EVS26
Los Angeles, California, May 6-9, 2012

Development of Dynamic Motor System Modeling for HEV Drive and Study on Operating Characteristic of Dynamic Motor System applying HIL Simulator

Myung-Hwan Yoon[1], Jae-Min Lee[1], Jung-Pyo Hong[1], *Senior member, IEEE*
[1]Department of Automotive Engineering, Hanyang University, 17 Haengdang-dong, Seongdong-gu, Seoul 133-791, Korea

Abstract

In this paper, the method of modeling dynamic motor system for HEV(Hybrid electric vehicle) drive is introduced and drive performance of the model is evaluated applying HIL Simulator for the security of evaluation technology in motor system such as motor, inverter, generator and converter which are necessary for HEV development. The result of static motor system model is standard of comparison and analyzed by reference speed, torque and SOC(State of charge) of battery. Time and cost can be saved in development of HEV motor system according to this paper. Development of more reliable and safety guaranteed product is expected.

Keywords: HIL Simulator, Motor, Simulink, Dynamic speed, Torque

1 Introduction

Means of transportation is expected to expand wider in the future. Demand for high efficiency and low emission cars increase due to energy depletion and environmental regulation. Therefore, intelligence, increase in safety, low emission and high efficient power technology are necessary. The field of HEV is a realizable alternative to these demands. This HEV field is expected to expand to heavy duty HEV as well as light duty and medium duty HEV. The effects of reducing carbon dioxide and saving energy are expected to be great. The importance of motor system such as motor, inverter, generator and converter is emphasized as much as engine system due to this process. Therefore, reliability and safety in development and production of various HEV are guaranteed by drive performance analysis through simulation in developmental step. Economic effect is also expected. However, hybrid drive system for the heavy duty such as bus and truck as means of public transportation is hardly developed and studied.

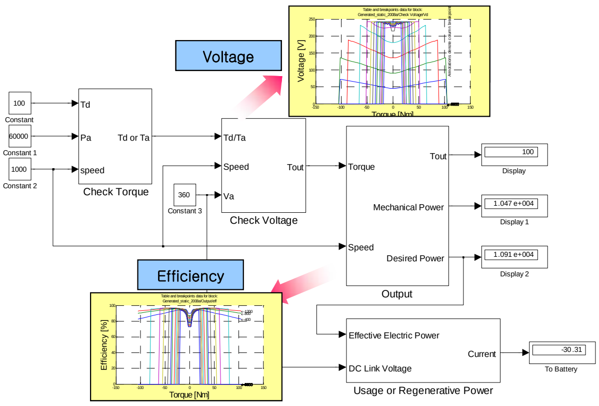


Figure1: Static model of motor system

The fundamental technology for managing reliability of key electric equipment and supporting key electric equipment for hybrid is very weak. Therefore, the motor system for HEV drive is developed by using MATLAB/simulink and applied to HIL Simulator in this paper on the basis of mathematical modeling. The model is compared with static motor model shown in Fig. 1 and the performance is verified.
This is useful to predict and analyze drive performance of the developed model. Great contribution in establishing the base of evaluation is expected.

2 Dynamic Simulink Model

2.1 Characteristic of study model

The motor which satisfies the specification of Table 1 is designed and the type of motor is IPMSM. The power and voltage of battery in vehicle model are considered by combination of vehicle model. The characteristics of the model are estimated by finite element analysis (FEA) and the voltage and torque equation; mechanical and iron loss are ignored. The equations in normal operation are expressed in d-q coordinates as follows (Chin and Soulard, 2003):

$$v_d = R_a i_d + L_d \frac{di_d}{dt} - \omega L_q i_q \qquad (1)$$

$$v_q = R_a i_q + L_q \frac{di_q}{dt} + \omega L_d i_d + \omega \Psi_a \qquad (2)$$

$$T = P_n \{\psi_a I_a \cos\beta + \frac{1}{2}(L_q - L_d) I_a^2 \sin 2\beta\} \qquad (3)$$

where i_d is d-axis current, i_q is q-axis current, V_d is d-axis voltage, V_q is q-axis voltage, Ψ_a is linkage flux by permanent magnet, L_d is d-axis inductance, L_q is q-axis inductance, R_a is armature winding resistance, T is electric output torque, P_n is number of pole pairs and β is current angle.

