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Component Design of x-EVs using Virtual Integrated Development Environment

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Abstract

In this study, component design of x-EVs was performed using virtual integrated development environment (VIDE). First, component library was developed for various components such as the engine, motor, battery and transmission. Vehicle performance simulator of x-EVs was developed using MATALB SimDriveline, which consists of the powertrain system and control system. Experiment and commercial software were used for the validation. A virtual environment was developed using the 3D rendering tool to simulate the road, buildings, traffic, signal system and weather. Using the VIDE, EV range and acceleration performance for various x-EVs were evaluated to design the battery and motor specifications. In addition, an electric heater was selected as an example and its performance at the vehicle level was investigated using the VIDE. It is expected that the VIDE can be used in component design for x-EVs.

Keywords: x-EV, component design, virtual integrated development environment (VIDE)

1 Introduction

Due to the high oil price and CO2 emission, the development of environment friendly x-electric vehicles (x-EVs) such as hybrid electric vehicle (HEV), plug-in HEV (PHEV) and electric vehicle (EV), have attracted the attention of the automobile manufacturers [1].

The x-EV is constructed by several components such as transmission, engine, battery and motor-generator(MG). Using the powertrain components, HEV and PHEV can be constructed with various configurations such as series, parallel and power-split, which have different power characteristics and control algorithms. Since the vehicle performance is directly related with the component design specifications, it is necessary to evaluate the component performance at the vehicle level as well as the component level. However, it is not easy to evaluate the vehicle level performance without applying the component to the target vehicle. Some researches had been performed on the component design and vehicle performance evaluation using the commercial softwares such as the powertrain system analysis tool (PSAT) developed by the Argonne National Laboratory and the Cruise developed by the AVL[2, 3].

In this study, component design of x-EVs was performed using the virtual integrated development environment (VIDE). x-EV simulators were developed and validated. Battery and motor specifications were designed using VIDE. In addition, an electric heater was selected as a design example and its performance was investigated at the vehicle level using the VIDE.

2 Performance Simulator of x-EV

In this study, EV (Nissan Leaf) and PHEV (Plug-in Prius, GM-Volt) are selected as the x-EV target vehicles.
The structures of the target vehicles are shown in Fig. 1. The target vehicle consists of engine, MGs, battery and transmission. The component specifications of the target x-EVs are shown in Table 1 [4].

Table1: Component specifications

(a) Nissan Leaf

MG2	Max output(kW)	80
	Max torque (Nm)	280
Battery	Type	Lithium-ion
	Capacity(kWh)	24

(b) Plug-in Prius

Engine	Displacement (cc)	1798
	Max output(kW/rpm)	73/5,200
MG2	Max output(kW)	60
	Max torque (Nm)	207
MG1	Max output (kW)	40*
Battery	Type	Lithium-ion
	Capacity	4.4kWh

(c) GM-Volt

Engine	Displacement (cc)	1398
	Max output(kW/rpm)	64/4800
MG2	Max output(kW)	111
	Max torque (Nm)	370
MG1	Max output (kW)	55
Battery	Type	Lithium-ion
	Capacity(kWh)	16

2.1 Component library

Component library is developed for various components such as the engine, motor, battery and transmission system with various capacity and specification using MATLAB SimDriveline (Fig. 2).
In addition, the component library is designed to allow the user to change the size and characteristics, which provides the freedom in the evaluation of the component performance such as torque, speed, voltage, current and battery state of charge (SOC).

