Predicting Energy-Saving Effects with the Train Operation Power Simulator

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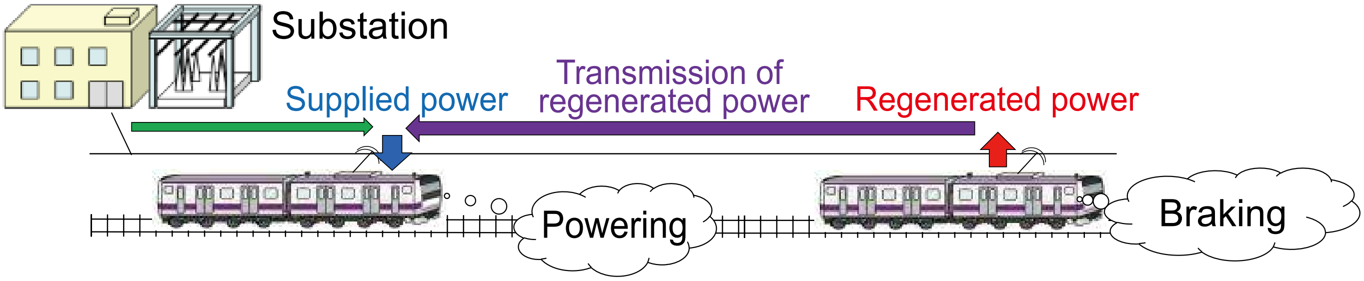
RTRI developed the Train Operation Power Simulator to calculate energy consumption by DC-fed train operation and predict the effects of energy-saving technologies for railways. This simulator closely reproduces average-realistic train driving profiles based on statistical data and train timetables. The results have been verified in terms of energy consumption for air-conditioning corresponding to outdoor temperatures. By considering important factors, we have used this simulator to examine the effects of energy-saving technologies for railways. This article describes examples of predicting energy-saving effects by introducing energy storage systems and energy-saving trains.

Introduction

Since the trains of electrified railways are operated with the electric power supplied via overhead contact line systems (OCS) or third rails, railway operators have been implementing measures to reduce energy consumption in train operations. One of the major efforts is to introduce onboard traction control system with regenerative brake function. During regenerative braking, motors are used as power generators when the brakes are applied, and the generated power is sent back to contact lines. In recent years, a variety of energy-saving technologies have been developed to use regenerative braking efficiently. In addition to regenerative braking, railway operators have changed improved the efficiency of on-board devices and/or the configuration of power supply facilities to reduce electrical resistance.

Given a limited budget, it is necessary to choose efficient measures among these energy-saving technologies. However, the cost-effectiveness varies depending on the technologies. The difficulty in introducing energy-saving technologies is that the effects vary depending on the locations of power supply facilities and the features of the lines. If technologies with the same specifications are introduced, more efficient ways of introduction are required. And, as is explained later, if higher-performance new vehicles are introduced to revenue services, it is possible to shorten running time as well as to save energy. Thus, it will also be important to examine the effects from different viewpoints as well as energy-saving when predicting the effects of



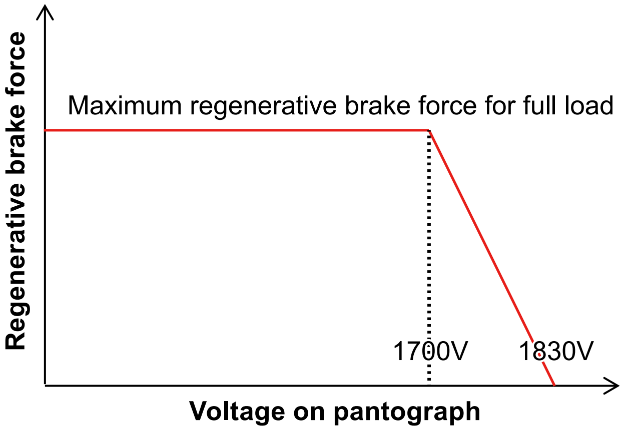
Transmission of regenerated power

introducing energy-saving technologies. For this purpose, RTRI developed the Train Operation Power Simulator to predict the energy consumption by the operation of a large number of trains in wide areas. This article explains the energy-saving technology with regenerative braking and describes the mechanism of the Train Operation Power Simulator with examples of predicting the effects of introducing energy-saving technologies.

Energy-saving technologies with regenerative braking

Transmission of regenerated power shows the power generated by regenerative braking is sent back to contact lines and used effectively by another train running close by. However, if other trains are not close by or braking is required according to geographical conditions such as curves and slopes, regenerative braking cannot be used effectively. Generally DC-fed trains have function of reducing regenerative brake effort as shown in *Controlling restriction of regenerative braking* not to exceed the limit of the maximum contact line voltage and mechanical brake takes the required braking effort over. Further energy-saving will be attained by avoiding such regenerative brake force reduction.