Table 1: Specification of study models

Item	Value
Desired Torque [Nm]	0~570
Power of battery [kW]	60
Voltage of converter [Vdc]	360
Speed [rpm]	0~6000

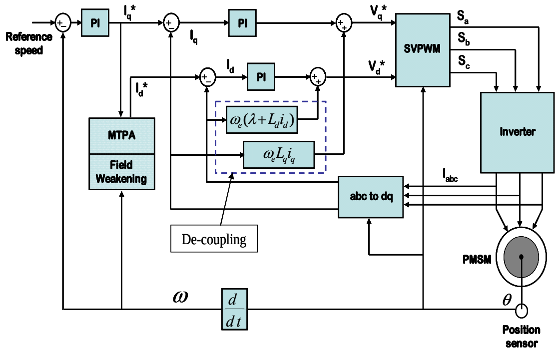


Figure 2: Typical configuration of PMSM drive system

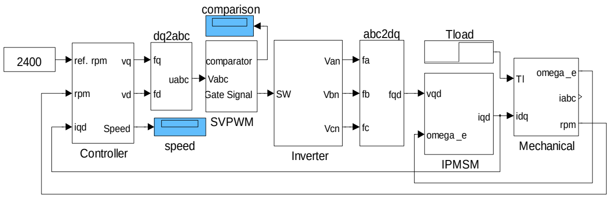


Figure 3: Dynamic simulink model of motor system

2.2 Typical PMSM drive system

Typical PMSM drive system can be expressed by configuration shown in Fig. 2. Analysis applied by equivalent model of d-q axis coordinate can be conducted for the convenience of control with 3 phase voltage input. Proper response can be obtained by appropriate gain of PI block such as equation (4).

$$u_{out}(t) = Limit\left\{e(t) \cdot K_p + K_i \cdot \int e(t)dt\right\} \qquad (4)$$

where k_p and k_i are p gain and i gain respectively.
Gain of current controller is dependent on inductance and resistance of all the parameter. P gain and I gain can be obtained as follows.

$$K_{pc} = L_a \cdot \omega_{cc} \qquad (5)$$

$$K_{ic} = \frac{R_a}{L_a} \cdot K_{pc} = R_a \cdot \omega_{cc} \qquad (6)$$

where, ω_{cc} is a cutoff frequency and limited by switching frequency which affects performance of current controller.

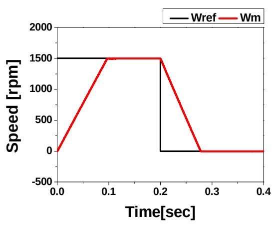
2.3 Parallel type motor system

The dynamic motor system model as shown in Fig.3 is parallel type model and performs role of motor and generator simultaneously. The system includes motoring region and generating region due to reference speed as shown in Fig. 4.

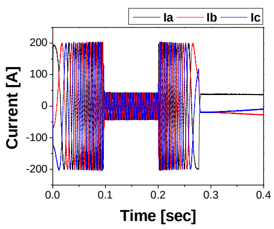
3 Apply for HEV model

3.1 I/O interface for HEV

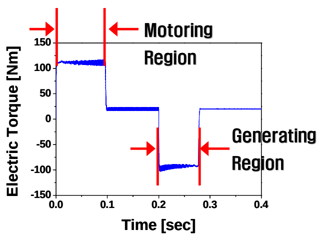
Parallel type HEV is the type where engine and motor are independently linked. The primary method of propulsion is engine and electric motor supports the engine. The required torque for vehicle distributed to engine and motor. I/O interface as shown in Fig. 5 is required in HEV vehicle model. In the study, the vehicle model is applied by dynamic breaking torque as reference current. The voltage of battery and speed of driving shaft are the input and current according to dissipative and regenerative power and mechanical torque are output. The voltage of battery substitutes for DC link voltage in the model of motor system.



