

Design of Torque Control Strategy for Hybrid Electric Vehicle (HEV) with Maximum Work of Self Commutation Brushless DC Motor using Fuzzy-PI

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Abstract—Hybrid Electric Vehicle (HEV) is vehicle with least two energy sources, such as Internal Combustion Engine (ICE) and Brushless DC Motor (BLDCM). BLDCM provide additional torque, to purpose of HEV can reach the set point speed according to the reference model. Commutation of BLDCM still complicated, because between the rotational speed of the motor and the speed of the rotary field on the stator should be kept synchronized. Self Commutation used to maintain synchronization between rotation of the rotor and rotary field velocity on BLDCM stator. In addition, this research also applies torque control strategy by using fuzzy-PI controller. Vehicle performance still follows the reference curve with steady state error of 0.1506 km/h and RMSE relative response speed HEV <2%.

Keywords—HEV, Self Commutation, BLDCM, Fuzzy-PI.

I. INTRODUCTION

HEV is a vehicle with driving force of at least two energy sources [1]. ICE and electric motors are combination of commonly used energy sources [2]. The development of HEV aims to improve efficiency of fuel consumption, reduction of vehicle exhaust emissions, and improvement of HEV speed and acceleration response [3]. HEV combines two torque generators, where the prime mover torque is provided by ICE and secondary torque is provided by the BLDCM.

BLDCM is a type of motor developed from DC motor. Development of BLDCM with a purpose to solve commutator brush problems [4]. BLDCM has advantages of high efficiency, large initial torque with smaller physical demands and easier maintenance [5]. However, in terms of setting, BLDCM is still quite complicated because between rotational speed of the motor and the speed of rotary field on the stator shall be kept in sync.

Some research has been done, the method used to synchronize the rotor towards the stator using stator current reading method with d-q transformation and compared with actual speed of the rotor. In practice, the method is still

complex and intricate. Another developed method is self commutation.

There are several methods used for BLDCM setting for motor rotation speed and rotational field speed in the stator to remain constant, such as show in Figure 1.

Self Commutation is a method to maintain synchronization between rotation of rotor towards rotary field velocity on stator BLDCM [6]. The circuit topology is also relatively simple and more easily applied to the real plant.

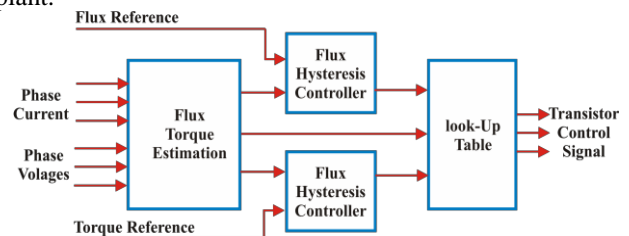


Figure 1. The topology of DTC structure [7]

This paper discusses development of self commutation method for BLDCM with torque control strategy by using fuzzy-PI controller for implemented in HEV.

II. CASE STUDY OF SELF COMMUTATION BLDCM IN HEV

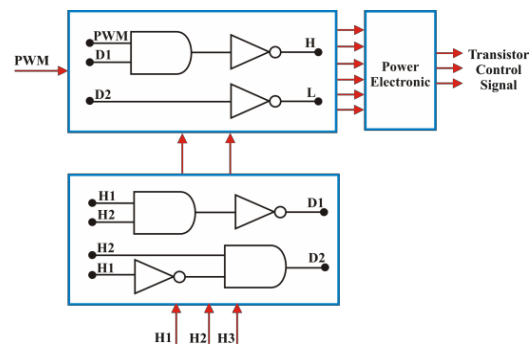


Figure 2. Circuit Topology of Modified Logic Commutation

HEV can be divided into three types: series, parallel and power split. [1]. This experiment uses parallel HEV.

