Development of a Train Simulator for Diesel-Hybrid Railcars and Locomotives

Tomoyuki Ogawa, Hideo Nakamura, Minoru Kondo, Kazumasa Kumazawa
(Railway Technical Research Institute)
Osamu Yamashita (New Media Research Institute)

1. Introduction

We have developed a train simulator of diesel-hybrid railcars and locomotives that is able to be adapted to various hybrid system configurations. The developed simulator calculates running time, fuel consumption, and exhaust gases. Various hybrid system configurations have been proposed aiming at reduction of environmental load and/or improvement of running performance. One of the hybrid system configurations among these proposed ones is a series hybrid system with a diesel generator, traction motors, and a battery. The other several are of types of parallel hybrid systems with a diesel engine, a transmission, a hydraulic torque converter, and electric equipment. For example, the electric equipment of parallel hybrid systems, which is a motor and a battery, is connected to a diesel engine or a transmission.

Design of a new hybrid system requires evaluation of its environmental performance and running performance. The developed simulator adapts itself to various hybrid system configurations of diesel-hybrid railcars and locomotives. The developed simulator has many components for traction such as motor components, an engine component, a transmission component, and so on. Users are able to define a hybrid system configuration easily by selecting “enable” or “unable” of the each component and assign characteristics to the enabled components.

In addition, running time depends on SOC (state of charge) for some hybrid systems, because tractive effort is changed depending on SOC. Therefore, it requires a simulation of the SOC as well as the train speed to schedule a train diagram of the hybrid trains. The developed simulator can be used to schedule train diagrams for diesel-hybrid trains, because it is based on a train performance calculation system commonly used by Japanese railway operators to schedule train diagrams.

2. Simulator profile

2.1 Simulator model

Fig. 1 shows conceptual model of the developed simulator. Running simulation is based on a route model, a vehicle model, and a definition of tractive effort of engines and motors. And, energy simulation is based on a battery model, a vehicle model, and a definition of power of motors and generators. Equipment mode definition is a definition of state of engines, motors, and generators. Running time is obtained by a result of running simulation, and fuel consumption and exhaust gases is obtained by an engine model.
Fig. 1 Conceptual model of the simulator

Fig. 2 shows an example of equipment mode definition. Equipment mode definition is a definition of equipment state depending on speed and SOC for each running mode and notch. Then running mode means powering, coasting, or braking, and notch means powering notch or braking notch. For example, in “maximum generation mode”, an engine is defined as maximum output, and a generator is also defined as maximum output. And, traction motors are defined to output maximum traction power while powering with maximum notch (Powering 5N) and to output no power while coasting.

2.2 Adapting hybrid system

The developed simulator can be adapted to various hybrid system configurations of diesel-hybrid
railcars and locomotives. The developed simulator has many components for traction as shown in the Fig. 2. Users are able to define a hybrid system configuration easily by selecting “enable” or “unable” of the each component and assign characteristics to the enabled components.

A diesel hydraulic system

A diesel hydraulic system composed of a transmission with a hydraulic torque converter adapts to conventional diesel railcars and diesel locomotives. Almost railcars and locomotives operated for non-electrified lines in Japan employ the diesel hydraulic system. The simulation model of the diesel hydraulic system is composed of a wheel, a reduction gear, a transmission including a torque converter, an engine, and an auxiliary load.

A series hybrid system

Appending an energy storage device to a diesel electric system is a series hybrid system. Diesel-hybrid railcars employing a series hybrid system are operated for commercial use by East Japan Railway Company [1]. And a diesel-hybrid shunting locomotive employing a series hybrid system is developed by Japan Freight Railway Company [2]. The simulation model of the series hybrid system is composed of a wheel, a reduction gear, a bogie motor including an inverter model, a battery, an engine motor meaning an engine generator including a converter model, an engine, and an auxiliary load.
Challenge B: An environmentally friendly railway

A parallel hybrid system with a transmission motor

Appending a transmission motor connected to a transmission to a diesel hydraulic system is a parallel hybrid system with a transmission motor. A diesel-hybrid railcar employing a parallel hybrid system with a transmission motor is developed by Hokkaido Railway Company in Japan [3]. The developing railcar without a torque converter starts by a transmission motor while low speed powering. Then an engine and a motor cooperate while high speed powering. The simulation model of the series hybrid system is composed of a wheel, a reduction gear, a transmission, a transmission motor, a battery, an engine, and an auxiliary load.