(a) Reference speed



(b) Induced current



(c) Electric torque

Figure 4: The simulation result of dynamic motor/generator model

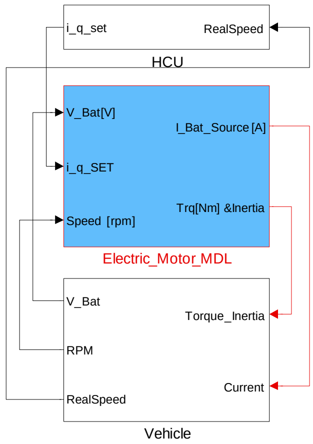


Figure 5: I/O interface in HEV model

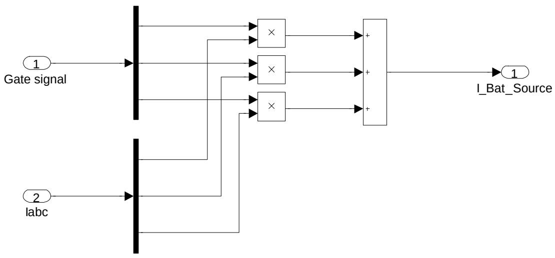


Figure 6: Model of regenerative and dissipative power

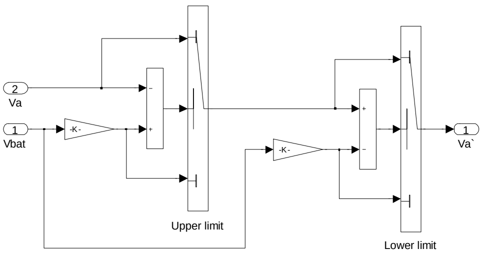


Figure 7: Model of voltage limit

3.2 Calculation of dissipative and regenerative power

Dissipative and regenerative current of battery can be calculated by current which is used in inverter. i_{DC} is computed by relation between turn-on time of switching element and current as shown in equation (7). The voltage level of battery is calculated by equation (8).

$$i_{DC} = i_a \cdot S_a + i_b \cdot S_b + i_c \cdot S_c \tag{7}$$

$$\Delta Q = C \cdot \Delta V \tag{8}$$

where, $S_a \sim S_c$ is a switching function which has values of zero and one and can be modeled from gate signal as shown in Fig. 6.

3.3 Calculation of phase voltage limit

Phase voltage limit is determined by following equation on the basis of DC link voltage in case of 3 phase motor. The limit value represents peak value.

$$\frac{1}{2}V_{DC} \times \left(\frac{T_s - T_d}{T_d}\right) \times PWM\ factor \tag{9}$$

where, it is the maximum output voltage which can be linearly controlled and PWM factor is 1.155 due to 3rd harmonic of SVPWM. T_s is switching period and T_d is dead time.

4 Static motor system model

Static model is on the basis of motor system map which can be obtained without operation. Therefore static model is an appropriate standard of comparison in response of dynamic model due to simultaneous response of speed. I/O interface for vehicle application is equally applied as dynamic model

4.1 Algorithm of motor drive

First of all, desired torque for vehicle should be in the range of available torque as shown in Fig. 8. The available torque is determined by the limit of output and the speed of vehicle which is driven by equation (10).

P=wt (10)

Threshold value of torque is obtained according to driving speed in case threshold voltage is reached. Finally desired torque can be calculated by mechanical output and efficiency map.

4.2 Configuration of Lookup table

Map of MATLAB/simulink is realized by lookup table and composed of voltage, torque and efficiency map resulting from characteristic analysis considering nonlinearity of study model. Configuration of static motor system model is presented in Fig. 1 which reflects (-) torque to consider motoring and generating. It is assumed that generator and motor has same performance.