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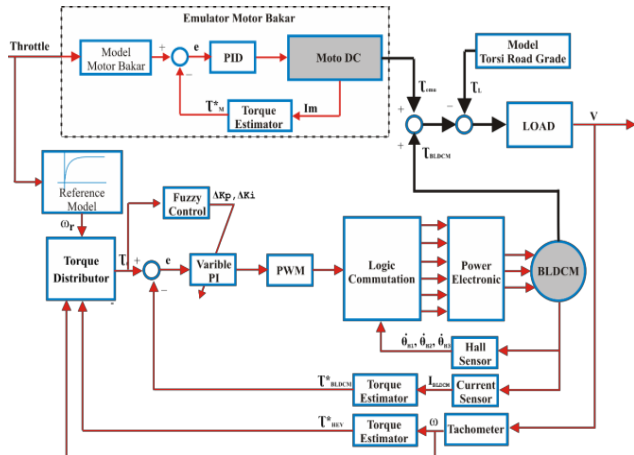


Figure 3. Block Diagram of HEV Using Fuzzy-PI

A. Modelling

Identification of ICE parameter is done by using Strejc method based on plot respond of ICE speed. Mathematic model of ICE:

$$G_{ICE}(s) = \frac{6.0507 \times 10^{-4}s + 26.62308 \times 10^{-4}}{0.00896696s^2 + 0.18938s + 1} \quad (1)$$

Identification BLDCM parameter is used by analyzing the result of measurement (Table 1).

TABLE 1.
PARAMETER OF BLDCM

Parameter (unit)	Mark
Pole (P)	3
Voltage Source (Volt)	48
Stator resistance (Ohm)	0,85
Stator inductance (H)	0,0142
Mutual inductance (H)	0,0136
Constant of torque (Nm/A)	0,366
Constant of back emf (V/rad)	0,09

Mathematic model of load:

$$G_L(s) = \frac{1}{3 \times 10^{-4}s + 13.2 \times 10^{-4}} \quad (2)$$

Reference model is a guide model for controller to increase HEV respond. Mathematic model of model reference:

$$G(s) = \frac{2.0169}{0.104s + 1} \quad (3)$$

BLDCM Stator current equation:

$$\frac{d}{dt} \begin{bmatrix} i_U \\ i_V \\ i_W \end{bmatrix} = D^{-1} \left\{ RI \begin{bmatrix} i_U \\ i_V \\ i_W \end{bmatrix} + I \begin{bmatrix} i_U \\ i_V \\ i_W \end{bmatrix} - I \begin{bmatrix} i_U \\ i_V \\ i_W \end{bmatrix} \right\} \quad (4)$$

B. Design Fuzzy-PI Controller

Torque control of BLDCM done by setting the BLDCM torque directly. At this phase designed fuzzy-PI controller. PI controller designed to set BLDCM torque. The PI Controller equation is given in the equation 3. The parameter PI obtained tuning with MATLAB.

$$u(t) = K_p e(t) + K_i \int_0^t e(t) dt \quad (5)$$

Error torque is obtained from the equation (6)

$$e(t) = T_{refBLDCM}(t) - T_{estBLDCM} \quad (6)$$

Where the torque of BLDCM estimates is

$$T_{estBLDCM}(t) = I_M(t)K_{TM}(t) \quad (7)$$

The BLDCM currents are obtained from the equation (8)

$$I_M = \frac{abs(I_U + I_V + I_W)}{2} \quad (8)$$

Which is the value of K_p and K_i always updated with equation (9) and (10).

$$K_p = K'_p + \Delta K_p \quad (9)$$

$$K_i = K'_i + \Delta K_i \quad (10)$$

K'_p is the gain of K_p and K'_i is gain of K_i before time t .

The rules tuner K_p are defined according to the following algorithm:

$$\text{If } T = K, \text{ then } \Delta K_p \text{ is Min} \quad (11)$$

$$\text{If } T = B, \text{ then } \Delta K_p \text{ is Max} \quad (12)$$

$$\text{If } T = \text{Nol}, \text{ then } \Delta K_p \text{ is Nom} \quad (13)$$

The rules tuner K_i are defined according to the following algorithm which has shown in Table 2.

