

Control Strategy of Integrated Starter and Generator for Fuel Economy in Parallel Hybrid Electric Vehicles

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Summary

Integrated starter and generator (ISG) is a type of electric machine that is usually linked to an internal combustion engine (ICE) mechanically and it conducts important roles for powertrain transient controls in parallel hybrid electric vehicle (HEV) such as engine start, stop, and so on. Especially, in HEV configuration with a clutch for connecting/disconnecting the engine, ISG control is one of the most important issues for better fuel economy in the EV/HEV mode transition. This paper introduces control aspects of ISG in detail and discusses ISG control strategies for better mileage in parallel HEVs

Keywords: integrated starter and generator (ISG), fuel economy, control, hybrid electric vehicle (HEV)

1 Introduction

ISG is a sort of electric machine, which is mechanically connected to ICE, and has important roles such as EV/HEV mode transition, engine-cranking and high battery voltage charge, etc. [1, 2] HEV can have frequent engine on/off events regarding driver's demand and driving environment. Especially, in the HEV configuration with a clutch (See Figure 1) for connecting/disconnecting the engine [2], ISG control is one of the most important issues for better fuel economy in the EV/HEV mode transition [3]. So how to control ISG has an effect on the vehicle performance in HEV. This paper introduces control aspects of ISG in detail and discusses ISG control strategies for better mileage in parallel HEVs.

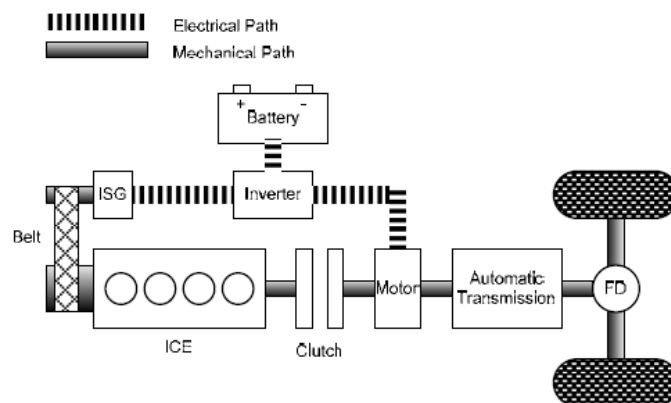


Figure1: HEV powertrain configuration

2 Characteristics of the EV/HEV mode Transitions in the Parallel HEV

Figure2 shows the powertrain behaviour of the parallel HEV in the federal test procedure (FTP). There exists the range in which the engine speed is not synchronized to the motor speed. That means there are frequent EV/HEV mode transitions in the parallel HEV under the city driving circumstance. If there is a way to improve the efficiency during the mode transition, better mileage can be achieved under the city driving.

