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# Predictive Vehicle Control with Geographic Information

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## Abstract

The controller designed to maximize the fuel economy of hybrid truck in expressway driving is introduced. It optimizes discharging power according to the predictive road information and minimizes thermal losses.

*Keywords: lithium battery, state of charge, GPS, HEV (hybrid electric vehicle), power management, regenerative braking.*

## 1 Background

In recent years, reduction of $CO_2$ emission is required since it causes environmental problems such as global warming. And furthermore, reduction of the fuel consumption, as well as $CO_2$ emission, is particularly required from the viewpoint of transportation cost reduction in commercial vehicles. Our company launched the world's first hybrid bus in 1991, and it achieved $CO_2$ emission reduction and fuel economy improvement as compared with conventional diesel buses. Since then, the hybrid technologies have been refined in every model change.

Development of HEV heavy-duty truck is considered to be the effective way to reduce $CO_2$, because heavy duty trucks are dominantly contributing to total amount of $CO_2$ emission from commercial vehicles as shown in Figure1. That's why we have been working on the development of HEV heavy-duty trucks.

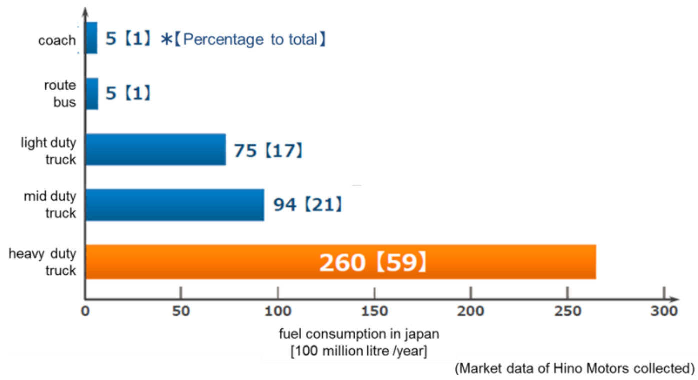


Figure1: Domestic fuel consumption of commercial vehicle

Light duty trucks and route buses which we have developed so far, are mainly used on general roads. HV control in general roads is shown in Figure2【General road】. In this case, regenerative energy is obtained from vehicle’s kinetic energy in deceleration. On the other hand, heavy-duty trucks, are mainly used in expressways, where the frequency of acceleration and deceleration occurrence is very low. So they regenerate energy not from kinetic energy in deceleration but from their own potential energy at downward slopes. In expressways is shown in Figure2【Expressway】.