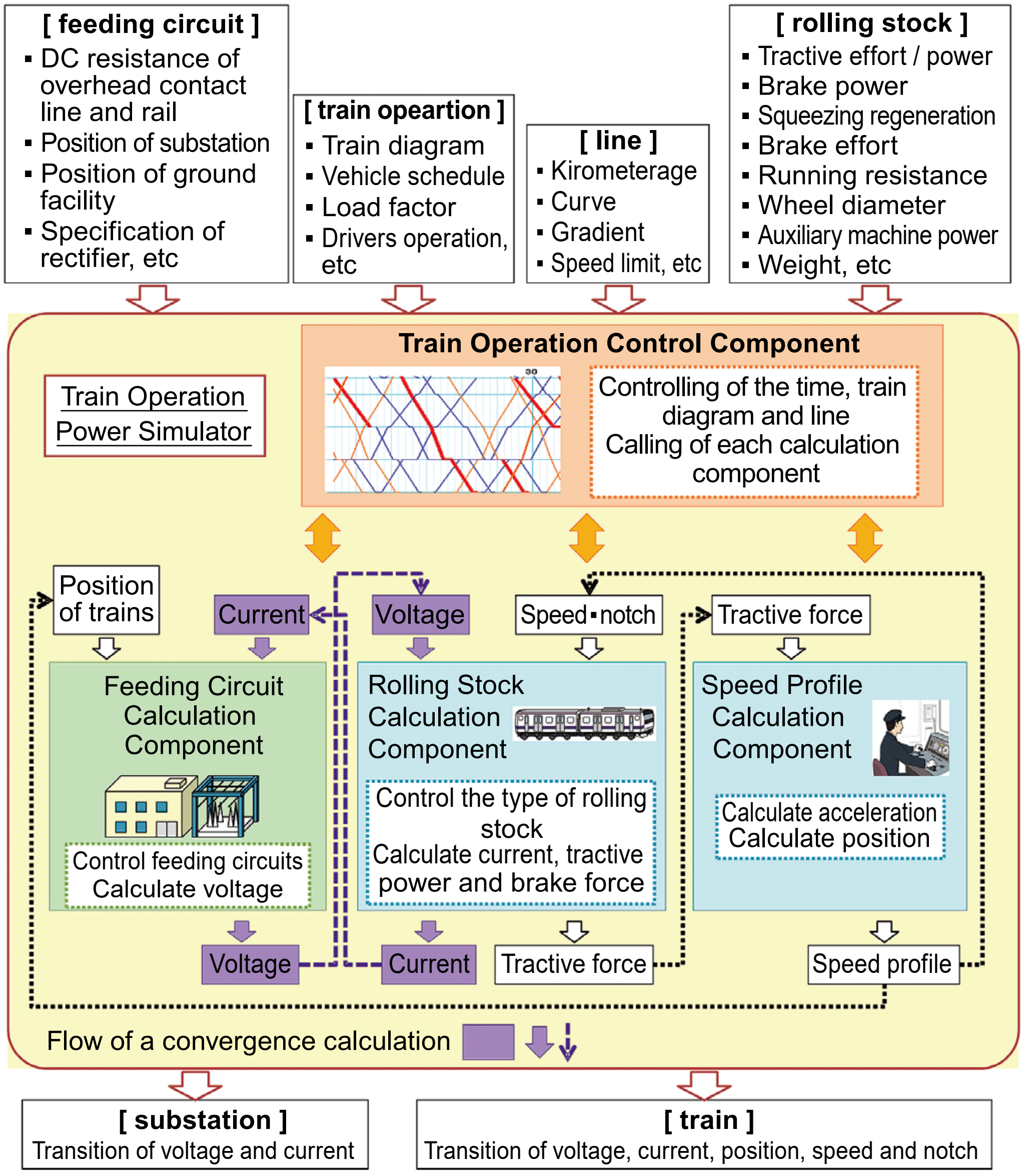
Among the efforts to improve the effectiveness of regenerative braking, some railway operators have installed stationary energy storage systems to reuse the energy in or regenerative inverters to send regenerated power at auxiliaries such as escalators and lighting in stations. The Train Operation Power Simulator has been developed with particular focus on controlling power regeneration and is capable of predicting the effects of energy-saving technologies.