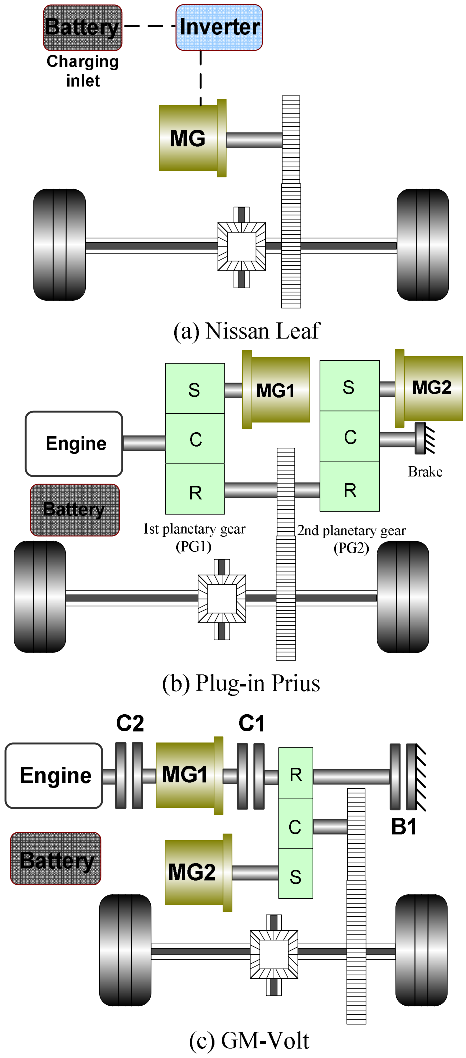


Figure1: Structure of x-EVs (Nissan Leaf, Plug-in Prius, GM-Volt)

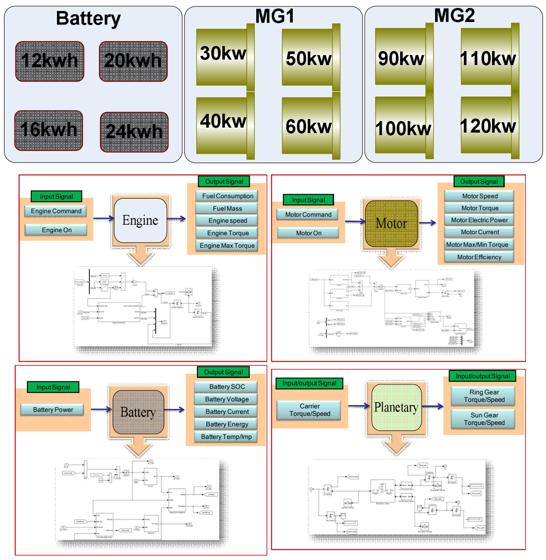
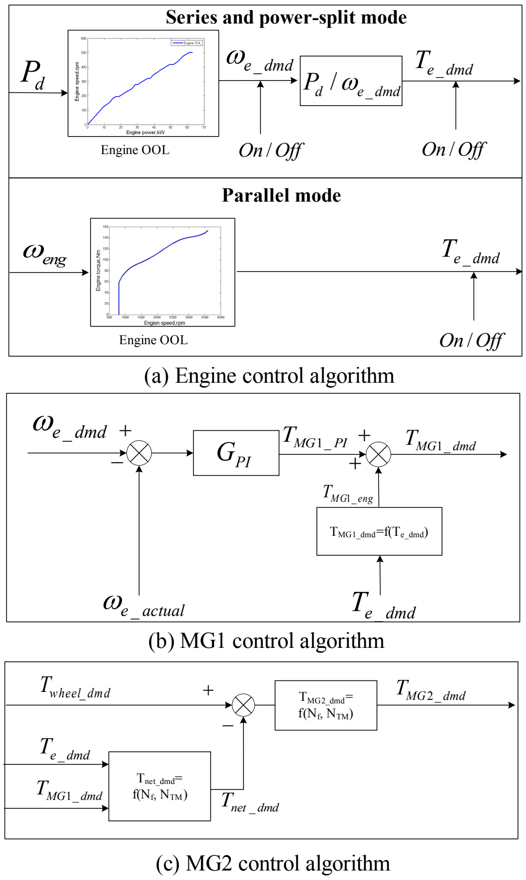


Figure2: Component library

2.2 Control system

For the PHEV, the component control algorithm is developed for the engine, MG1 and MG2 considering the driving mode of the target vehicle (Fig. 3).



