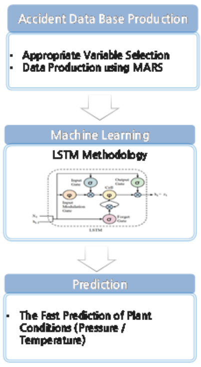
Prediction of SMART Plant Conditions in DBA using Machine Learning

Keon-Yeop Kim[a*], Su-Won Lee[a], Young-Suk Bang[a], and Jin-Hee Park[b]
[a] FNC Technology Co., Ltd.,
[b]Korea Atomic Energy Research Institute
*Corresponding author: kykim@fnctech.com

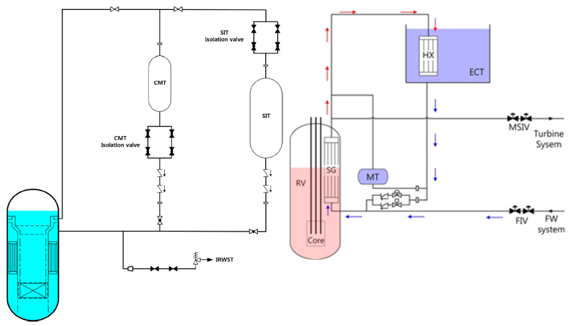
INTRODUCTION

- After the TMI accident, concern in the human factor for safety and efficiency of nuclear power plants has increased. If a number of measurement and alarm signals generated in an emergency situation are automatically analyzed and the operation support system, which can provide decision making to operator. Operation support technology can be implemented using AI techniques.
- This study aims to predict condition of **SMART** (System-integrated Modular Advanced ReacTor) using **machine learning AI** technologies that can be based on operator support techniques. Because SMART adopts the passive system depends on the natural forces (e.g., gravitational force or natural circulation), of which **uncertainties are significant**, operation support technology may be more necessary in the accident situation.
- By selecting representative variables that represent plant phenomena for machine learning, the accuracy of prediction and the efficiency of computation can be increased. The machine learning is conducted using long short-term memory (LSTM) methodology.



PASSIVE SAFETY INJECTION SYSTEM

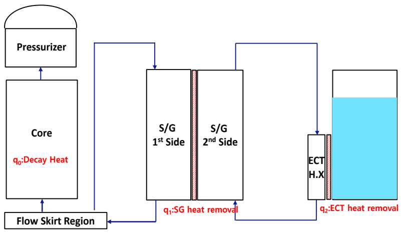
- **PSIS (Passive Safety Injection System)**
  - Prevents core uncovery in case of a small break loss-of-coolant accident (SBLOCA)
  - Consists of **four mechanically independent trains**, and each train is composed of one core makeup tank (**CMT**) and one safety injection tank (**SIT**).
  - The **CMT** injects the emergency boric acid solution into the RCS by the gravity under the **high temperature and pressure condition** during the system operation.
  - The **SIT** prevents uncovering of the core by supplying emergency cooling water and **secures core cooling capacity** for at least **72 hours.**
- **PRHRS (Passive Residual Heat Removal System)**
  - **Removes the RCS heat** by natural circulation in emergency situations where normal steam extraction or feedwater supply is unavailable at least **72 hours** .
  - The PRHRS consists of four independent trains and each train is composed of one emergency cooldown tank (ECT), one PRHRS heat exchanger (PHX) add one PRHRS makeup tank (PMT).



< PSIS >   < PRHRS >

VARIABLE SELECTION

- The thermal hydraulic behavior of SMART can be identified from the equation of mass & energy balance equations. The variables for machine learning are selected considering these equations.



Mass Balance

$$\dot{m}_{net} = \dot{m}_{CMT} + \dot{m}_{SIT} - \dot{m}_b - \dot{m}_P$$

Energy Balance

$$q_0 - q_1 - \dot{m}_{PSV} h_0 - \dot{m}_{break} h_0 = C_1$$

$$q_1 - q_2 = C_2$$

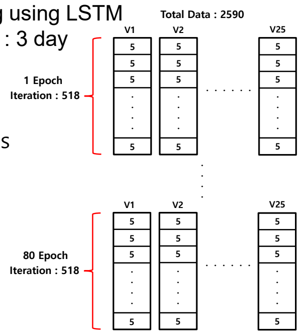
Number	Selected Variable	Number	Selected Variable
1	Reactor Pressure Vessel Level	14	Main Steam Line #1 Pressure
2	Core Make up Tank (CMT) #1 Level	15	Main Steam Line #2 Pressure
3	Core Make up Tank (CMT) #2 Level	16	Main Steam Line #3 Pressure
4	Core Make up Tank (CMT) #3 Level	17	Main Steam Line #4 Pressure
5	Core Make up Tank (CMT) #4 Level	18	Main Steam Line #1 Temperature
6	Safety Injection Tank (SIT) #1 Level	19	Main Steam Line #2 Temperature
7	Safety Injection Tank (SIT) #2 Level	20	Main Steam Line #3 Temperature
8	Safety Injection Tank (SIT) #3 Level	21	Main Steam Line #4 Temperature
9	Safety Injection Tank (SIT) #4 Level	22	Main Steam Line #1 Flow Rate
10	Pressurizer Pressure	23	Main Steam Line #1 Flow Rate
11	Pressurizer Temperature	24	Main Steam Line #1 Flow Rate
12	RCS Flow Rate	25	Main Steam Line #1 Flow Rate
13	Core Power		

NUMERICAL DEMONSTRATION

- Machine Learning Prediction Cases
  - Case 1 : SBLOCA for evaluating Passive Safety System
  - Case 2 : SGTR for predicting plant state in unstable hydraulic behavior

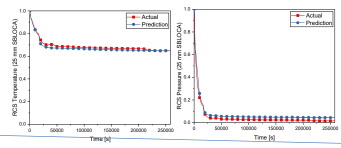
No	Machine Learning	Prediction
1	**SBLOCA** - 50mm break - 2 PSIS Actuation **LOMF** - 50mm break - 2 PRHRS Actuation	**SBLOCA** - 25mm break - 2 PSIS Actuation - 2 PRHRS Actuation
2	**SGTR** (0~129,500 s)	**SGTR** (129,500 ~259,000 s)

- Machine Learning using LSTM
  - Simulation Time : 3 day
  - 2,590 rows data
  - Epochs : 80
  - Batch Size : 5
  - 41,440 Iterations

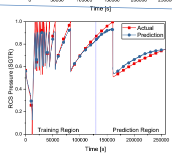


- The Analysis Result
  - The trends are **predicted similarly**.

CASE 1 SBLOCA



CASE 2 SGTR



CONCLUSION

- Plant condition prediction using machine learning is conducted using accident analysis data and LSTM methodology.
- The essential variables including passive safety system for machine learning based on the physics, and plant condition prediction using machine learning is conducted. As a result, **the actual and predicted values are similar**.
- And physical-based analysis using thermal hydraulic codes requires a lot of time, but AI enables **high-speed prediction**. Therefore, this technology can be used for real-time and optimization analysis and it can be based on operator support systems or autonomous nuclear technology.