Controlling restriction of regenerative braking

Mechanism of Train Operation Power Simulator

The Train Operation Power Simulator simulates train operation of DC railways and calculates energy consumption (*Functions and configuration of Train Operation Power Simulator*)$^{1)}$. Its train operation control component calls a calculation program to start trains according to a train timetable. The speed profile calculation component develops speed profiles for the operating trains. The component solves the equation of motion with the tractive force calculated by the rolling stock calculation component. It determines the driving status of the train among powering, coasting, or braking, and develops speed profiles. The tractive force varies depending on the catenary voltage and is calculated by the feeding circuit



Functions and configuration of Train Operation Power Simulator

calculation component. Catenary voltage is calculated by solving the equation of the feeding circuit, but changes depending upon train positions, that is, train timetable and speed profile. It means that catenary voltage, tractive force, and speed profile depend on one another. The speed profile is recalculated at each time step based on the catenary voltage.

One of the functions of the Train Operation Power Simulator is to provide speed profiles for energy consumption estimation (*Creating a speed profile for energy consumption estimation*). Since speed profiles have significant impacts on the calculation of energy consumption, we have refined this function to simulate actual train running based designated running time as accurately as possible based specified running time[2]. When the speed profile for energy consumption estimation is developed, coasting is inserted for the shortest running time and the profile for specified running time is completed.

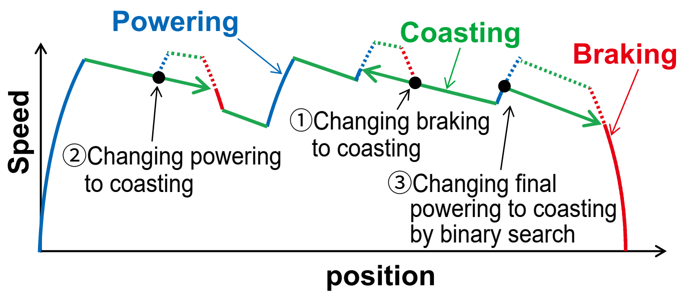
The power to operate trains is divided into traction circuit power to accelerate and decelerate trains and auxiliary circuit power for cabin lighting and air-conditioning. Since the power load for air-conditioning fluctuates significantly depending on the seasons, seasonal adjustment is necessary when calculating it. *Auxiliary power load depending on outdoor temperatures* shows an example of seasonal fluctuation of auxiliary power. As the dots plotted in *Auxiliary power load depending on outdoor temperatures* indicate, more auxiliary circuit power is used for heating in cold seasons and for cooling in hot seasons. To adjust this fluctuation, the simulator sets the fluctuation pattern of auxiliary circuit power as is shown with the orange-colored line.

The Train Operation Power Simulator has been verified through numerous test measurements[3]. Here, an example of predicting daytime energy consumption at a substation is shown. Since the energy consumption at substations also fluctuates due to changing air-conditioning power load, the measurement was continued over total a year and used as data for verification.

Verified energy consumption depending on outdoor temperatures shows the results. Although measurement results fluctuate due to reasons different from changing outdoor temperatures, the distribution of calculation results is similar to average measured values. Thus, Train Operation Power Simulator can predict the energy consumption of train operations.

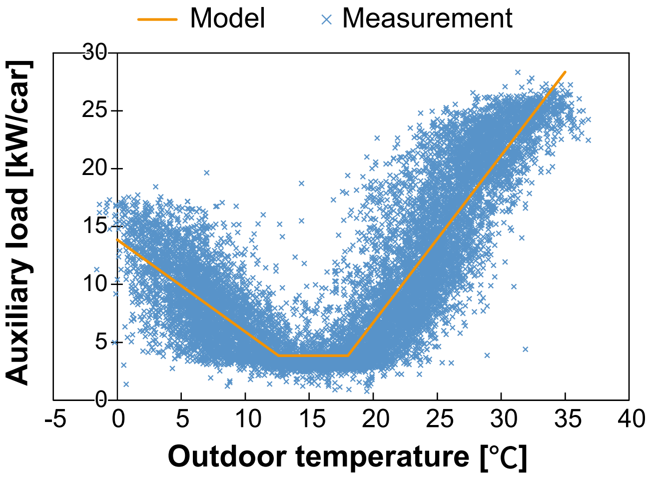
Energy-saving effects of energy storage systems

An example of predicting the energy-saving effects of an energy storage system to store regenerated power is described here. It is known that regeneration restriction is likely to occur in spring and fall when the air-conditioning power load is small. Therefore, the energy storage systems controlling regeneration restriction

