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An Integrated Model-Based Development Framework for Automotive Thermal Energy Systems

Bumseok Choo [1)]

1) Hyundai Motor Company
150, Hyundaiyeonguso-ro, Hwaseong-si, 18280, Republic of Korea (E-mail: bschoo@hyundai.com)

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With the advancement of Software-Defined Vehicles (SDV), automotive systems are becoming increasingly complex due to the continuous addition of software-based functions. In particular, the development of automotive thermal energy systems, which involve battery thermal management, motor and controller cooling, and cabin heating and cooling, requires efficient collaboration among the design, analysis, control, and testing domains. To address this challenge, this study proposes an integrated development framework for automotive thermal energy systems based on Model-Based Development (MBD).

The proposed framework integrates fragmented system information, including system architecture, operating modes, interfaces, component functions, performance data, and control specifications, into a unified digital model developed using Simulink and MATLAB. In this model, components are linked through ports and connections, while subsystem models embed detailed component information. Various operating modes, such as cabin heating/cooling, battery thermal management, and heat pump operation, can also be visually represented and managed within the same environment.

To support collaboration between the design and analysis domains, a Python-based toolchain was established between the integrated model and GT-SUITE, enabling the automatic generation of a thermal-fluid analysis model from architecture and component specification data. This approach supports continuity and consistency in the development process while reducing the manual work required for analysis model generation.

The proposed framework was demonstrated using a heat pump system and a Rankine Cycle model. Comparison of the constituent elements of the Simulink integrated model and the GT-SUITE analysis model showed automation rates of 63% for components, 67% for ports, 66% for connections, and 100% for component specification sheets. These results indicate that the proposed process can reduce manual engineering effort by automating a substantial portion of the model generation workflow. The remaining gap from 100% automation is mainly due to structural differences in heat exchanger representation between the integrated model and GT-SUITE.

Overall, the results indicate that the proposed framework can improve development efficiency and support cross-domain collaboration in the SDV environment.

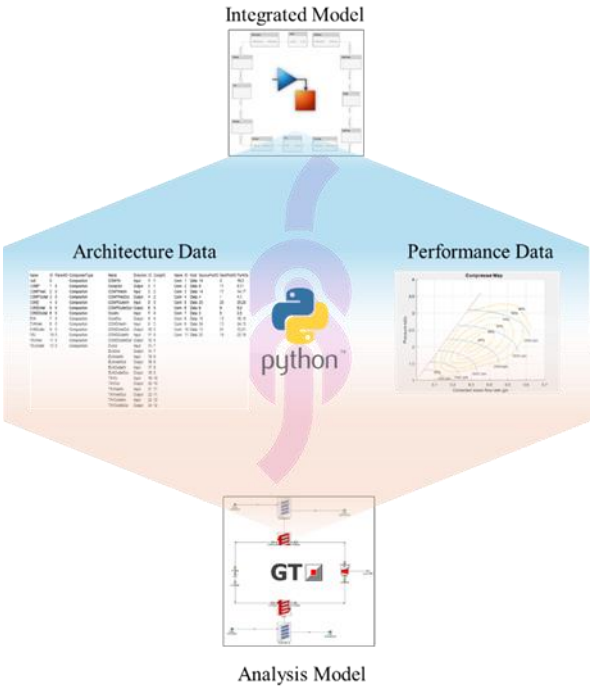

Fig.1 Automated Generation of a Thermal-Fluid Analysis Model Using Integrated Model Data