(a) Engine control algorithm

(b) MG1 control algorithm

(c) MG2 control algorithm

Figure3: Component control algorithm

For the engine, control algorithm is developed for the optimal operation based on the engine optimal operating line (OOL). Since the engine optimal operation is realized by the MG1 control, a PI-type MG1 torque control is used for the engine speed control. The MG2 torque and the net torque that comes from the engine and MG1 are used together to propel the vehicle. The demanded MG2 torque is obtained by subtracting the net torque from the demanded wheel torque.

In addition, an energy management strategy is developed for the PHEV considering the battery SOC (Fig. 4) [4]. The vehicle is driven under charge depleting (CD) mode when the battery is fully charged by the external electric grid. When the battery SOC drops to a predefined value, the drive mode of the PHEV is switched from the CD mode to the charge sustaining (CS) mode. The battery SOC is sustained in the CS mode [4].

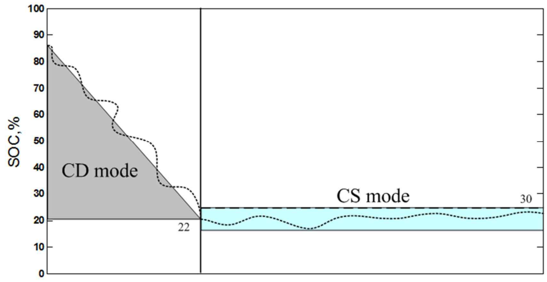


Figure4: Energy management strategy [4]

For the EV, only the component control algorithm is required and the demanded MG2 torque is obtained from the demanded wheel torque.

The performance simulator of the x-EVs was developed by combining the powertrain system and control system.

3 Validation of x-EV Performance Simulator

The x-EV performance simulators are validated by comparing with the commercial softwares and test results. The validation of the GM-Volt is performed in the previous research [5].

