Model-based Development Process for HCU Software of Advanced HEV System

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Abstract
Recently, vehicle ECU development is based on model-based design (MBD) process which has some benefits such as shortening the development period, defect reduction, quality improving, etc. The V-cycle process is a systematic way to enhance benefits of using the MBD process in the ECU development. The MBD process is more emphasized in developing the hybrid control unit (HCU) which should coordinate powertrain controllers such as EMS, TCU, and MCU for achieving better performance in a high level. However, for developing a variety of new HEV (ex. parallel, series, power split), it is difficult to establish initial control concepts and set up calibration variables in experiment step. In this paper, we discuss the method that can reduce the initial development time by applying global optimization methodology in the V-cycle process for the HCU. We applied the dynamic programming technique which finds global solution by backward calculation for the way to find optimal solutions. The results of applying global optimization methodology itself to the HEV system are engine on/off power level and engine operating range by demand power, transmission shift pattern by vehicle speed and demand power, control strategy according to SOC level, and powertrain’s operating modes according to vehicle speed and demand power in the case of multi-mode HEV. Based on these findings, the initial control concepts are derived for the detailed control logic design of the HCU software. In addition to this, the obtained optimization outcomes serve as a guideline at calibrating process for optimal operating of HEV’s powertrain. The global optimization methodology can be installed in the V-cycle process and the outcomes deployed as a main guideline at deriving control concepts and calibrating control parameters. It will help to overcome the lack of know-how and understanding about system, so that the HCU software development time can be considerably shortened.

Keywords: list 3-5 keywords from the provided keyword list in 9.5pt italic, separated by commas

1 Introduction
The modern vehicle control ECU is developed by Model-Based Development process for advantages such as development time, defect reduction, improved quality. The V-cycle that is a development process from initial concept design to vehicle test must be using systemically to take full advantage of the benefits of such a model-based development process. [1], [2]
In particular, the significance of the V-cycle in the development of the HCU (Hybrid Control Unit) for controlling powertrain system with the optimum operating condition of HEV (Hybrid Electric Vehicle) is even greater. The HCU prosecutes a cooperative control with powertrain controllers such as, EMS (Engine Management System), TCU (Transmission Control Unit), MCU (Motor Control Unit), BMS (Battery Management System) to execute the high level control on vehicle with driveline holistic perspective. So if you do go through the V-cycle development process, it is difficult to find out errors in the software development process due to the high system complexity. [3], [4]

On the other hand, HEV drive system uses a sub-system such as an engine, an electric motor in common, but the system is varied according to the structure of the transmission method, or to place them. In general, HEV systems are classified as serial type, parallel type, series-parallel type, and power-split type. There are diverse systems on the market because each systems have a number of variations. In order to maximize the performance of each of the HEV system, the HCU software that is optimized for the system is necessary. The power distribution control function is a key feature in the HCU that is determined by the composition of HEV drive system. However, in the process of developing a new HEV system, it is difficult to establish the initial control concept and set the Calibration values in the testing phase due to with low understanding of the system and the lack of experience.

In most cases, HCU software optimization is going to raise a lot of experience and know-how to complete by hand. However, in this paper global optimization techniques are applied to the HCU development process on the new HEV system will be introduced for ways to reduce the initial development time. In particular, a selection of the HEV system is TTR HEV System with diesel engine is introduced in this paper.

2 System Architecture

In this paper, the HCU development process of TTR(Through The Road) HEV system is equipped with a diesel engine and an electric motor to drive the rear wheels is introduced.

The system configuration is as shown in Fig.1. The front powertrain has diesel engine, transmission and ISG(Integrated Starter and Genearator). Hard Type HEV is to be available for the EV running mode and Idle charging, so a clutch to disconnect the engine from the drive shaft is needed. This was used for the Dual Clutch Transmission. A rear clutch, a reduction gear, electric motor for driving and differential gear is arranged on rear wheel drive shaft. The rear clutch disconnect the drive electric motor for reducing resistance because electric motor will act as a resistance when engine only drive on high speed. ISG of the front wheel and electric motor of rear wheel are electrically connected to the high voltage battery.