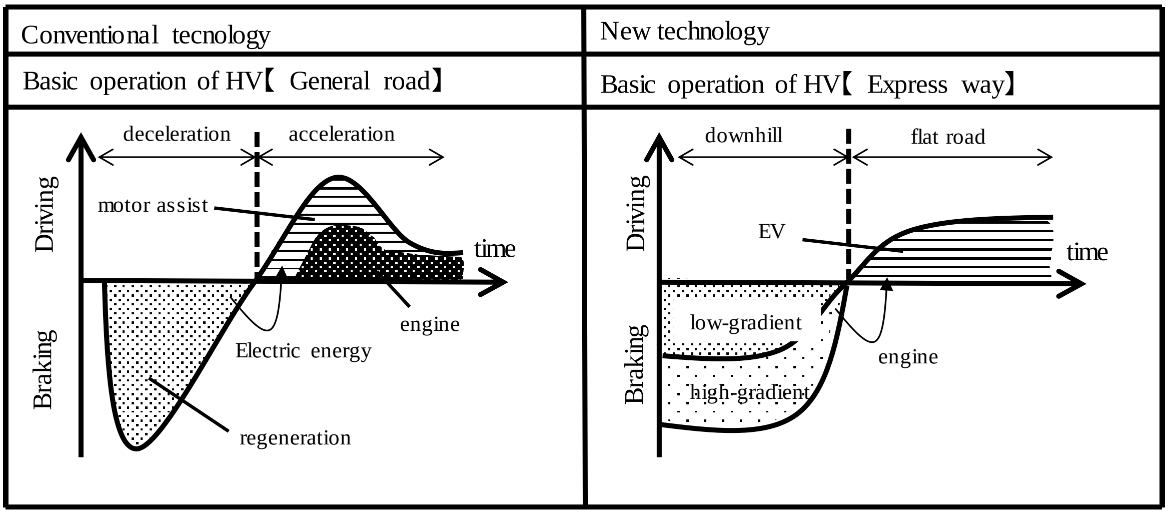


Figure2: Energy regeneration

This kind of regeneration supplies large amount of energy and it continues for a long time and distance, so the battery can easily be fulfilled from empty state in only one regeneration period. This means that battery SOC(State of Charge) should be adjusted at low level in advance and secure the capacity for forthcoming regeneration in order to avoid the waste of potential energy. (Figure3)

In the case that the distance to forthcoming regeneration period or amount of energy which the vehicle can obtain at the period are unknown, SOC has to be maintained at low level constantly by aggressive discharging. But high-rate discharge causes the energy losses by increasing heat generation in high voltage circuit including battery, motor, electric cables and etc. : regeneration energy recovery and heat generation are in trade-off relationship.

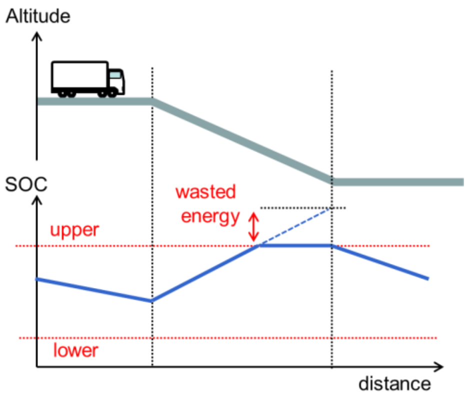


Figure3: Waste of potential energy

## 2 Introduction of locator

The device called locator contains the GPS antenna, gyro sensor, and road map database, and it has functions to identify its present position and generate geographic information around it from its database. With this device, altitude values from present point to 100km ahead along roads can be obtained, and it becomes possible to predict the change of vehicle's potential energy: amount of energy which the vehicle obtains or loses with obtained altitude values and vehicle information like mass, speed, and running resistance coefficients, and the battery capacity which have to be secured, which means the energy need to be consumed at least before arriving at the entrance of regeneration period to avoid the waste of potential energy can be calculated.

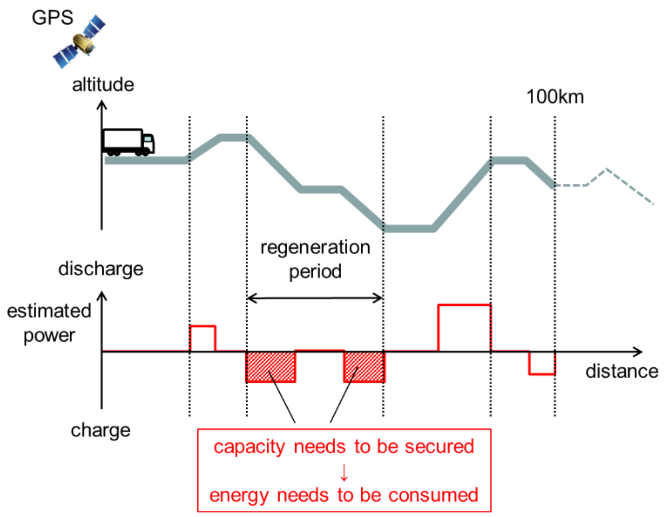


Figure4: Energy estimation with locator

## 3 Strategy

Generally, amount of heat generation in the circuit is proportional to average of squared current which flows in the circuit, and this can be expressed as the summation of square of average current, expressed as $(I_{ave})^2$ and rest, expressed as $(I_{\sigma})^2$. $(I_{ave})^2$ represents heat which is originated from DC components of current and $(I_{\sigma})^2$ represents heat originated from AC component. AC component depends on the dispersion of current distribution, and it becomes zero when current is completely constant.

