

Development of On-board PV System Model Using Modelica Language and Its Application to xEV Model

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In preparation for the introduction of an off-cycle credit scheme in Japan, quantitative methods are required to evaluate energy-saving technologies whose benefits are difficult to capture using conventional chassis-dynamometer fuel economy tests. An on-board photovoltaic (PV) system is one such technology, but its electricity generation varies significantly depending on season, weather, time of day, region, module temperature, and partial shading. In this study, an on-board PV system model applicable to vehicle-level simulation was developed using the Modelica language to evaluate its contribution to improvements in fuel or electric power consumption in xEVs.

The PV module was represented by a single-diode equivalent circuit model coupled with a thermal model based on the energy balance of absorbed solar radiation, electric power conversion, convective heat transfer, and radiative heat transfer. This formulation enables the model to reproduce both the electrical characteristics and temperature response of the module under varying irradiance and thermal conditions. The model was implemented in OpenModelica taking advantage of acausal multi-domain modeling to connect electrical, thermal, mechanical, and control components in a unified simulation environment.

The PV system model includes maximum power point tracking (MPPT), charge cut-off control, and a boost converter model, and it can be integrated with existing electrified vehicle models by connecting it in parallel to the DC electrical circuit. Model parameters were identified using measured P-V and I-V characteristics of a test PV module, and the module temperature response was validated using real-world driving data. The results confirmed that the developed model can reproduce the main generation and thermal behaviors of the on-board PV module with sufficient accuracy for vehicle-level studies.

The developed model was then applied to battery electric vehicle (BEV) and series hybrid electric vehicle (HEV) models. In the BEV case study, the installation of the PV system reduced the rate of decrease in battery state of charge during the WLTC cycle, extending the calculated driving range from 324 km to 351 km, corresponding to an improvement of approximately 8%. In the series HEV case study (Figure 1), PV charging slightly increased the battery state of charge and reduced engine operating frequency. After correcting fuel economy so that the net battery energy balance became zero, the PV system improved fuel economy by approximately 27% in the Low phase and by approximately 9% over the Low, Medium, and High phases of the WLTC (Figure 2).

These results demonstrate that the proposed Modelica-based on-board PV system model can be readily integrated into xEV simulation models and used to quantify the practical benefits of vehicle-integrated photovoltaic systems under assumed or real-world irradiance conditions. The model therefore provides a useful platform for evaluating off-cycle technologies and for supporting model-based development of future electrified vehicles.

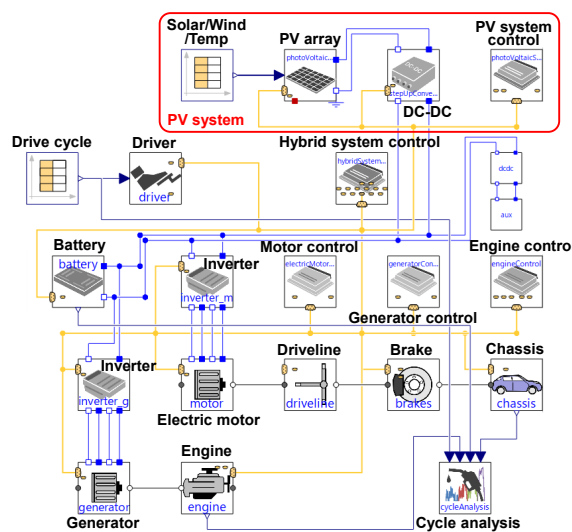


Fig.1 Top-level GUI of the series HEV model with the PV system

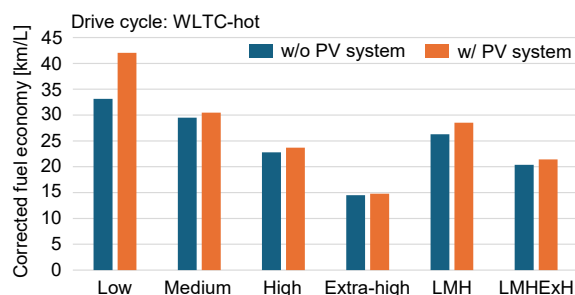


Fig.2 Corrected fuel economy in each WLTC phase for the series HEV with and without the PV system