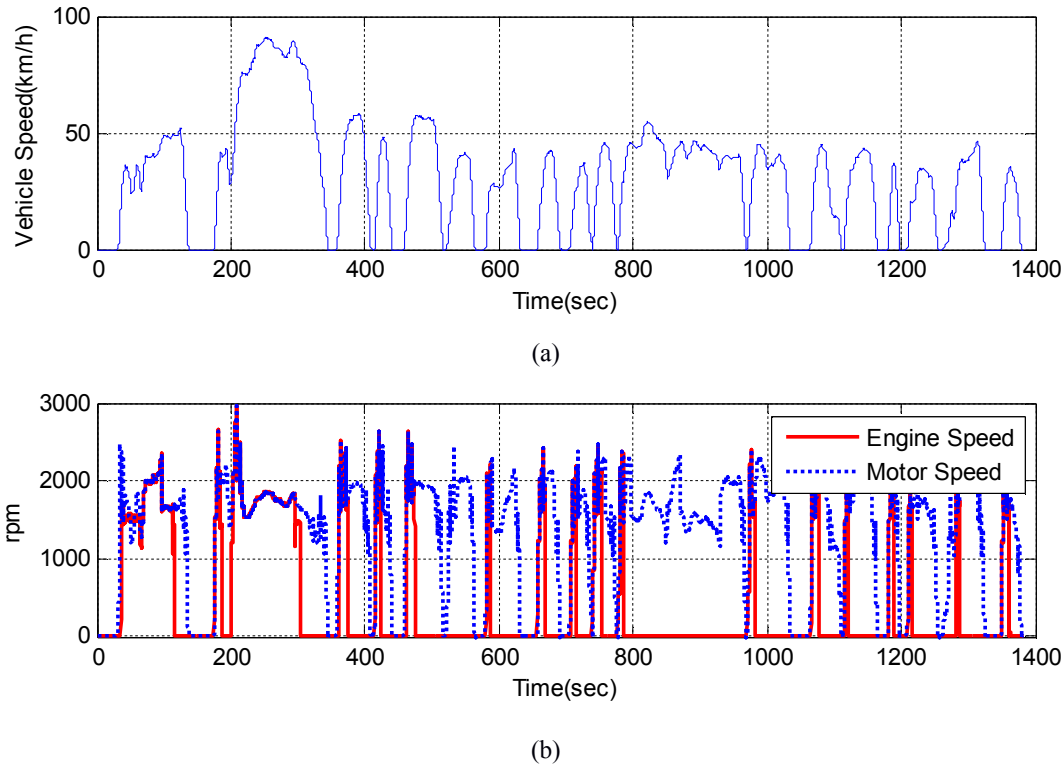


Figure2: FTP 4-bag mode (phase1,2) behaviour in the parallel HEV

(a) vehicle speed, (b) engine and motor speed

Figure3 describes the detail mode transitions. HEV mode transition is a step of engaging the clutch so as to connect the ICE to the driveline. EV mode transition consists of two-step such as the clutch disengagement control and engine-stop control. In order to improve the system efficiency during those transient situations, it is necessary to make the powertrain operate efficiently. Especially, the operating efficiency of the ICE is dominant to the overall powertrain efficiency. This study proposes the effective methods using ISG to make the ICE operate on the efficient range during the mode transition.

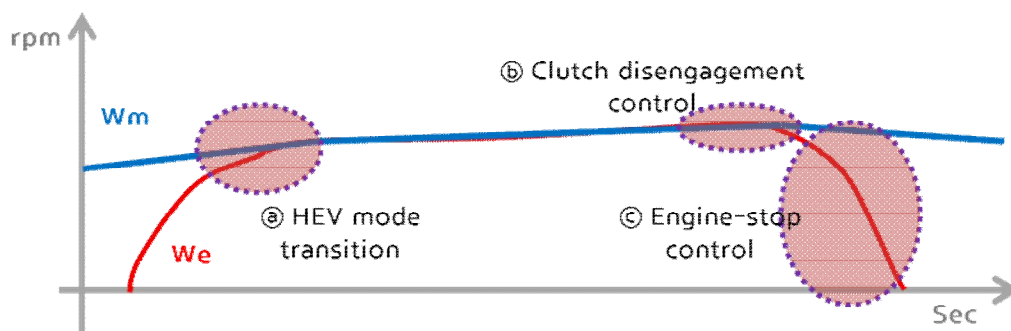


Figure3: Overview of the EV/HEV mode transition

3 ISG control Strategies in the EV/HEV mode Transitions

3.1 HEV mode transition

In the HEV mode transition from EV mode, ISG torque is applied to the engine axis so that the clutch can be engaged quickly. Conventionally, the engine was operating around the low torque range so as to cancel the engine friction term in the HEV mode transition. So engine operating efficiency was very low. In newly proposed strategy, the engine provides additional torque and ISG conducts to charge the battery. This strategy can make it possible to improve the engine operating efficiency during HEV mode transition.