3 Development of ECU

3.1 General ECU Development

Typically when a model-based ECU development, ECU software for requirement can be designed without any defect when it is using a common model in V-cycle development process. Details of the V-cycle development process is as follows.

① Deriving Requirements: During vehicle development, vehicle specifications is determined, it is determined if the hardware must be designed to meet the specifications for the software controlling it. Requirements deriving process is a process for determining whether to decide how to control the control target, and have certain features in order to control the control object. For example, assuming that the requirements of the HCU of TMED derived systems, the requirements deriving process is as follows. Engine and the electric motor, the high-voltage battery is a control target of the HCU, they are to control so as to drive at the optimum efficiency point, if the HCU is when a certain
torque command to the EMS and the MCU, and each have a CAN communication controller to the communication structure. How is that you can configure.

② Logic Design: Logic design process is a process of designing the functions determined by the process requirements derived using a model-based design tool. Model design tool MATLAB / Simulink, dSPACE Targetlink, ETAS ASCET etc. are typical. The model-based design tools to develop the model is designed to meet the requirements, there are no errors on the logic that verifies MIL (Model In the Loop) process are also included in Logic design process.

③ Target Implementation: MATLAB / Simulink, dSPACE Targetlink, and ETAS ASCET have a function to convert the design model automatically to the C code. However, if you have not set up a separate model design will generate a C code that is computed in floating point. Therefore, the parameter setting work is needed to enable operation in Embedded Target. Then, the design model in the 'Logic Design "process is the Application Software that implements the functionality of the controller. This software requires a Base Software to create an environment that can be operated from the Embedded Target. Target Implementation is all the work. Model-Based Design, the logic is to act in the Embedded-Target. The course also includes the SIL (Software In the Loop) process to verify that the software is designed to meet the Embedded Target.

④ HIL (Hardware In the Loop) Verification: First, the purpose of the software is complete the SIL verification is to confirm that the actual controller operates normally. Secondly, it is an object to set the initial value for controlling the control target Calibration before testing in the actual vehicle or the target. To achieve these two objectives are HIL system is configured as a system capable of simulating the vehicle controller and Embedded Target.

⑤ Vehicle Testing and Calibration: By applying the output obtained through the HIL verify the actual vehicle, verify the function implemented in the controller, the process of performing operations to meet the vehicle Calibration development initially set target parameters. The process is configured as shown in Fig.2, each process may be associated with organic by doing Feedback to minimize defects in the software.

![Fig.2 V-cycle Process](image)

### 3.2 HCU Development of Advanced HEV

#### 3.2.1 Global Optimization Methodology

HEV vehicle is unlike regular gasoline and diesel vehicles, the engine and the motor as an energy source for generating the vehicle output is used by a driver demand. Power distribution control is to tune the output of the engine and the motor. Power distribution control of HEV are given in the form of the optimal control problem because of the many ways in view of the engine and the motor produce the driver's requested output. In other words, all the time while satisfying the driver's requested output that determines the output distribution of the engine and the motor to minimize the fuel consumption of the vehicle.

That is, the global optimization control is the process of finding the optimal combination of engine and motor power \([P_{\text{eng}}, P_{\text{mot}}]\) that minimizes the fuel consumption \(J_{\text{fuel}}\) of the vehicle for a particular drive. This can be expressed simply as the equation (1).

\[
[P_{\text{eng}}^*, P_{\text{mot}}^*] = \text{argmin}_{J_{\text{fuel}}} (\text{Formula 1})
\]
In this optimization process with a constraint that must be satisfied for all the time during the running durability of the battery SOC level should maintain the difference between the initial SOC and running at the end of the final SOC of the battery as close to zero level. This can be expressed as (Formula 2).

\[ |SOC_{init} - SOC_{final}| \leq \varepsilon \] (Formula 2)

In addition, the constraint that must always meet the demand power of the driver to the engine and the motor output is added. This is shown in (Formula 3).

\[ P_{out} = P_{eng} + P_{mot} \] (Formula 3)

Fig.3 shows the overall configuration of the input and output of the global optimization techniques. The global optimization technique derives the power distribution control concept combines optimize the power distribution control program and the problem of HEV vehicle model.