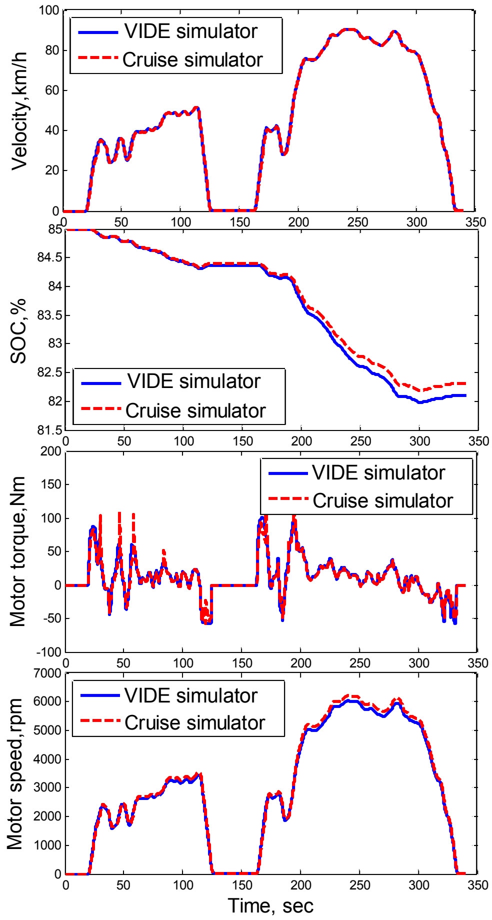


Figure5: Validation of Nissan Leaf using Cruise

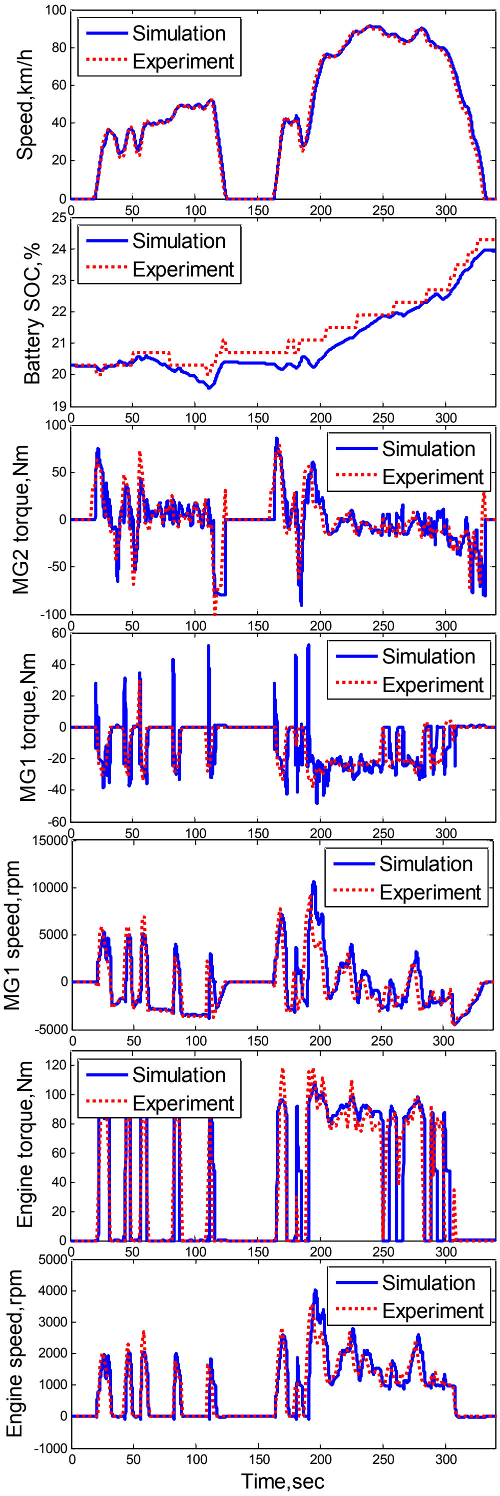


Figure6: Validation of plug-in Prius using test results

For the Nissan Leaf, commercial software Cruise is used for the validation (Fig. 5). It is seen that the VIDE simulation results of the vehicle velocity, battery SOC, motor speed and torque are in good accordance with the results of Cruise simulator.

Validation of the plug-in Prius is performed using test results (Fig. 6). From the comparison results, it is seen that the simulation results of the vehicle velocity, battery SOC, engine/MG1/MG2 torque and speed are in good accordance with the test results, which demonstrates the validity of the x-EV performance simulator.

4 Virtual Integrated Development Environment

Based on the developed x-EV performance simulator, a GUI environment is developed to select the vehicle platform and simulation type (Fig. 7). As shown in Fig. 7, the user can select the vehicle type, vehicle platform, simulation condition and send the selected vehicle to the virtual driving environment.

To perform the virtual driving, the virtual environment is developed using the 3D rendering tool, which can simulate the road, buildings, traffic, signal system and weather [6].

The real time driving devices are used to combine the x-EV simulator and virtual driving environment (Fig. 8) [6]. The driver can manipulate the steering and accelerator/brake pedal to drive the vehicle in the virtual environment for various test conditions: simulation mode, test mode and virtual driving mode. At the same time, the component performance such as torque, speed, voltage, current and fuel economy are evaluated on real time feature (Fig. 9). For the virtual driving environment, a results management GUI is also developed [6].

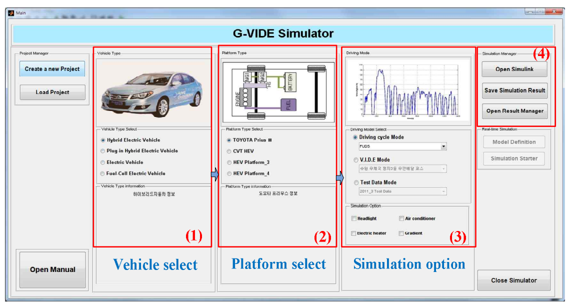


Figure7: GUI environment of VIDE [4]

