# Fuzzy methodology applied to probabilistic safety assessment for digital system in nuclear power plants


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A fuzzy inference system (FIS) modeling technique to treat a nuclear reliability engineering problem is presented. Recently, many Nuclear Power Plants (NPPs) have performed a shift in technology to digital systems due to analog obsolescence and digital advantages. The fuzzy inference engine uses these fuzzy IF-THEN rules to determine a mapping of the input universe of discourse over the output universe of discourse based on fuzzy logic principles. The risk priority number (RPN) (typical of a traditional Failure Mode & Effects Analysis - FMEA) is calculated (RPN=OxSxD), where O is occurrence, S is Severity, and D is not detection, and compared to fuzzy risk priority number (FRPN), obtained by the use of the scores from expert opinions. It was adopted the Digital Feedwater Control System as a practical example in the case study.

The test case for applying the approach proposed involves a digital feedwater control system (DFWCS) of a two-loop pressurized water reactor. Each of the two reactor-coolant loops contains a reactor coolant pump and a steam generator (S/G). The main feedwater system (FWS) consists of steam-turbine-driven Feedwater Pumps (FWPs), minimum flow control valves, a pump-seal water system, main feedwater regulating valves (MFRVs), bypass feedwater regulating valves (BFRVs), high-pressure feedwater heaters, and associated piping and instrumentation. The feedwater of each secondary loop is controlled by a DFWCS, which is described in detail in Chu et al. (2008) [1] in the Section 4.

In the Fig. 1 is a simplified diagram that shows only one of the reactor coolant loops with its associated DFWCS.

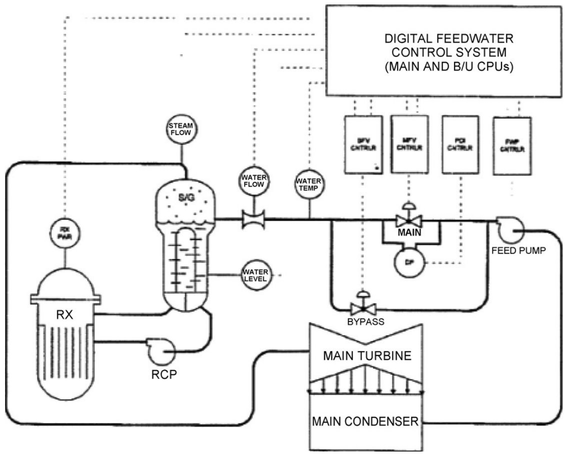


Figure 1. One of the reactor coolant loops with its associated DFWCS. (Source: Chu et al. (2008).

The Top-Level of FMEA for digital feedwater control system (DFWCS) is summarized in the Table 1. FMEA of FWP (Level of Module) is presented in another Table. In Chu et al. (2008) it was developed the FMEA and in this report the numbers for O, S and D were defined by experts as a result of the work developed. [2]

Table 1. Top-Level FMEA of DFWCS.

| Mode of operation of the plant: Power operation<br>Mode of operation of the MFW: High power | | | | | |
|---|---|---|---|---|---|
| Failure Mode | Detection of Failure Mode | Failure Effect on Main Feedwater System | O | S | D |
| No or "low" signal from DFWCS to controlled components | Indications in control room of low feedwater flow and low level in steam generator | Low level in SGs can cause reactor trip | 3 | 7 | 2 |
| | | Reduction of level in SG(s) can possible contribute to steam generator tube rupture (SGTR) | 3 | 10 | 2 |
| "High" signal from DFWCS to controlled components | Indications in control room of high feedwater flow and high level in SGs | Excessive feedwater to steam generator(s) can cause reactor trip | 3 | 7 | 1 |
| Abnormal fluctuations of signal from DFWCS to controlled components | Depending on frequency and severity of fluctuations, operators in control room may be able to detect changes in feedwater flow and in level in SGs | Effects are expected to be similar to those resulting from the previous two failure modes | 4 | 8 | 4 |
| Failure to transfer to low-power mode when reactor power decreases below 15% and remains above about 2% | Indication in control room of high level in SGs | A mismatch between the power produced by the reactor and the cooling of the SGs by the DFWCS. The mismatch may result in excessive feedwater to SGs causing a reactor trip. | 4 | 7 | 5 |

The results demonstrated the potential of the inference system to this class of problem.

## References


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