Control of IPMSM for Hybrid Electric Commercial Vehicle

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***Abstract*—The traction motor of Hybrid Electric Commercial Vehicle(HECV) should have the characteristics such as high power versus weight ratio and very high torque at low speed. So interior permanent-magnet synchronous motor(IPMSM) is suitable for HECV. This paper presents a maximum torque per ampere(MTPA), a field weakening (FW) control and a reduced-order observer of IPMSM for HECV. By using computer simulation, we validate the effectiveness of the proposed system.**

Keywords-HEV, IPMSM, MTPA, Field Weakening, Observer

I. INTRODUCTION

Nowadays, hybrid electric vehicles (HEV) have been brought to public attention as a next generation vehicle to reduce the air pollution, and large research activity has been carried out in this field. However, the researches of hybrid electric commercial vehicle (HECV) are just in progress in countries such as Europe and United States [1].

Recently, the major commercial vehicle companies have been promoting research and development about fuel cell buses, compressed natural gas (CNG) hybrid buses, hybrid diesel vehicle and hybrid gasoline vehicle in Europe, United States and Japan.

HECV system is composed of the battery pack, the traction motor, the inverter and the engine. The traction motor of HECV should have the characteristics such as higher power versus weight ratio and much higher torque at low speed than those of the HEV. Also, it should be possible not only to drive high torque at the low speed range but also to have stability at the high speed range. Interior permanent-magnet synchronous motor (IPMSM) is suitable for HECV.

This paper deals with a maximum torque per ampere (MTPA) and a field weakening (FW) control algorithm and a reduced-order observer in order to speed control of IPMSM for HECV.

The proposed system operations can be divided into general speed mode (GSM) and high speed mode (HSM). In GSM, it uses the MTPA control algorithm to speed control of IPMSM for HECV. In HSM, it applies both MTPA and FW control algorithm to speed control of IPMSM for HECV. Also in both GSM and HSM, the reduced-order observer is applied to reduce the speed ripple and to improve the torque response.

To improve the control performance, flux and inductance values are compensated by the look up table.

Also the current depreciation table is used to control a torque component current.

The simulation results are provided to verify the MTPA and FW control and reduced-order observer strategy for HECV.

II. INFORMATION

A. Control Method

Fig. 1 shows a control block diagram of the whole system.

Applied techniques in IPMSM to improve torque control are MTPA and FW, and reduce-order observer is also used to compensate the torque. We make the beta, flux and inductance table to improve the control performance of the system.

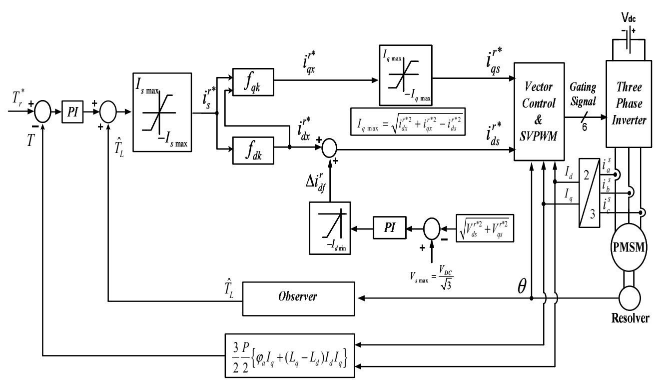

Fig. 1 Control block diagram of the whole system.

The torque of IPMSM is the sum of the magnetic torque and reluctance torque, and it is as following:

$$T = \frac{3}{2}\frac{P}{2}\left\{\varphi_a I_q + (L_q - L_d) I_d I_q\right\} \tag{1}$$

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The total current, Is, can be expressed as:

$$\begin{bmatrix} i_{ds}^{r*} \\ i_{qs}^{r*} \end{bmatrix} = i_s^{r*} \begin{bmatrix} -\sin(\beta) \\ \cos(\beta) \end{bmatrix} \quad (2)$$

Among the motor parameters, the torque component current, i_q, are obtained from the beta angle table which is created according to the speed variation.

Using (1) and (2), the flux component current, I^{r*}_{dx}, can be calculated as:

$$I_{dx}^{r*} = \frac{\varphi_a}{2(L_q - L_d)} - \sqrt{\frac{\varphi_a^2}{4(L_q - L_d)^2} + i_{qx}^{r*2}} \quad (3)$$

The FW control can be easily implemented by using the DC link voltage and the output voltage, the flux current is as follow:

$$\Delta i_{df}^{r} = I_{dx}^{r*} + I_{d\_fw} \quad (4)$$

$$I_{d\_fw} = \frac{V_{dc}}{\sqrt{3}} - \sqrt{(V_{ds}^{r*2} + V_{qs}^{r*2})} \quad (5)$$

The FW control algorithm starts when I_{d_fw} has negative values.