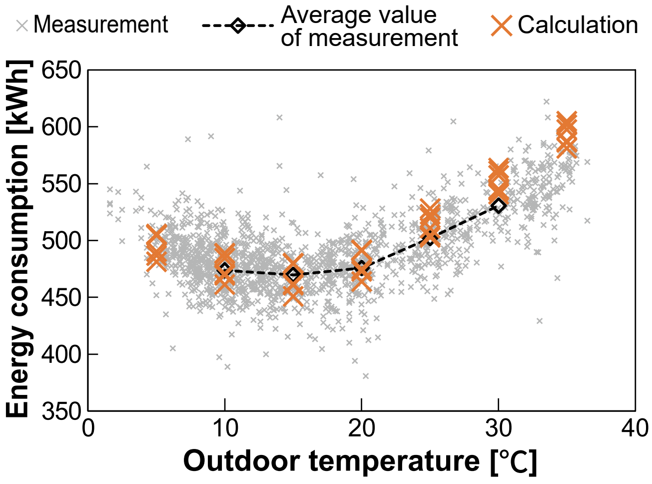


＊After the shortest speed profile (dotted line) has been created, a speed profile for energy consumption estimation (solid line) is created by inserting coasting lines one by one to meet the designated running time.

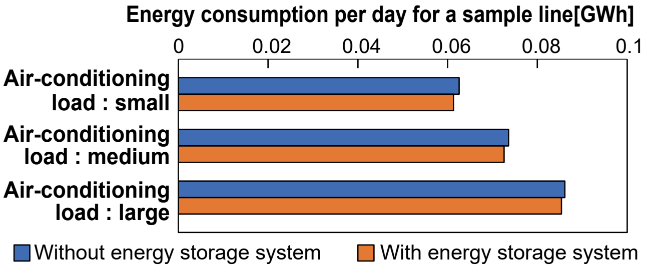
Creating a speed profile for energy consumption estimation



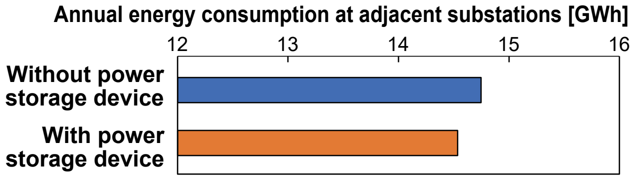
Auxiliary power load depending on outdoor temperatures



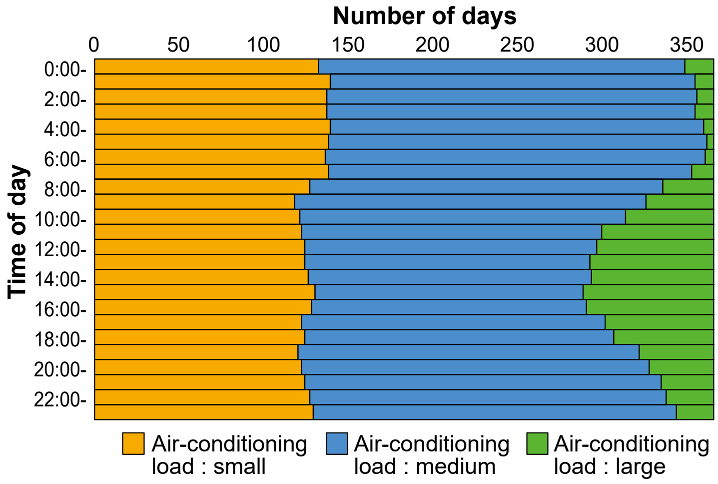
Verified energy consumption depending on outdoor temperatures



Energy consumption by air-conditioning power load



Energy consumption at substations with or without power storage device



Number of days for each air-conditioning load

have larger impacts on energy-saving by preventing regeneration restriction in spring and fall, but smaller impacts in summer and winter. Thus, seasonal fluctuation in air-conditioning power load needs to be considered when the effects of energy storage systems are estimated. RTRI has simulated several patterns of fluctuation according to air-conditioning load and calculated energy consumption for each pattern (*Energy consumption by air-conditioning power load*).

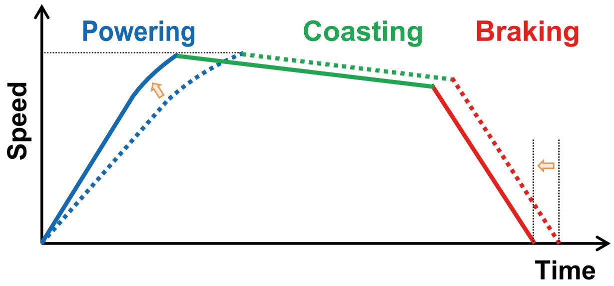
In this example, air-conditioning power loads are divided into three patterns and daily energy consumption for each pattern is calculated. Then the numbers of days in a year for each pattern are calculated based on the outdoor temperature data obtained from the database of the Japan Meteorological Agency (*Number of days for each air-conditioning load*). In the example here, similar air-conditioning load has been identified on an hourly basis using the outdoor temperature data for one year. Then annual energy consumption is predicted by multiplying daily energy consumption in each air-conditioning pattern by the number of days (*Energy consumption at substations with or without power storage device*).

