Challenge A: A more and more energy efficient railway

Development of mild hybrid system for diesel railcar

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Hybrid, Diesel railcar, Battery, Regenerative brake

Abstract
Generally in Japan, the diesel railcar used in non-electrified section is powered by diesel engine, and propulsion power is transmitted to wheels by hydraulic transmission. So the diesel railcar cannot use regenerative brake like electric railcar. But the reduction of energy consumption is demanded in late years. We developed mild hybrid system for diesel railcar from the energy transmission efficiency point of view, use regenerative electric power to auxiliary devises. we confirmed the effect of this system both running test and simulation.

1. Introduction
In West Japan Railway Company “JR West”, diesel railcar has one engine per one car. And this engine supplies all energy such as propulsion power, air conditioner and room light. Propulsion power is transmitted to wheels by hydraulic transmission. Conventionally we reduce fuel consumption by adopting multi direct drive stages type transmission. And auxiliary devises such as air conditioner, heater, room light and power supply for control equipment have been droved by electricity in order to standardize to electric railcar, majority in JR West.

How to reduce fuel consumption
In hybrid system we can use two energy resources, engine and battery. We improved energy efficiency while making use of the characteristic of JR west diesel railcar system as follows.
(1)Engine energy which is supplied by mechanical energy is used to propulsion force preferentially. If mechanical energy is converted to electricity, efficiency is not so high.
(2)Regenerative energy which is accumulated to battery by electricity is used to auxiliary devises preferentially. If electricity is converted to propulsion force by motor, efficiency is not so high.
Fig.1 shows an example of the transmission efficiency from two energy resources. We thought that we can improve efficiency by considering transmission efficiency of each energy resources.
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If we use regenerative energy to auxiliary devises, engine load became lighter. So propulsion force is the highest in spite of auxiliary devises running. And it can be accelerated faster and engaging time of engine becomes shorter. Also when stopping at station we can stop engine idling. As a result engaging time of engine became shorter and energy consumption reduces. As we mention above, a way of thinking that using regenerative energy not to propulsion energy but to auxiliary devises to idle reduction is called “mild hybrid”(3).

2. Hybrid System

System configuration
To achieve a thought as we mentioned above, we try to remodel our conventional system of diesel railcar. Fig.2 shows conventional system configuration and hybrid system configuration. Conventional system consists of an engine, a hydraulic transmission, “constant speed unit”CSU” which can take out constant rotational frequency from engine, and three phase alternator. In contrast the hybrid diesel railcar system consists of an engine, a transmission, an induction motor directly connected to engine, a traction inverter, a static inverter and battery. Induction motor serves both as generator and motor for hybrid. This system enables to do the function of the hybrid systems such as regenerative brakes, idle reduction, auxiliary power supply, and motor assist in power running. In addition, because induction motor directly connected to engine, we can start an engine by using battery electricity, traction inverter and induction motor. As a result this hybrid system can omit a cell motor and battery for start engine.

(a) Conventional system

(b) Hybrid system
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Characteristics of the system

(1) Simple and compact
Because we unify the motor for hybrid system and the generator for auxiliary devises, availability is high and additional machinery is little. In addition, battery capacity may be small because input/output electricity power to battery is not so high.

(2) High efficiency
Comparing this hybrid system with conventional auxiliary generating system, efficiency of generation improves because of inverter. In addition, we can do idle reduction for a long time because we do not need to use regenerative energy to propulsion energy.

(3) High reliability
Even if battery is not available, this system can generate auxiliary power. So we can run this system as a conventional diesel railcar.

3. Typical operation mode
Hybrid system needs to control engine and motor according to state of car condition and to state of charge of battery. Therefore we categorize state of car to 4 modes, stopping, acceleration, coasting and deceleration. Basic operation mode of system is as follows.

(1) Stopping mode (Fig.3)
Engine: Idle reduction.
Motor: No generation.
Battery: Electricity power supply to auxiliary devises.

(2) Acceleration mode (Fig.4)
Engine: Power supply to propulsion.
Motor: No generation. If necessary motor act as assist motor to reduce noise and exhaust gas for example start at station.
Battery: Electricity power supply to auxiliary devises.
(3) Coasting mode (Fig.5)
Engine: Idle
Motor: Generate to auxiliary power supply.
Battery: If necessary electricity power supply to auxiliary devises.

(4) Deceleration mode (Fig.6)
Engine: Direct connect to wheel for regenerative brake.
Motor: Full power generation to regenerative brake.
Battery: Charge regenerative electric power.

4. Test run
In order to test functions of hybrid system and to estimate the effect of the system, we produce prototype model such as inverter, induction motor and battery. And we mounted these products on test car and carry out test run.