$$P_{heat} \propto I^2{}_{ave} = (I_{ave})^2 + (I_{\sigma})^2 \qquad (1)$$

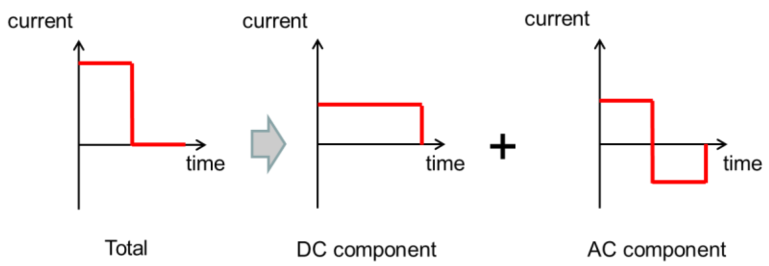


Figure5: Current divided into AC/DC components

DC component cannot be reduced because it is proportional to the amount of energy with which the battery supplies the vehicle as traction force and affects the fuel economy directly. In contrast, AC component is erasable because it doesn't affect the amount of traction energy supply at all.

Therefore, the controller is designed to minimize AC component without affecting DC components of current by making the current profile as constant as possible with information obtained from the locator. As shown in Figure6, ideal current for heat loss can be calculated with C: energy needs to be consumed and T: time to the entrance of regeneration period.

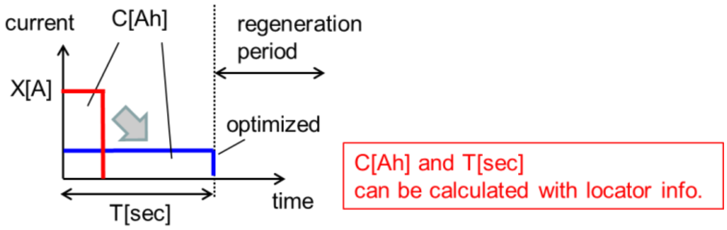


Figure6: Current optimization

# 4 Hybrid system

Basic structure of hybrid system is shown in Figure7. In this parallel hybrid system, the diesel engine, the clutch, the motor/generator and the transmission are arranged coaxially. And this system contains battery which powers the hybrid system, inverter, Hybrid Vehicle ECU(HVECU) which controls the hybrid system, and in addition, locator ECU which enables predictive vehicle control with geographic information. HVECU gets altitude profile from the locator ECU by CAN communication, and controls motor power according to obtained altitude profile.

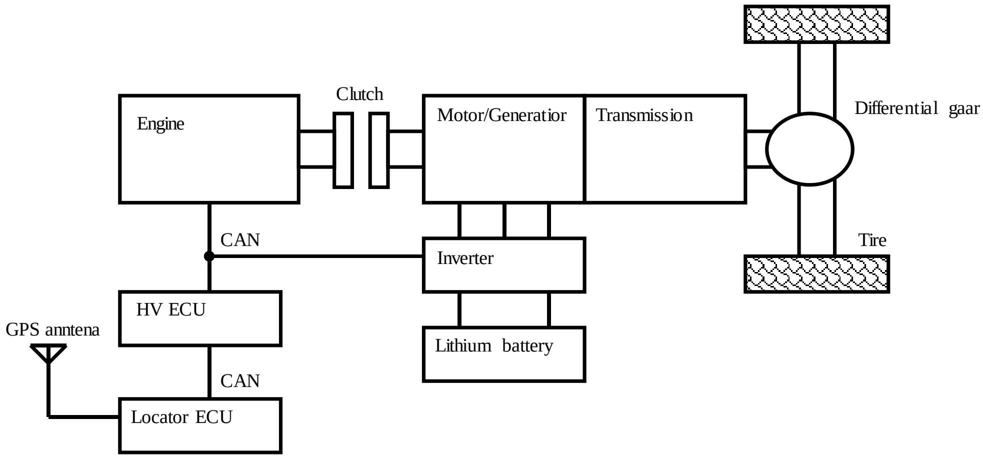


Figure7: Components of HV system

# 5 Algorithm Design

Ideal performance described above can be realized by following processes.