A parallel hybrid system with an engine motor

Appending an engine motor connected to an engine to a diesel hydraulic system is a parallel hybrid system with an engine motor. A diesel-hybrid railcar employing a parallel hybrid system with an engine motor is developed by West Japan Railway Company [4]. The simulation model of the series hybrid system is composed of a wheel, a reduction gear, a transmission including a torque converter, an engine, an engine motor, a battery, and an auxiliary load.
A parallel hybrid system with bogie motors

A parallel hybrid system with bogie motors is composed of an engine bogie and a motor bogie. The simulation model of the parallel hybrid system with bogie motors is composed of an engine bogie, a motor bogie, a battery, an engine, and an auxiliary load. The engine bogie is composed of a wheel, and a reduction gear. The motor bogie is composed of a wheel, a reduction gear, and bogie motors.

2.3 Running simulation

The running simulation of the developed simulator is based on a train performance calculation system commonly used by Japanese railway operators to schedule train diagrams [5]. Running time depends on SOC (state of charge) for some hybrid systems, because tractive effort is changed depending on SOC. Therefore, it requires a simulation of the SOC as well as the train speed to schedule a train diagram of the hybrid trains. The developed simulator can be used to schedule train diagrams for diesel-hybrid trains, because it is based on the train performance calculation system.

For example, a parallel hybrid railcar with an engine motor developed by West Japan Railway Company improves tractive effort by a battery. To evaluate effect of hybrid system comparing conventional diesel railcars requires considering running time. The developed simulator calculates running time based on an algorithm of the train performance calculation system, in addition to fuel consumption. The calculated running time and fuel consumption can properly evaluate hybrid system.
2.4 User interface

The developed simulator equips user-friendly graphical interface. The user interface of the developed simulator employs that of the train performance calculation system.

Fig. 9 is a component edit window of a train edit mode. On the component edit window users select “enable” or “unable” and assign characteristics to the enabled components. A highlighted component shows “enable” and selectable of characteristics. Users are able to define various hybrid system configurations easily by using the component edit window.

![Component Edit Window](image)

Fig. 9  A component edit window

Fig. 10 is a train performance curve window. The train performance curve window of the developed simulator is based on that of the train performance calculation system. This window shows a speed curve, a time curve, and a SOC curve with a route profile. Users easily recognize characteristics of speed and SOC depending on gradients, curves, speed limits and so on. For example, users recognize that a rising gradient decreases speed and SOC.
3. Simulation results

The simulator outputs a detail result file including time, speed, position, fuel consumption, exhaust gases, SOC, tractive effort, motor power, engine power and so on.

Fig. 11 shows an example of the simulation result of a parallel hybrid railcar with a transmission motor for a simplified railcar model and a simplified line. The railcar starts by a transmission motor and an engine runs idle while low speed powering. While low speed powering, fuel consumption is nearly zero and decrease of SOC is high, because the railcar is powered by a battery. Then an engine and a motor cooperate while high speed powering. While high speed powering, fuel consumption is high and decrease of SOC is low, because the railcar is mainly powered by an engine.
4. Verification

The effectiveness of simulator has verified by some experimental test result of prototype diesel-hybrid trains. Fig. 12 shows comparison between the simulation results and the experiment results for a series hybrid shunting locomotive. As for the experiment, a hauling test of a hybrid shunting locomotive was executed while measuring many items, including fuel consumption, exhaust guess, SOC, and so on, with dead weight freight load. Because detail information can be obtained, this experiment is suitable to verify the effectiveness of the developed simulator model. Differences between the simulation results and the experiment results of fuel consumption and NOx emission are within 5%. And SOC has similarly no remarkable difference between the simulation results and the
experiment results. Because SOC of the experiment includes some estimation error, SOC calculation accuracy of the developed simulator is enough for practical use. Additionally the results of some other experiments of hybrid trains have also verified the simulation of speed, SOC, and so on.

![Graph showing comparison between simulation results and experiment results for a series hybrid locomotive](image)

Fig. 12  Comparison between simulation results and experiment results for a series hybrid locomotive

5. Conclusion

The developed train simulator of diesel-hybrid railcars and locomotives can be adapted to various hybrid system configurations. This paper has shown an example of a simulation result. Then the effectiveness of the developed simulator has been verified by the results of many experimental tests.
The developed simulator is effective for the design and evaluation of the hybrid system. It should be added that the simulator employs the running simulation algorithm and the user interface of the train performance calculation system commonly used by Japanese railway operators. The simulator can be easily introduced by railway operators for scheduling train diagrams for hybrid trains.

References