As can be seen in Fig.3, the fuel economy optimization of HEV is composed of the AV information (speed and gradient profile, etc.) and HEV vehicle model and optimizer. The optimizer finds the \([P_{eng}^*, P_{mot}^*]\) of all possible combinations that satisfy the target vehicle input speed and the target input torque. Algorithms for finding the optimal solution was to apply the dynamic programming technique. [5] Dynamic programming techniques are more efficient than direct search the entire area of the forward way backward way. Vehicle model and optimizer was implemented in the form of m-file Matlab S/W.

Fig.4 maximum fuel economy driving SOC route discovery process

Fig.4 is to follow the running speed profile inputted by the optimization technique, and shows the process of finding the optimal power distribution path from the initial SOC to the final SOC.

3.2.2 V-cycle application of the optimal control strategy derived techniques

HEV drive system is capable of various configurations, depending on the arrangement and the operation method of the engine and the motor. For systems that have already developed experience you can set the initial concept and Calibration value of the control logic on the basis of experience and know-how. In the meantime, if you develop a new HEV system due to lack of understanding and experience with the system, these initial direction the difficulty arises to set up. In this paper, for developing new HEV systems, methodologies, techniques derived by applying the optimal control strategy for ECU development process, the V-cycle that defines the initial control concepts and requirements, and reduce development time, such as setting the initial Calibration value the study was performed. The optimal control strategy derived techniques that can be obtained by applying the results to development of new HEV system described in the previous chapter are as follows.

1. On / off power level / engine operation region of the engine in accordance with the SOC and the required power
2. Shift schedule according to the vehicle speed and power demand
3. Control strategy changes in the battery SOC low / medium / high
4. In the case of multi-mode HEV, the operating range in each mode according to vehicle speed and required power

The above results are optimized and HCU control logic can be utilized when developing, leading Calibration control concept and initial value setting of the novel HEV system. Fig. 5 shows the HCU V-cycle development process of the prior HEV.
3.3 HCU Development of TTR HEV System

3.3.1 Deriving Requirement
TMED system and leading TTR system is being developed, but all of a parallel HEV system may differ significantly from two perspectives. TMED manner while using the gasoline engine and the drive motor is located on the front end transmission, TTR method is that the use of a diesel engine and the drive motor is located at the rear wheel.

![Efficiency Map of Gasoline Engine and Diesel Engine](image)

Fig.6. Compare efficiency of gasoline engines and diesel engines

Fig 6 shows the efficiency map of each of the gasoline engine and diesel engine. As can be seen in Fig.6 the diesel engine has the best engine efficiency characteristics in the high load region, unlike the gasoline engine. However, when operating a diesel engine in the high load region cannot be thought to occur because only the efficiency of the exhaust gas, such as NOx excessive to drive the engine, combined with the efficiency characteristics and exhaust characteristics shall determine the engine operation region. TMED like manner, when the drive motor is located at the front end transmission, the motor generating a part of the required output, or may be secondary to operate in the charging part of the engine output, the engine OOL (optimum operating line). Because TTR method is to position the motor to the rear wheel, in the event of a part of the required output is the same as TMED manner, if the motor is to charge the engine output, there will be differences. That is, the engine power is transmitted to the vehicle through the front wheel, because this method of charging in the rear wheels, the engine can operate at optimum efficiency region, but may be held against the lower fuel consumption efficiency in the mechanical path side. The above control strategy for the two cases which cannot be secured by the system because of the development of the existing TMED way, by applying the optimal control strategy was derived techniques to determine the initial control concept. Fig.7 shows the diesel engine operation region determined by the optimum control strategy derived techniques. As the suppression of NOx generation to meet the emission condition can be confirmed that the operation region of the engine is down.

![Diesel Engine Operating Point for Efficiency](image)

Fig. 7. In the operation region of the diesel engine (optimization results)

The other control concept was initially applied in the same way of TMED, engine on / off strategy map according to the SOC, the initial key value, such as the shift pattern map will Calibration was set using the results obtained by applying the global optimization techniques.