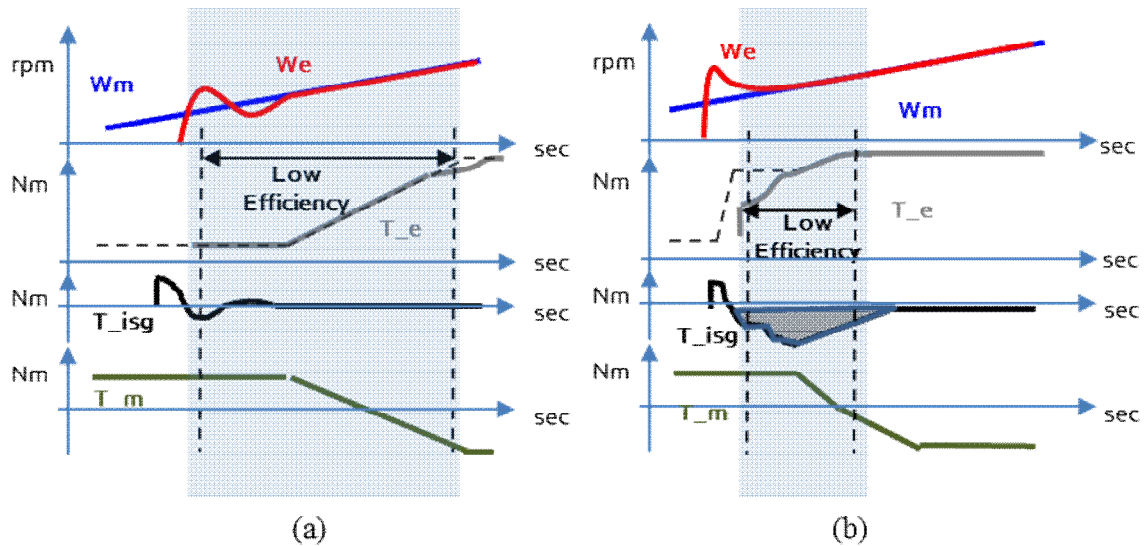


Figure4: HEV mode transition strategy

(a) Conventional torque distribution strategy, (b) Newly developed strategy

3.2 EV mode transition

3.2.1 Clutch disengagement control

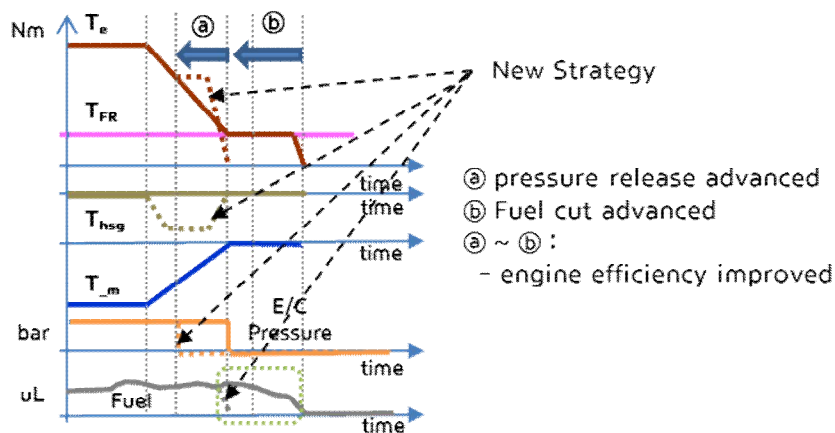


Figure5: Clutch disengagement control strategy

In order to disengage the clutch, following steps are conducted. The input torque of the clutch (engine side) is controlled to zero. Then the clutch pressure is released so that the slip state of the clutch can be blocked. Since estimating the clutch torque during slip state is quite difficult, this strategy as above is normally used. If the clutch is disengaged completely, the engine fuel is cut. For the better fuel economy, it is necessary to disengage the clutch quickly in the EV mode transition. Since the engine fuel-cut with the clutch engaged can make driveability issues such as shock and jerk, the engine fuel is usually cut after the clutch is disengaged.

This paper suggests the control strategy to reduce the control time and save the engine fuel. Conventionally, the input torque of the clutch was controlled to zero only by the engine. So the clutch pressure is released after the engine torque is fallen to the zero torque (net torque based). Newly proposed method employs ISG as well as the engine when the input torque of the clutch is controlled to be zero. This strategy can give us two benefits. ISG can make the input torque of the clutch zero very quickly. Moreover, the engine can be operated on the higher efficiency range during EV mode transition

3.2.2 Engine stop control

After the clutch is disengaged, the engine fuel is cut. Then the engine is moving from the current speed to the zero speed. Since the inertia moment of the engine is not equal to zero, the engine has the energy to recover. The HEV configuration has ISG directly connect to the engine, so that ISG can absorb the additional energy. This study discusses the optimal solution to maximize the energy recovery during engine stop transition.

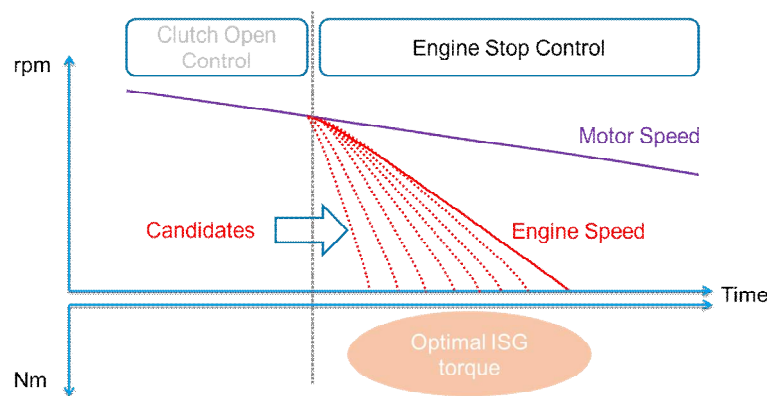


Figure6: Overview of engine stop control

This study employs the dynamic programming (DP) in order to find the optimal ISG torque profile to maximize the charging energy in the engine stop transition [4,5]. Figure7 shows the detail procedure and result of DP in the engine stop control.