step1. Estimation of actual SOC

Estimate SOC profile in the period from present point to 100km ahead with altitude values obtained from locator and vehicle specifications. SOC can be calculated as integral of battery current which is roughly proportional to battery power. Battery power is calculated as shown in Figure8. Battery power depends on the power the vehicle generates or regenerates. According to the energy conservation law, it has to be equal to the derivative of vehicle's energy expressed as the summation of kinetic and potential energy. In expressway, vehicle speed hardly changes, so derivative of kinetic energy can be estimated to be zero. The derivative of potential energy (dEp/dt) can be calculated as the product of the derivative of altitude(dh/dt), mass, and gravitational acceleration, and the derivative of Altitude can be calculated as the product of slope and speed. When calculate the battery power from dEp/dt, power loss caused by running resistance and charge and discharge power limit set by HV system has to be considered.

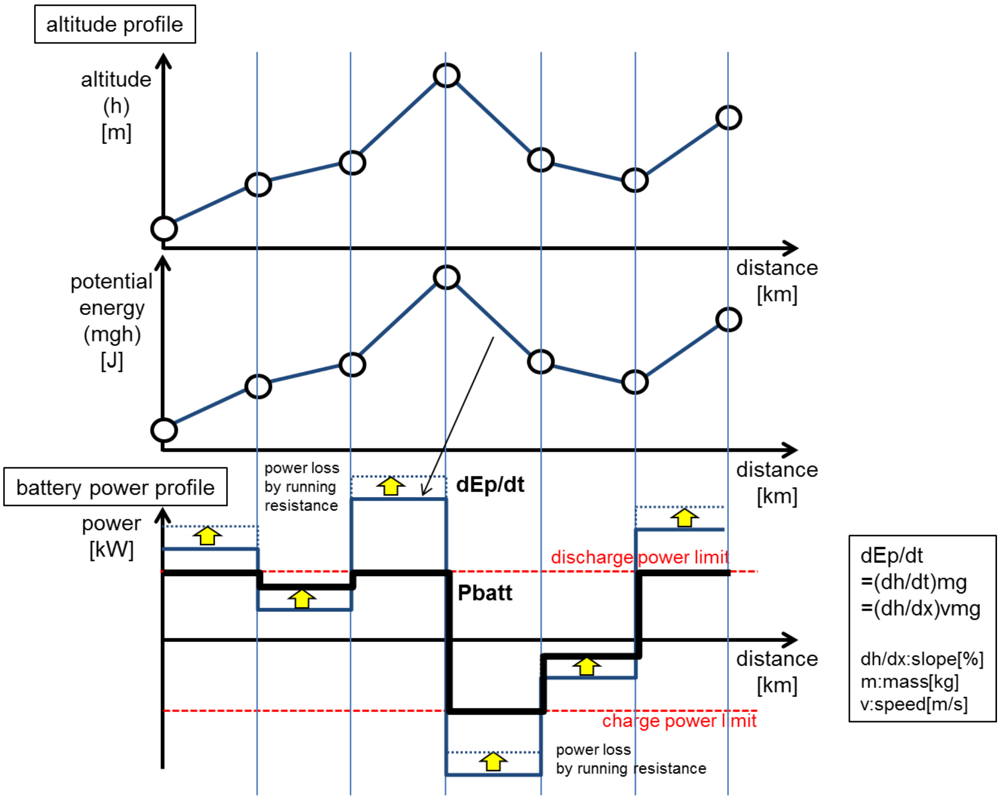


Figure8: Battery power calculation from altitude profile

step2. Extraction of target period

Extract target period which satisfies two conditions below.

(1) SOC gets empty

(2) Target period has regeneration period where SOC gets full right after that

step3. Definition of target SOC

Calculate the ideal current in target period. Ideal current is equal to the lowest current which can consume the same energy amount as original value in constant current mode. And then draw SOC profile by integrating calculated current as target SOC.

