Development of MCR HVAC ROM model for simulation-based digital twin system

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1. Introduction

Recently, Digital Twin is being expanded to various fields throughout the industry, and a lot of research and development are being conducted to build digital twin for nuclear power plants. However, due to the specificity of nuclear power plants, direct data collection/analysis is often difficult. For this reason, it is necessary to build an environment for building a digital twin environment based on simulation that connects the physical model and the virtual model. In this paper, we develop a ROM (Reduced Order Model) for building a digital twin that connects a physical model and a virtual model to respond to the real-time changing HVAC in the MCR(Main Control Room) of a nuclear power plant. In addition, based on this, a real-time HVAC simulation result deployer of the MCR that can be applied to the digital twin is developed.

2. ROM(Reduced Order Model)

The order reduction model is a technique that reduces the computational complexity of mathematical models in CFD simulations, which is similar to the concept of metamodeling around mathematical modeling.

The order-reduced model simplifies an actual complex physical system to a level that does not lower the level of analysis results. The behavior of the original system is extracted, and the governing equations of the system are derived empirically. This model allows engineers to quickly determine the effects of key variables in the system using minimal computational resources. Fig.1 shows the steps of creating a rom using CFD simulation and applying it to the system.

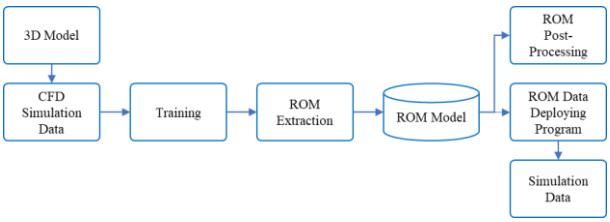


Fig. 1 ROM workflow in Digital Twin.

3. MCR HVAC Simulation

3.1. CFD - Analysis conditions

A CFD analysis was performed on the MCR including HVAC and heat sources to be used for ROM generation. The MCR to be analyzed was developed with several HVAC inlets/outlets, and the heat source of the heating equipment of the devices (display, computer, monitor, server, etc.) inside the main control room was set. Dense grids were applied to the vicinity of HVAC equipment and heating devices, and the number of grids is more than 4.5 million.

Training data was created through the following fixed and variable conditions for an environment where multiple CFD analyzes are required for ROM generation.

Table I: CFD analysis conditions

Fixed Condition	Initial Temperature	25℃
	Inlets	44 pcs
	Total Heat Load	53,700 W
HVAC condition (9 cases)		9,100 ~ 18,900 CFM

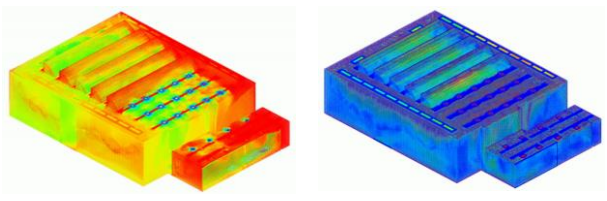
For the analysis environment, a 3D steady-state analysis was performed, and a standard $k-\epsilon$ model was used to consider the effect of turbulence. The working fluid is wet air, and the analysis environment was configured to consider the change in physical properties due to temperature. Parametric analysis was performed according to the HVAC air volume, which is a changing condition.

3.2. CFD – Simulation Data

We develop a technology that combines CFD analysis technology and machine learning technology to calculate the air flow and temperature distribution inside the MCR in real time. Using the developed real-time analysis technology, air flow and temperature distribution inside the MCR were calculated, and the results were compared with the CFD analysis results.

3.3. CFD - Results

Fig.2 shows the analysis result for ROM generation.



(a) Temperature (b) Velocity magnitude

Fig. 2 CFD analysis results

4. ROM Model

4.1. ROM creation process

To generate a ROM model, the parametric analysis result was input into the AI model to determine the reduced order. To build a ROM model for the analyzed results, 8 out of 9 analysis cases were used for training, and one analysis result was used for verification purposes.

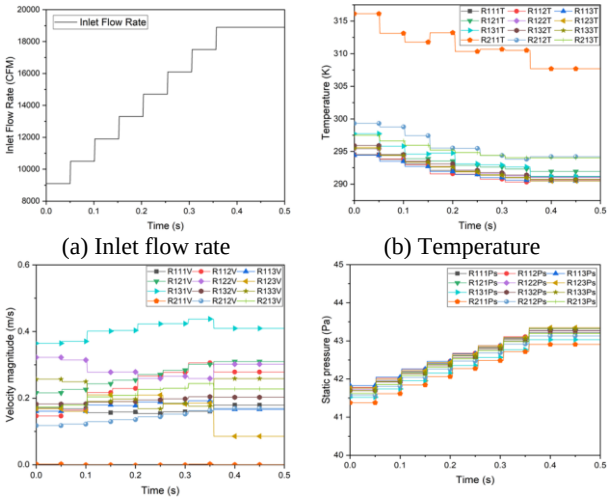
For the ROM model to generate real-time analysis information, information on air flow and temperature distribution inside the MCR was created, and the ROM model was created using Ansys Twin Builder.

Through comparative analysis of the training data and the verification data, the ROM error was confirmed to be up to 0.352%.

4.2. ROM verification

To apply the generated ROM model to the digital twin environment, the twin model deployer in the form of an independent module must be used. This is essential to obtain simulation results according to the conditions specified by the user in the AI model in the form of a closed box.

To confirm the reliability of the twin model deployer, a comparative evaluation was performed between the analysis results from the ROM model (monitoring points specified by the user) and the results obtained using the twin model deployer. For comparative evaluation, 12 monitoring coordinates(R1-1-1 ~ R1-3-3, R2-1-1 ~ R2-1-3) of the ROM model were designated.



(a) Inlet flow rate (b) Temperature

(c) Velocity magnitude (d) Static pressure

Fig. 3 Twin model parameters

4.3. ROM vs Twin Model comparative evaluation

Since the ROM model used in this study is based on the steady state, it is necessary to evaluate it by putting the input data as constants during verification. The range of input variables is 9100 CFM ~ 18900 CFM, and verification was performed for 5 analysis cases (9100, 12000, 14000, 16000, 18900 CFM).

Comparative evaluations were performed on temperature, flow rate, and pressure at the monitoring points of the ROM model and the Twin model. As a result of the comparison, the results of the Twin and ROM models were completely consistent.

5. Conclusions

In this study, a CFD analysis was performed on the MCR, a program was developed to apply it to the digital twin environment, and a comparative evaluation was performed with the original ROM model.

The research conducted for this purpose is as follows,

- Perform MCR HVAC CFD analysis
- Establishment of order reduction model and data verification
- Building a Twin model application deployer.

It was confirmed that the results output from the developed program matched the ROM model result values.

The developed ROM model has currently been cross validated. In future research, we plan to complete the simulation-based digital twin system by applying the twin model to the digital twin system.

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