Energy-saving effects of new types of vehicles

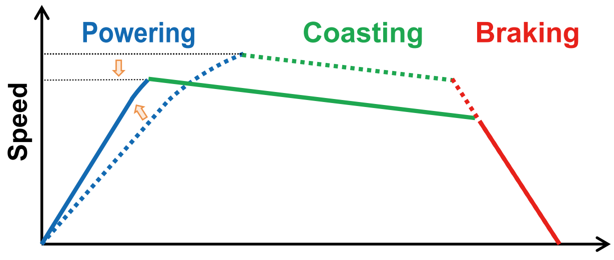
The next example shows prediction of energy-saving effects of new types of vehicles equipped with energy-saving motors and inverters. In general, since the weight and tractive effort are different between the new types of vehicles and existing ones, their accelerations are also different. This example shows energy-saving effects and reduced running time by introducing new vehicles with significantly improved acceleration.

There are two running patterns for the vehicles having high-acceleration performance. One is reducing running time by improved acceleration (*Running pattern for improved acceleration (a)*). The other is increasing coasting time by quickly accelerating and shifting to coasting earlier (*Running pattern for improved acceleration (b)*). In the latter pattern, if the running time is unchanged, coasting can be started at lower speeds, which leads to reduced energy consumption. Therefore, if the acceleration performance of vehicles is changed, it is necessary to estimate the energy consumption under proper running patterns. If energy-saving devices are installed on the new types of vehicles, further energy-saving benefits from vehicle equipment with improved efficiency can be expected. Both energy-saving effects by the changed running patterns and energy-efficient equipment need to be accurately estimated.

The energy-saving effects of new types of vehicles have been estimated under different conditions. We have compared the cases where a new type of vehicle runs in the same running time as an existing vehicle and where it runs for a shorter running time. For the same running time,



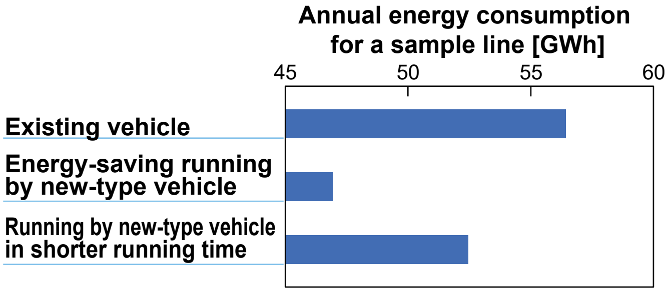
(a) Running in shorter running time



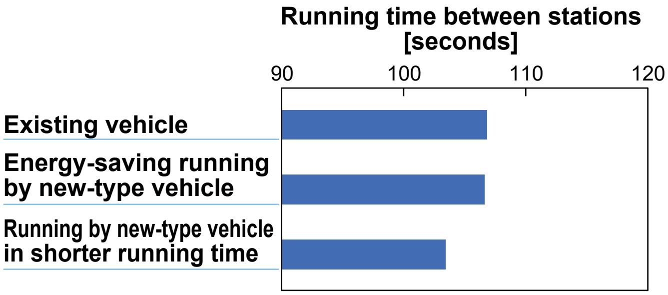
(b) Energy-saving running

(Solid line: new-type vehicle , broken line: existing vehicle)

Running pattern for improved acceleration



Difference in energy consumption by vehicle type



Difference in running time by vehicle type

the function of the speed-profile for energy consumption estimation sets the running pattern according to the current train timetable. The results are shown in *Difference in energy consumption by vehicle type* and *Difference in running time by vehicle type*. Difference in energy consumption by vehicle type shows total energy consumption, and Difference in running time by vehicle type shows running time for one section between stations. The energy consumption of the new type of vehicle is reduced when the running time is shortened in this example. However, the energy-saving effect is larger if it runs for the same running time. As is indicated by this example, improved acceleration performance contributes to shortening running time as well as to reducing energy consumption.

Conclusion

This article has introduced the method to predict the effects of energy-saving technologies using the Train Operation Power Simulator. We will continue the research into effective ways of introducing these technologies by evaluating their effects with this method.

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References

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