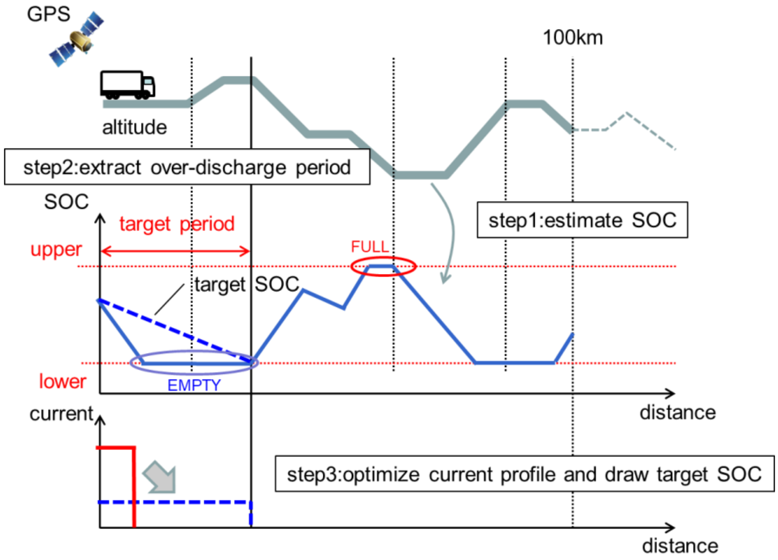


Figure9: Locator application for current optimization

step4. SOC control

The block diagram for SOC control is shown in Figure10. This controls actual SOC to trace target SOC by adjusting discharge power limitation by feedback-feedforward combined system. Feedback term is calculated based on the proportional control, and feedforward term is calculated to be the derivative of target SOC. The final direction to the vehicle from controller is done in the dimension of torque, so the controller has another feedback system, indicated at bottom of Figure10, to transform power limitation into torque direction.

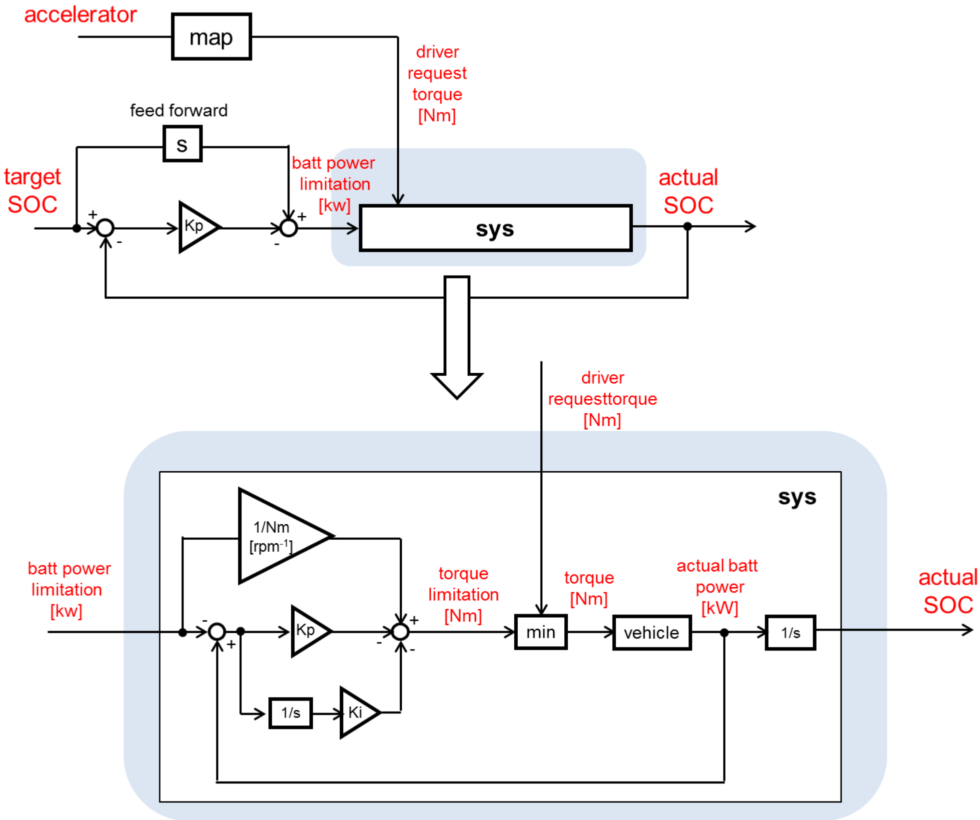


Figure10: Block diagram for SOC control

# 6 Experiment

Evaluate the effect on fuel consumption and current profile in following test condition.