A sensor for speed control is a resolver. The initial position and speed can be obtained from the sensor signal.

However, when the reference torque commands to the controller, the pushed back phenomenon of HECV occurs because of the initial load.

The reduced-order observer compensates the speed and the torque by using the estimated parameters in order to solve this problem. The observer equation for system parameters estimation is represented equation (6).

$$\begin{bmatrix} \dot{\hat{\omega}}_m \\ \dot{\hat{T}}_L \end{bmatrix} = \begin{bmatrix} -\frac{B_m}{J_m}\hat{\omega}_m - \frac{1}{J_m}\hat{T}_L + \frac{1}{J_m}T_e + l_1(\omega_m - \hat{\omega}_m) \\ l_2(\omega_m - \hat{\omega}_m) \end{bmatrix} \quad (6)$$

Where, $l_1 = -(\beta_1 + \beta_2) - \frac{B_m}{J_m}$

$l_2 = -\beta_1 \beta_2 J_m$

For IPMSM control of HECV, the torque response characteristic is one of the important factors and it can be improved through the torque estimation.

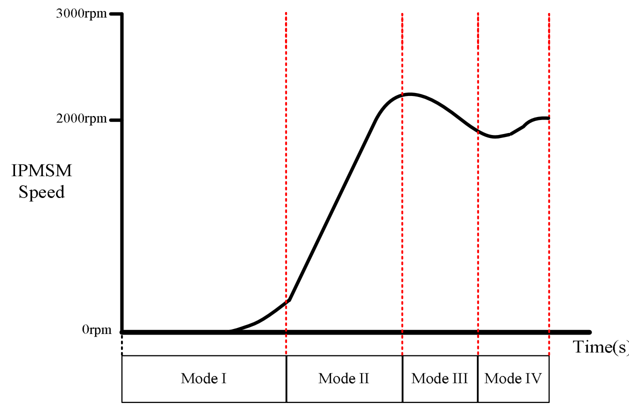


Fig. 2 Operation modes of HECV.

Fig. 2 shows operation modes of HECV. HECV system should not be slip for starting and climbing a hill. This function was implemented by reduced-order observer. Mode operations are shown below for an explanation.

▪ Mode I : System start.

This region drives using only IPMSM. The characteristic of this area should not be occurred speed slip. Gradually the torque is increasing according to rpm rising in the initial start region of HECV.

▪ Mode II : Acceleration area .

After starting, the speed of IPMSM is accelerating rapidly. This is an important area of the motor performance.

▪ Mode III : Regenerative operation.

The regenerative should occur at the negative torque after the sudden departure of the brakes or gear shift.

At this point, regenerative energy is generated. Energy-saving mode is required for improved efficiency in HECV.

▪ Mode IV : Switch operation for engine.

Around 20Km/h over of the vehicle speed, operation mode is switched to engine operation mode.

B. Simulation Results

A matlab simulink was used for simulation to investigate the operational characteristics of IPMSM for HECV. The system specifications and parameters are given in Table 1.

Fig. 3 shows the simulation block diagram of the whole system.

The IPMSM was modeled by using equations, and current controller was used anti-windup PI controller. In addition to, the speed and load estimation was implemented by using the reduced-order observer. The position sensor to obtain the initial angle was a resolver.

Table I

Parameters of IPMSM

Output Power[kW]	30
Rated Speed[rpm]	1000
Rated Torque[Nm]	300
Rated Current[A_{peak}]	265
Number of Pole	8
Permanent Magnet Flux[Wb]	0.20
D- axis Inductance[mH]	0.67
Q-axis Inductance[mH]	1.07
Resistance[mΩ]	4.77

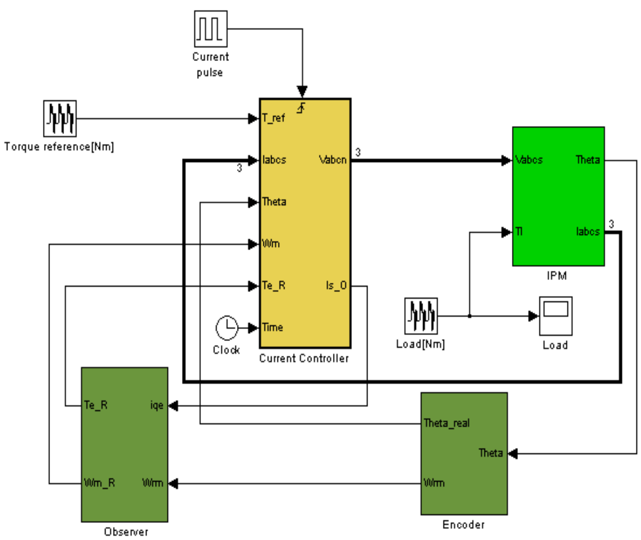


Fig .3 Block diagram of the simulation.