TABLE 2.
RULES BASE OF FUZZY TUNER K_i

Torque	Σ Torque		
	N	O	P
N	Max	Max	Nom
O	Max	Nom	Min
P	Nom	Min	Min

III. RESULT AND DISCUSSION

HEV simulation and modeling is made with Matlab Simulink. Here are the test results:

A. Acceleration Testing of HEV

1) HEV Testing with External Torque Disturbance

Testing this stage is done by providing an external load of 0.08 N.m which is assumed as slope of the road, then getting fuzzy control strategy applied. Gain speed regulator is given with value of $K_p = 5$, $K_i = 1.5$, The speed response (Figure 4) indicates the steady state speed value of 60 Km/h. When given a load at time of 0.8 s, HEV can still maintain speed as per reference.

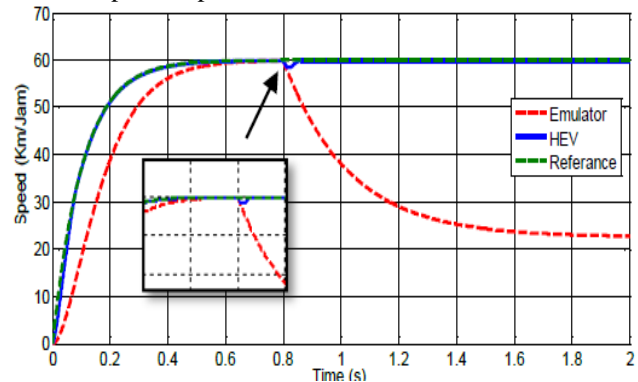


Figure 4. Response Speed Test of HEV

Figure 5 represents steady state error value of 1,566 Km/h and RRMSE of $<2\%$ for application of fuzzy control strategy.

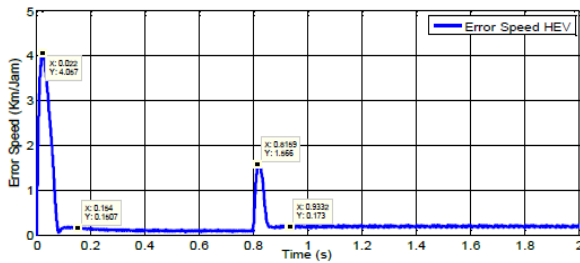


Figure 5. Response Error Speed Test of HEV

HEV torque response (Figure 6) points out torque ripple with steady state value of 0.1422 N.m before the load is applied. At the time of 0.8s, torque value is changed due to given load and average torque value of HEV 0.1444 N.m. HEV torque is a combined torque of ICE and BLDCM torque, thus the value is greater.

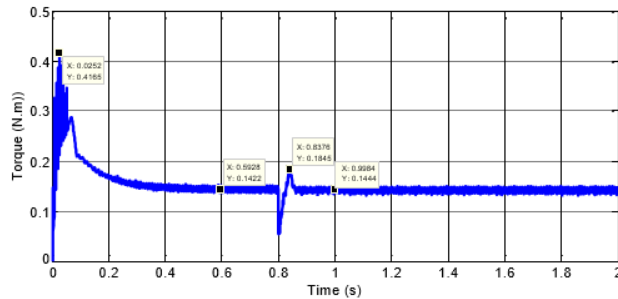


Figure 6. Response Torque of HEV

TABLE 3.
TEST RESULT

Disturbance (N.m)	Speed (km/h)	Average Error (km/jam)	RRMSE (%)
0	59,9086	0,1938	0,932
0,07	59,8445	0,2488	0,968
0,08	59,8385	0,2595	0,983
0,09	59,8189	0,2719	1,004

0,1 59,7974 0,2848 1,027

IV. CONCLUSION

The results showed that Self Commutation method can synchronize well rotation speed of the rotor towards speed of rotary field on the stator. The self commutation BLDCM scheme can be applied to HEV. Vehicle performance still follows the reference curve with steady state error value 0.1506 km/h and RRMSE response speed <2% when the control strategy applied in HEV.

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