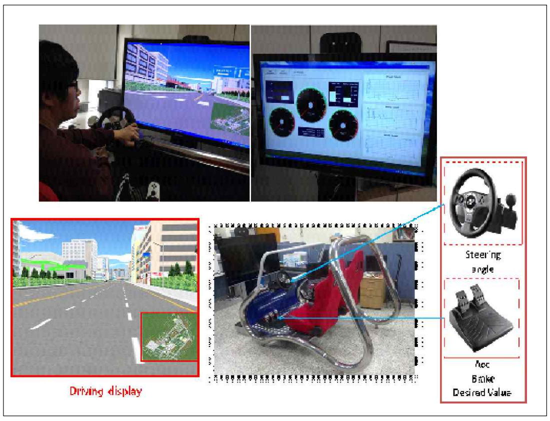


Figure8: Virtual integrated development environment

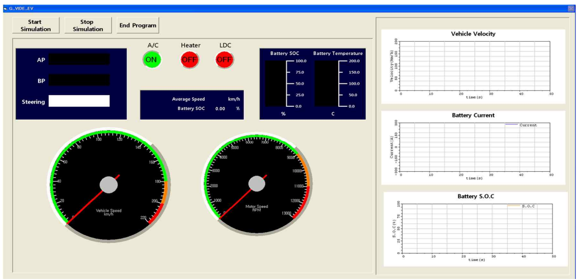


Figure9: Real time monitoring display

5 Component Design using VIDE

Using the VIDE, the EV range and acceleration performance are evaluated to determine the component design parameters.

5.1 Battery

For the PHEV and EV, the battery specifications such as the battery capacity have direct influence on the all electric driving range.

Using the VIDE, the EV range of the selected battery specifications for the target x-EVs are obtained and compared with the official values (Table 2). From Table 2, it is seen that the simulation EV range of the target x-EVs are similar with that of the official value. Using similar procedure, the battery capacity of the x-EVs can be designed by evaluating the EV range using the VIDE.

Table2: EV range for x-EVs

	Leaf	Prius	Volt
Battery apacity (kWh)	24	4.4	16
△SOC	70%	60%	63.8%
VIDE EV range (km)	118.1	18.2	57.5
Official EV range (km)	117	18	56.3

5.2 Motor

In the EV mode, the MG works as the power source to propel the vehicle and its design specifications has direct relationship with the vehicle acceleration performance.

Acceleration performance for the target x-EVs is obtained using VIDE (Table 3). It is seen that the acceleration performance obtained from the VIDE has similar results with the official values.

Table3: Acceleration performance for x-EVs

	Leaf	Prius	Volt
Battery capacity (kWh)	24	4.4	16
Motor power (kW)	80	60/40	111/55
Vehicle mass (kg)	1520	1420	1815
VIDE (0~100kph, sec)	9.7	10.3	8.7
Official (0~100kph, sec)	9.9	10.7	9

5.3 Component design using VIDE

For the PHEV and EV, an electric heater is required to warm the cabin in the winter since the battery is used as the energy source.

When the component manufacturer wants to design the electric heater, the influence of the electric heater on the vehicle performance such as the EV range should be investigated. The heater with the maximum power of 6kW is selected for the performance investigation (Table 4).

Table4: Specifications of heater

Nominal voltage (V)	300V
Heater power (kW)	6
Resistance number	10

The heater model is constructed, which consists of the heater resistance, core fin and air flow model (Fig. 10).

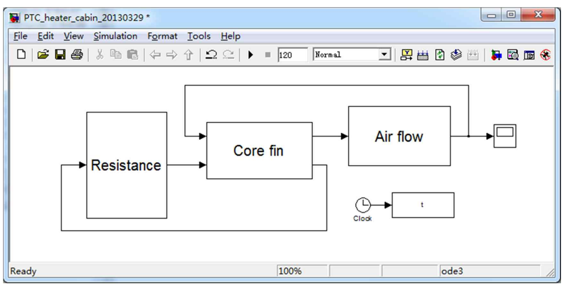


Figure10: Heater model

The heat transfer process can be described as: heater resistance → core fin → air flow → cabin. The heat generated from the heater resistance is transferred to the core fin and the heat from the core fin is transferred to the cabin by the fan.
Cabin heat transfer model is developed (Fig. 11).