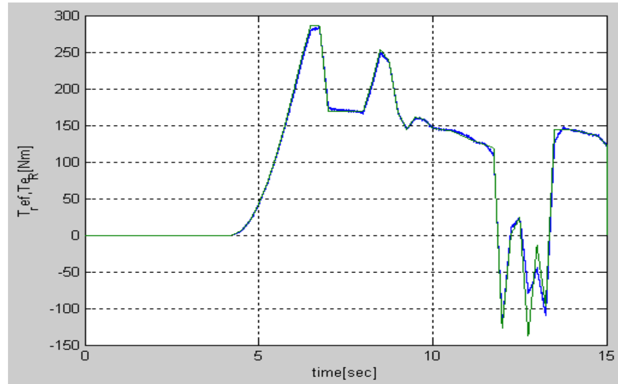
Fig.4 shows the simulation results of torque control for IPMSM. Torque reference was obtained by actual engine modeling and the load was made from actual engine speed and torque.

HEV system has engines instead of departing from IPMSM because it will perform the role of the engine. Also beta of equation (6) make a table, it was applied this simulation.

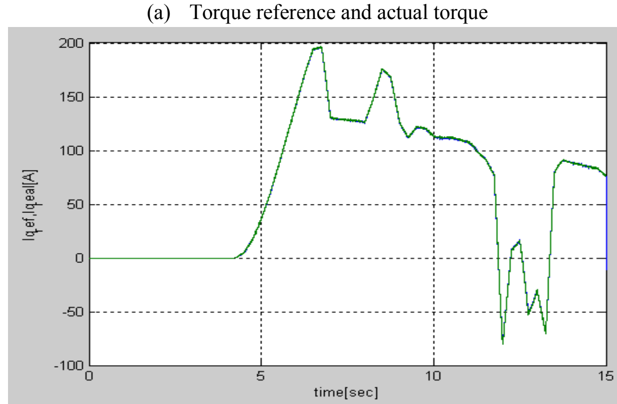
Total time is 15s and if motor speed is more than 1500rpm, it is to enter the FW control. MTPA control is performed in less than 1500rpm.

Fig. 4 (d) shows the start around 5s without negative speed because reduced-order observer compensates torque.

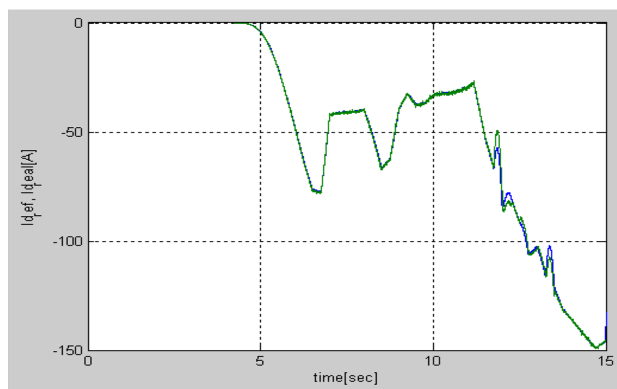
Simulation results for the torque reference and real torque response show good performance. And the regeneration region has a negative q-axis value and torque when the speed is a deceleration.



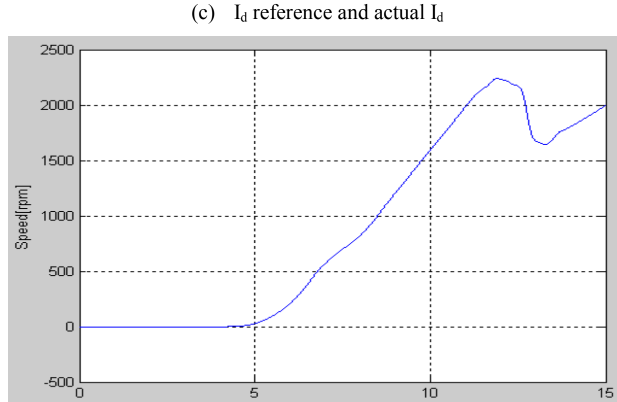
(a) Torque reference and actual torque



(b) I_q reference and actual I_q



(c) I_d reference and actual I_d



(d) Actual speed

Fig. 4 Simulation results of torque control for HECV.

III. CONCLUSION

This paper presents a maximum torque per ampere(MTPA), a field weakening (FW) control and reduce-order observer of IPMSM for HECV. The torque control is used by adapting engines parameters and real HEV load. By using computer simulation, we validate the effectiveness of the proposed system .

To control the proposed system will be applied to HECV system and it will be good performance control of IPMSM. Later, it is able to show experiment results.

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