## 6.1 Test condition

Test condition is shown in Table1.

Table1: Test condition

| | |
|---|---|
| **Test vehicle** | **HINO700sries HV** |
| **GVW** | 25,000kg |
| **Route** | Tomei expressway(Atsugi-Yaizu) |
| **Distance** | 140km |
| **Set speed** | 80km/h |

## 6.2 Result

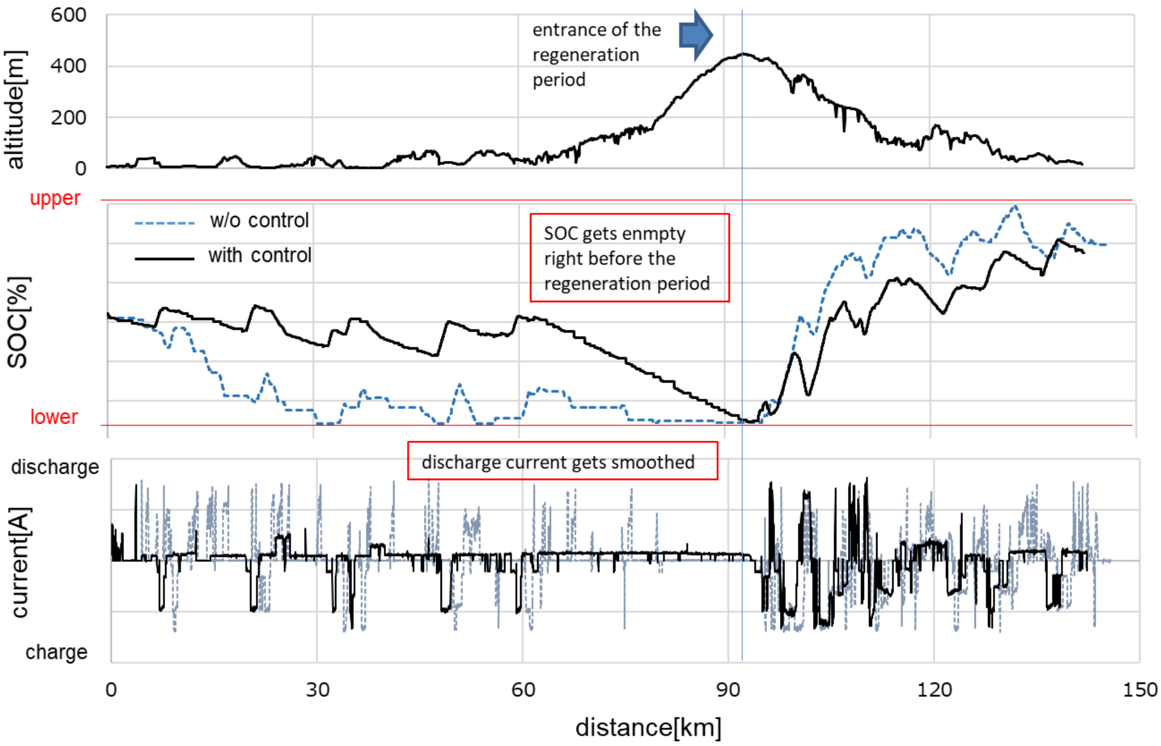


Figure11: Current optimization at actual vehicle test

As shown in Figure11, current was controlled as expected.

Heat generation in discharge was reduced by 56%.

Fuel efficiency was improved by 2.7%

## 7 Conclusion

The controller which optimizes the fuel economy of heavy duty hybrid vehicle in expressway driving was introduced. It realized the improvement of fuel economy by 2.7% by reducing heat generation caused by AC component of current with predictive geographical information from locator.

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