3.3.2 Logic Design
The basic configuration of the HCU logic is as follows. Input and output signal processing unit (CAN signal processing and digital signal processing), HEV Ready determining unit (determining the 'System Ready' through the digital input signal), the driver's requested power / torque operating section (the operator will determine the acceleration and deceleration), the target mode, determining unit (determining the operation mode of the power train target elements
through the vehicle state in response to a request of the driver), operating point computing section (determining the steady-state operation point of the engine and the electric motor for driving the driving mode), the system limit operation unit, transient period schedule determiner, a transient interval operation decision section, and has a flow such as Fig.8.

Function of the basic logic of HCU is the result of a global optimization technique is applied as follows:

- **Target mode decision unit**: direction of Logic design and Calibration values are determined by no. 1 and no. 3 are the result of the global optimization to determine a target mode such as EV / HEV. In particular, when the target mode is determined by current SOC state and driver demand power, the result of global optimization technique is used for determining strategy of Load-Levelling control that is operating electric drive motor on rear wheel and ISG motor on front wheel.

- **Operating point computing section**: Logic Design and Calibration value was determined by the result of no.3 and no.4 of the global optimization technique's result to determine the operation range of engine, electric driving motor, and ISG. The results of the global optimization technique are proposed a guideline to set up the optimum operation region of powertrain systems based on current SOC state and driver demand power on the determined mode.

Logic design, ASCET Tool of ETAS GmbH was used for modelling as with Fig.9. Designed Logic is verified by the function called MiLS(Model-in-the-Loop Simulation) of ASCET. Lower level function models are integrated after verification operation(MiLS).

### 3.3.3 Target Implementation

HCU's μController was used as Freescale's MPC5644. In this step, setting the type and scale of the variables to design Logic is operable at Target. And variable of the Type and Scale setting is completed, and determines the order in which to perform each Function. If done in the wrong order setting Logic design intent and can behave differently. For example, operation point determiner operation to be performed after the driver's requested power determining operation. but, if the order is reversed, the previous operating point computing section 1 sampling time driver's required torque / power calculated value based on the points in the operation the error that the operation. C code and Header files are generated by Auto code generation function of ASCET after this series of operation is completed. Binary files are generated by integrating the outputs is C codes and header files and base software through the compiler.

### 3.3.4 Hardware In the Loop Simulation

The HIL system is largely composed of three. Host PC, HIL controller, Embedded Target. As shown in Fig.10, a driver model and vehicle models designed with MATLAB / Simulink are mounted in Host PC, a vehicle model consists of a model to simulate the behavior of controller signals and powertrains. HIL controller acts that connect the CAN signals or digital input and output signals of the Embedded Target and Host PC. The HIL controller using National Instrument's PXI-1042Q. PXI-1042Q exchange the vehicle and driver model and information through the NI Veristand program. In HIL validation process, to ensure the HCU logic is working properly on the real vehicle view and find the errors of logics, and the results of the global optimization techniques was used for initial calibration values.
Fig. 10 Configuration of HILS

Fig. 11 is a graph of the results of verifying the operation of the HCU control logic HIL system. HCU controller is designed through the HIL simulation was found to operate normally. With your HIL validation results here in the real vehicle needs additional development, including consideration of drivability and fuel economy.

Fig. 11 The Results of HILS Verification

4 Conclusions

In this paper, the HCU software to develop advanced HEV, define the initial control concepts and requirements, and introduced the model-based development process for setting the Calibration value. By introducing an optimum control strategy to control development of techniques derived V-Cycle, the controller was set to design requirements and design guidelines for deriving a control logic based on the derived requirements. In particular, the target mode determining unit that the operation of the control logic of the operation unit HCU in the process could be applied to the result of the optimal control strategy derived techniques. The HCU software development process for leading HEV proposed development is expected to be used as a tool to complement the system, lack of understanding and experience in development and other leading HEV systems, including the TTR HEV system.

References


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