display complements this by making the protection and support-system logic explicit, while the event log provides traceability at component level. Taken together, these materials support event reconstruction, post-scenario discussion, and lessons learned. This is very much in line with recent IAEA lessons-learned guidance, which emphasizes that operational experience becomes more useful when it is captured and structured in a way that supports reuse and organizational learning.

3.4 Comparison with Existing References and Contribution of the Study

Compared with established nuclear references, the present findings are consistent in three important ways. First, they support the safety-culture view that abnormal conditions must be interpreted with sustained attention and not reduced to isolated technical symptoms [1]. Second, they are consistent with the simulator-training literature of the IAEA, which treats simulators as tools for strengthening system understanding and procedural awareness during abnormal and infrequently encountered events [2]. Third, they align with IAEA knowledge-management guidance by showing that simulator outputs can be transformed into structured operational knowledge that supports review, sharing, and future learning [3].

The contribution of the present paper is therefore practical rather than purely theoretical. It shows that a single GPWR malfunction scenario, an inadvertent turbine trip initiated with a 10-second delay which can be used not only to display plant response, but also to reinforce safety culture and support knowledge management within a unified simulator-based activity. In this respect, the study contributes a focused example of how turbine-generator scenarios can be used as training cases that strengthen both safety-oriented operational awareness and the capture of reviewable operational knowledge.

4 CONCLUSION

This study demonstrated the value of the Generic Pressurized Water Reactor (GPWR) simulator as a practical tool for examining safety culture and knowledge management in turbine-generator operations. Using an inadvertent turbine trip scenario initiated with a 10-second delay, the simulator provided a controlled environment in which plant response, protection logic, and system behaviour could be observed from normal operating conditions through the development of the transient and into the shutdown state. The results showed that the scenario was able to produce meaningful changes in key plant parameters and operating conditions, making the event suitable for structured technical review.

From a safety culture perspective, the simulator scenario emphasized the importance of maintaining awareness of plant conditions, recognizing abnormal events, and understanding the significance of trip indications and protection system responses. From a knowledge management perspective, the combination of plant overview displays, engineered safety features indications, and event logs showed that simulator outputs can be used as reviewable sources of operational knowledge that support discussion, documentation, and future learning. In this way, the study highlights that simulator-based malfunction scenarios can contribute not only to technical training but also to the strengthening of safety-oriented practice and organizational learning.

Overall, the paper contributes a practical example of how a GPWR simulator scenario can be used to connect turbine-generator malfunction analysis with the broader goals of safety culture reinforcement and knowledge management in nuclear operations. This approach may be useful in future training and review activities where simulator-generated information is intended to support both operational understanding and continuous improvement.

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