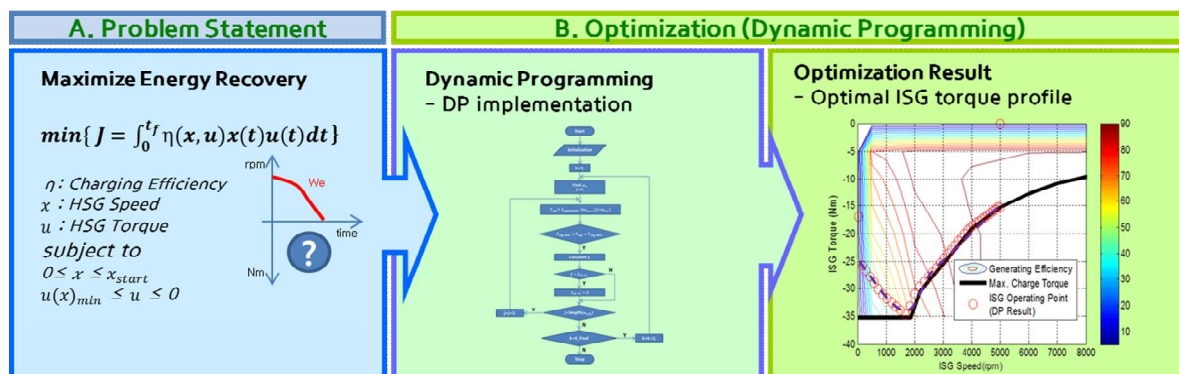


Figure7: Detail DP procedure of engine stop control

4 Test Results

The vehicle test was conducted with the control strategies mentioned above in the mid-size HEV sedan. The powertrain control system consists of several controllers of each components (engine, motor, ISG, etc.) and a supervisory controller which employs the online control strategy based on mentioned above.

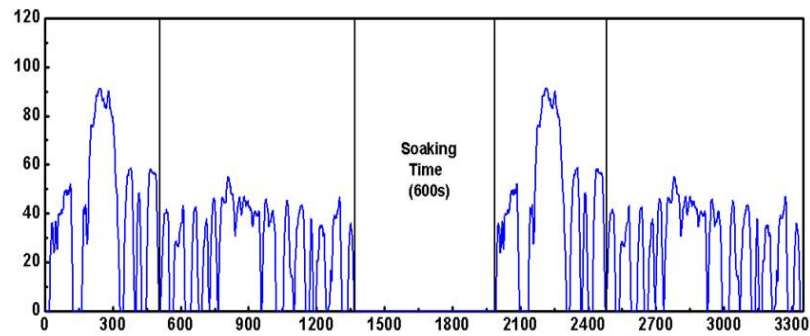


Figure8: Vehicle speed profile of FTP 4-bag cycle

The experiment was performed under FTP 4bag cycle with speed profile as Figure8 shows. The supervisory controller determines the powertrain torque commands regarding the mode transition. The vehicle experiment resulted in an improvement of 2.45% better mileage under FTP 4bag cycle. Table1 shows the effect of each control strategies in the fuel economy improvement.

Table1: The effect of the fuel economy improvement at each control strategy

No	Contents	Effect (%)
1	HEV mode transition	0.9 ↑
2	Clutch disengagement control	0.85 ↑
3	Engine stop control	0.7 ↑
Total		2.45 ↑

5 Conclusion

In this paper, ISG control strategy is proposed for improving the fuel economy in the parallel HEV. ISG can be an important role to improve the powertrain efficiency in EV/HEV mode transition. ISG is able to output the charge/discharge torque for the ICE to operate the efficient operating point during mode change. The obtained ISG control strategy was implemented to the vehicle controller in real-time. The vehicle experiment resulted in an improvement of 2.45% better mileage under FTP 4bag cycle.

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