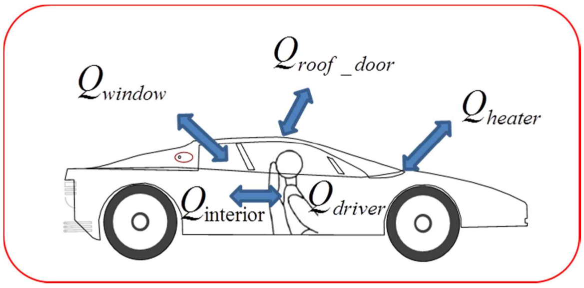


Figure11: Cabin heat transfer model

The temperature in the cabin is obtained as

$$T_{cabin} = \int \frac{P_{air} + P_{driver} - P_{loss}}{\rho V_{cabin} C_p} dt \qquad (1)$$

where T_{cabin} is temperature in cabin, P_{air} is the input air heat power, V_{cabin} is the cabin volume, C_p is specific heat of air and P_{loss} is the power loss from window, roof, door etc.

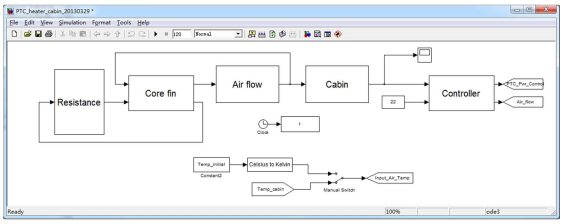


Figure12: Vehicle climate model

The vehicle climate model is constructed by combining the heater model and cabin heat transfer model (Fig. 12). Using the VIDE, the influence of the electric heater on the vehicle performance is investigated by applying the heater on the target vehicle (e.g., GM-Volt). The simulation conditions are shown in Table 5.

Table5: Simulation conditions

Required temperature (℃)	10
External temperature (℃)	-10
Occupants number	2
Battery SOC (%)	85.8%~22%

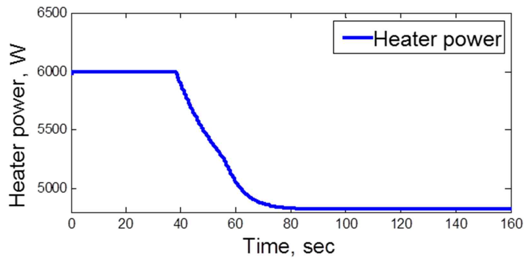


Figure13: Heater power

It is seen from Fig. 13 that the heater consumes 4.8kW to 6kW to satisfy the cabin temperature requirement.
Due to the power consumption of the heater, the EV range of the target vehicle is decreased from 57.6km to 30.2km (Fig. 14).

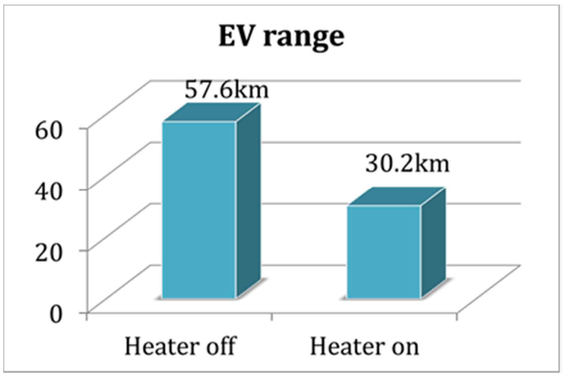


Figure14: Simulation results

6 Conclusion

Component design of various x-EVs was performed using the virtual integrated development environment (VIDE).
Vehicle performance simulator of x-EVs was developed using component library and controller model. The simulators were validated by experiment and commercial software. Using the VIDE, the EV range and acceleration performance of the x-EVs were evaluated in design of the motor and battery specifications. An electric heater was selected as a design example and was applied to the target x-EV to investigate the EV range using the VIDE. It is expected that the VIDE can be used in component design of the x-EVs.

Acknowledgments

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