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Optimization Method of Power-Split Hybrid Electric Vehicle Considering Moment of Inertia of PSD

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Summary

In this paper, we propose an optimization method to evaluate the actual fuel efficiency of Power-Split(PS) type hybrid vehicles(HEV) using Dynamic Programming(DP) considering dynamic characteristics of engine and motor speed changes. Frequent speed changes in HEV's engines and motors cause energy loss and adversely affect drivability. Therefore, by adding the number of cases of gear ratios to the DP-based optimization, the engine and motor behave similarly to the actual physical situation with no penalty. In addition, the optimization is ensured by reflecting errors in the problem of dividing the grid in DP. The simulator developed through this optimization method is useful for setting target values for improving the fuel efficiency of PS type HEV.

Keywords: Power-Split HEV, global optimization, dynamic programming, battery SOC, energy consumption

1 Introduction

PS type HEV has the advantages of both parallel type and series type HEV. Since the engine and wheels rotate independently, the PS type HEV has the potential to achieve high fuel efficiency through torque and speed control of the engine. However, due to the variety of possibilities, the engine is more difficult to control. Therefore, optimal control is necessary to realize the maximum fuel efficiency of PS type HEV.

The result of the optimization using the DP shows the best fuel economy as a reference value and can be used to set a target for improving the fuel economy of the vehicle.[1] However, to apply the target value to the actual vehicle, the DP solution must be realistic. To make the DP solution realistic, methods were developed to take into account the transient state of the HEV (mode change, gear ratio change, torque change). T. Miro-Padovani *et al.* proposed to reflect the transient state by imposing a penalty on the gear shift of the Parallel type HEV.[2] However, optimization is not guaranteed because the result varies with penalty values. In addition, the PS type HEV can be continuously shifted, so it is difficult to impose a penalty on the gear ratio change.

In this paper, we propose a method that guarantees optimization even if the gear ratio of PS type HEV changes. Engines and motors can act as batteries because they can output and store energy in the form of kinetic energy when the speed changes. This means that the number of cases for speed change should be considered. This is solved by adding the number of cases for the planetary gear ratio.

In addition, the error caused by DP quantization is considered. R. Wang and S.M. Lukic said that accuracy should be sacrificed if the calculated value does not fit the grid point due to quantization of the state of charge (SOC), and this error can be ignored if the SOC increment is small.[3] However, because DP is a global optimization method, it creates a path solution that vibrates unrealistically to obtain the path gain caused by error. To prevent unrealistic path vibrations, the DP's error must be reflected. The problem is solved by accumulating the error and reflecting it on the SOC grid.

Considering the dynamic characteristics of the engine and motor speed changes, the optimization result is applicable to the actual vehicle, and the error is reflected to ensure the optimization. The proposed DP solution is more realistic and more useful for setting the target fuel economy of the vehicle.

2 Optimization method

2.1 Dimension to account for gear ratio changes

DP deals with the situation where decisions are made at each stage. Therefore, in order to ensure optimization in consideration of gear ratios at each stage, information about each gear ratio must be stored so that the number of cases can be considered. This can be solved by adding new axis to DP that used only SOC and time axis and saving information about each gear ratio. Figure 1 shows a DP model with an additional gear ratio axis.

To control the engine, speed and torque must be controlled. The gear ratio axis preserves the number of cases for the engine speed, and the SOC axis preserves the number of cases for the engine torque. When the gear ratio changes, the engine and motor release or absorb kinetic energy. The energy generated causes losses through the energy conversion efficiency of the engine and motor. DP uses this loss as a penalty to find the optimal solution. As a result, the solution shows the changes applicable to real vehicles.

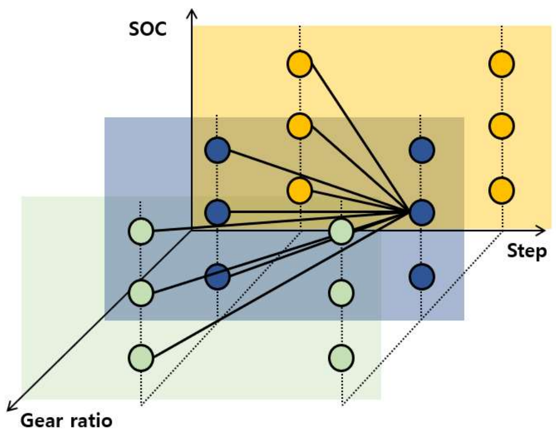

Figure1: DP model with added gear ratio dimension

2.2 Error reflection through accumulation

In Figure 1, when the gear ratio is fixed, a change in the SOC grid represents a discharge or charging of battery power. In DP this value is quantized according to the SOC increment. When the engine is on, no errors occur because the engine's power can be adjusted so that the battery power values match the grid values. When the engine is off, an error is generated because the battery power cannot fit perfectly in the grid. Ignoring the error, the information is stored in the nearest grid, as shown in Figures 2 and 3. As can be seen in Figure 2, the power of the battery used in the DP shows less discharge by error than the actual calculated value. Figure 3 shows the battery charging slightly more than the actual calculated value. If the error is not taken into account, the DP solution changes the gear ratio and derives the type shown in Figure 2 and Figure 3 to obtain the gain from the error. As a result, the DP solution shows an unrealistic change in gear ratio, which is more severe with higher SOC increments.

In this paper, the error values generated at each step are accumulated. If the accumulated value is greater than half of the quantized value, the accumulated value is included in the battery power and reflected in the battery grid. This eliminates the unrealistic vibration of the gear ratio and ensures optimization by reflecting errors.

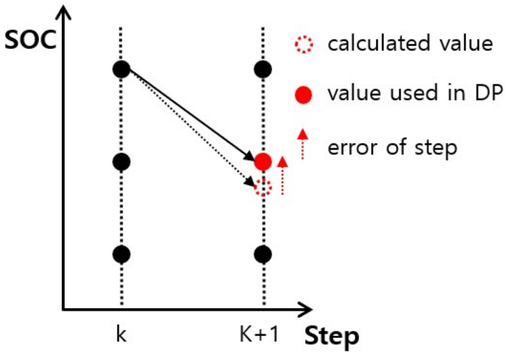

Figure:2 Grid change during battery discharge

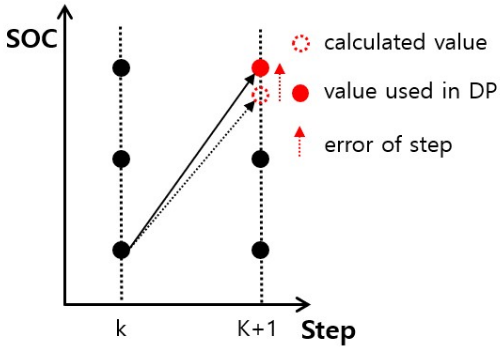

Figure:3 Grid change during battery charge

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