Outline of test run
(1) Test run term: Nov/2009 to Dec/2009
(2) Test run section: From Yonago station to Yasugi station at San-in line.
(3) Bench test: Charging battery test, Idle reduction test
(4) Running test in workshop:
  Performance of acceleration and deceleration
  Function of regenerative brake
  Operation mode control
(5) Running test in San-in line:
  Electro-pneumatic co-operation brake test
  Measurement of fuel consumption
(6) Spec of prototype model:
  Induction motor 120kW (Photo.3)
  Lithium-ion Battery 600V-30Ah (Photo.4)
(7) Weight of train: 2ton heavier than conventional diesel railcar
  (Conventional diesel railcar is about 40 ton.)
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Condition of test run is shown in Chart 1. "Ordinary generation" is same as conventional diesel railcar. In this mode motor supply axially devise with electric power. Battery current is 0A.

In "Axially power assist" mode, battery supply axially devise with electric power. Motor current is 0A.

Test number 1 is “assumption of CSU”. In this test we try to estimate influence of weight increase by hybrid system devises such as battery, inverter and converter. So generation load of engine is adjusted to conventional “constant speed unit” generation system. In this test battery is charged little by little because efficiency of generation is better than “constant speed unit”.

Test number 2 is “ordinary generation”. In this test we try to estimate effect of inverter generation system, efficiency of generation is better than conventional “constant speed unit” generation system. In this test battery is not charged because generated electricity is equal to axially devise.

Test number 3 is “Axially power assist”. In this test we try to estimate effect of hybrid system by using “Axially power assist”, regenerative brakes and idle reduction.

<table>
<thead>
<tr>
<th>No.</th>
<th>Test name</th>
<th>Estimation</th>
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<th>Deceleration</th>
<th>Stopping</th>
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<td>Ordinary generation</td>
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<td>Influence of weight increase</td>
<td>Generation equal to CSU load</td>
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<td>Effect of inverter generation</td>
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<td>Regenerative brake</td>
<td>Idle reduction</td>
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Test result

Fig. 7 shows result of test run of a round trip between Yonago station and Yasugi station.
In test number 1, fuel consumption increase about 5% compared to conventional diesel railcar. This is considered influence of weight increase by hybrid system devises.
In test number 2, fuel consumption decrease about 3% compared to conventional diesel railcar. This is considered effect of improvement of efficiency of generation by using inverter.
In test number 3, fuel consumption decrease about 24% compared to conventional diesel railcar. It is considered effect of load reduction of engine and effect of idle reduction of engine. However, in this test, state of charge of battery decrease after running, because regenerative electricity is not sufficient to axially power assist and idle reduction. So it may be said that fuel consumption decrease by using battery energy instead of using fuel.

5. Running simulation

Test run is an estimate only from Yonago station to Yasugi station at San-in line. Furthermore, regenerative electricity is not sufficient to supply axially power and battery energy has the imbalance. Therefore test run is not really estimate the general effect of this hybrid system. For this reason we estimate it by using “diesel hybrid simulator” (4). This simulator has been developed by “Railway Technical Research Institute RTRI”.

First we configure the parameter of simulation based on test run result, and we run the simulation which is same condition as test run. As a result, simulation result became approximately same as test run, and validity of the simulator is confirmed.
Next we run the simulation to estimate the general effect of this hybrid system when battery
energy is balanced.

**Condition of simulation**
Section: from Himeji station to Kouzuki station at Kisin line (Ordinary line in JR West)
Distance: About 50km
Time: About 1 hour
Spec of devise: Induction motor 200kW
Lithium-ion Battery 600V-30Ah
Weight of train: 2 ton heavier than conventional diesel railcar.
(Conventional diesel railcar is about 40 ton)
State of charge of battery is less than 1 % difference between start and after running.

**Simulation result**
Fig.8 shows running simulation result. Hybrid diesel railcar accelerates faster than conventional diesel railcar especially high speed area. This is due to “Axially power assist”, which reduce engine load and performance of railcar is improved. Moreover, when stopping at stations, hybrid diesel railcar can stop engine. As a result fuel consumption of hybrid diesel railcar is less than conventional diesel railcar about 12%.

![Fig.8 Simulation result between Himeji station and Kouzuki station](image)

**6. Conclusion**
We developed mild hybrid system from the energy transmission efficiency point of view, use regenerative electric power to auxiliary devises. This hybrid system consists of an engine, a hydraulic transmission, an induction motor directly connected to engine, a traction inverter, a
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Static inverter and battery. In order to test functions of hybrid system and to estimate the effect of the system, we produce prototype model and carry out test run. By using “diesel hybrid simulator”, we estimate the general effect of this hybrid system. As a result of simulation fuel consumption of hybrid diesel railcar is less than conventional diesel railcar about 12%.

References