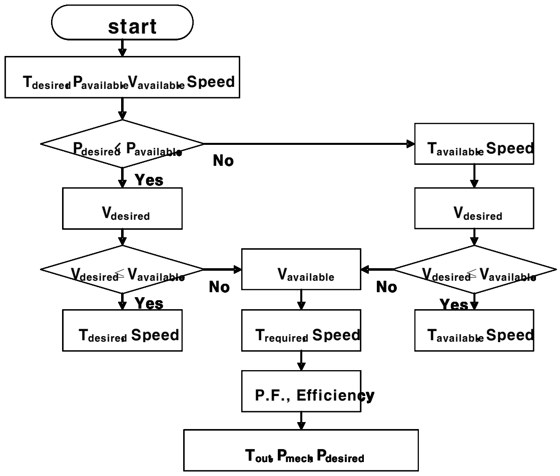


Figure 8: Algorithm of motor drive

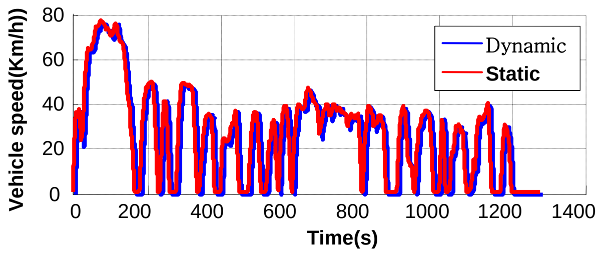


Figure 9: The comparison of dynamic and static speed

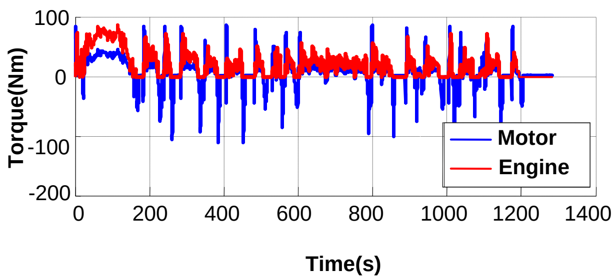


Figure 10: The comparison of engine torque and motor torque

5 Simulation Result

The speed simulation results of dynamic HEV model and static HEV model with identical vehicle are compared in Fig 9. Response speed is simulated by speed profile of FTP75 which is desired speed for the simulation. Response speed of static HEV model which has no delay in operation is similar to speed profile. The response speed of dynamic HEV model applied by experimental condition of proper gain is shown in Fig. 9 and delayed compared with speed of static model. The resulting performance of dynamic motor system model suggested in the paper is a reliable result. Torque distribution of engine torque and motor torque in dynamic HEV model is shown in Fig. 10.

6 Conclusion

In this paper, MATLAB/simulink model which is necessary for development of motor system in Hybrid Electric Vehicle is suggested. Considering nonlinearity and simple structure are the merits of static motor model but obtaining appropriate data for mapping through complex process of FEA and characteristic analysis is the demerit. Non linearity in dynamic model which is suggested in the paper can not be considered, however, performance can be evaluated by lumped electric parameters of motor.
The performance is evaluated by the control simulation of tracking speed profile with combination of vehicle model and dynamic motor system which is suggested.
Reliability is verified by applying the response of static model simulation which is the standard of comparison under the same condition with dynamic model. Dynamic model includes inverter and has different characteristic from static model because evaluation of voltage and current by PWM feeding is available. Dynamic HEV model suggested in this paper can be contributed to the development of motor system.

References

[1] W. Hong, C. Choi, W. Lee, J. P. Hong, and D. Kum, “Advanced permanent magnet motor drive modeling for automotive application under matlab/simulink environment,” International Journal of Automotive Technology, Vol. 10, No. 4, pp. 489−495, 2009

[2] X. Li, X. Mao, And W. Lin, "Permanent Magnet Synchronous Motor Decoupling Control Sturdy Based on the Inverse System", PIERS Proceedings, Cambridge, July 5-8, 2010, USA

[3] B. K. Lee, and M. Ehsani, "A simplified functional simulation model for three-phase voltage-source inverter using switching function concept," IEEE Trans. Ind. Electron., vol.48, no.2, pp. 309-321, Apr. 2001

[4] P. Pillay, R. Krishnan, "Modeling, simulation, and analysis of permanent-magnet motor drives, part II: the brushless DC motor drives, part II: the brushless DC motor drive," IEEE Trans. Ind, Appl., vol.25, no.2, pp. 274-279, Mar/Apr. 1989

Authors

Myung-Hwan Yoon received degree in mechanical engineering from Hanyang University, Korea in 2011. Currently he is pursuing Master’s Degree in automotive engineering from Hanyang University. His main field of interest are electromagnetic field analysis and electrical motor design.

Jae-Min Lee received degree in electronic engineering from Hanyang University, Korea and Master’s degree from Hanyang University. His main field of interest are optimization, analysis and design for electrical motor.

Jung-Pyo Hong received Ph.D. degree in electrical engineering from the Hanyang University, Korea, in 1995. From 1996 to 2006, he was professor of Changwon National Univ., Chang-won, Korea. Since 2006 he has been working as a professor in the Hanyang University, Korea. His research interests are the design of electric machines, optimization and numerical analysis of electromechanics.