A Torque Compensation Control Scheme of PMSM considering a Wide Variation of Permanent Magnet Temperature

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This paper presents a control method that compensates the reduction of power output of a permanent magnet synchronous motor caused by the change in rotor temperature. The characteristics of the permanent magnet according to the rotor temperature were analyzed and the need for a motor parameter estimation method was identified. An adaptive filter and computational method were used to estimate the motor parameter. The estimated parameters were used to propose a torque compensation control method based on the maximum power output of permanent magnet synchronous motor considering the change in rotor temperature. The method was verified by dynamo test on an interior permanent magnet synchronous motor.

***Index Terms*— Motor drives, Permanent magnet motors, Temperature, Torque control, Parameter estimation**

I. INTRODUCTION

PERMANENT magnet synchronous motors (PMSM) have high drive efficiencies and are evaluated to be the most appropriate as vehicle traction motors due to their high power density that enables miniaturization. Automotive motors are constrained by their size, are required to meet the N.V.H. requirements such as low-noise and low-vibration, and have extreme condition standards for temperature and humidity. Also these motors require a high-output design due to their low speed, high-torque drive and high-speed driving conditions. Increasing number of studies attempting to improve output density and miniaturize the motors for their optimization in the automotive industry has reported the problem of heat generation due to losses in the motor.

Change in the magnetic flux according to the rotor permanent magnet temperature appears as a decrease in magnetic flux with increase in temperature. When the temperature of the rotor permanent-magnet increases in a PMSM, the magnetic flux decreases, which decreases the torque, which leads to a lower output power.

II. PARAMETERS VARIATION DUE TO MAGNET TEMPERATURE

When the magnetic flux changes with the rotor permanent magnet temperature, magnetic saturation level in stator iron changes as well. This magnetic saturation level in the stator iron changes the magnetic permeability of the iron and changes inductances.

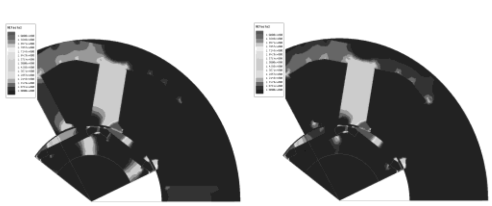

Fig. 1. Finite element analysis results against rotor permanent magnet temperature of PMSM(left. Room temperature condition / right. High temperature condition)

III. PARAMETER ESTIMATION METHOD FOR COMPENSATION OF MAGNET TEMPERATURE VARIATION

The voltage equation in the time-domain was derived within the Z-domain using a Zero-Order-Hold. The four parameter coefficient terms in the exponential equation were approximated to a linear equation using the Taylor Series to eliminate the higher degrees. The voltage equation in the Z-domain including the approximated parameter coefficient terms can be written as follows:

$$i_d(z) = \frac{d_2[v_d(z) - e_d(z)]}{z - d_1}, \quad d_1 = 1 - \frac{R_a T_s}{L_d}, \quad d_2 = \frac{T_s}{L_d}$$
$$i_q(z) = \frac{q_2[v_q(z) - e_q(z)]}{z - q_1}, \quad q_1 = 1 - \frac{R_a T_s}{L_q}, \quad q_2 = \frac{T_s}{L_q}$$

The method of Steepest Descent and Affine Projection Algorithm were used to estimate the magnetic flux and dq-axis inductances of the permanent magnet[2].

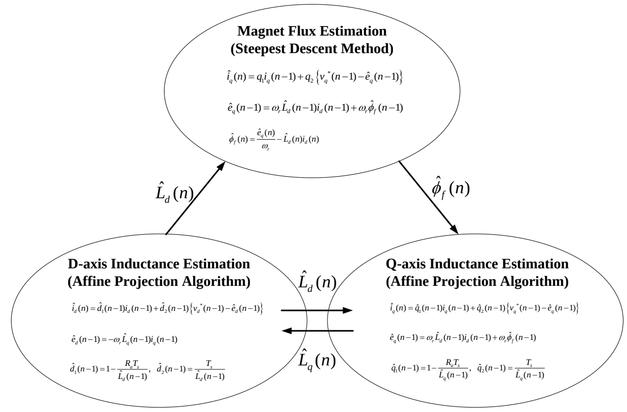

Fig. 2. Relationship between parameter estimators

IV. PROPOSED TORQUE COMPENSATION CONTROL METHOD

A torque compensation control method was proposed by estimating the parameter change using the parameter estimation methods and indirectly estimating the magnet temperature. The torque feedback was calculated using the information from the estimated parameters to reflect the change in rotor temperature. And the maximum torque per ampere(MTPA) control in the base speed under region employs the parameter information for optimal control. Fig. 3 shows the configuration of the proposed torque compensation control method.

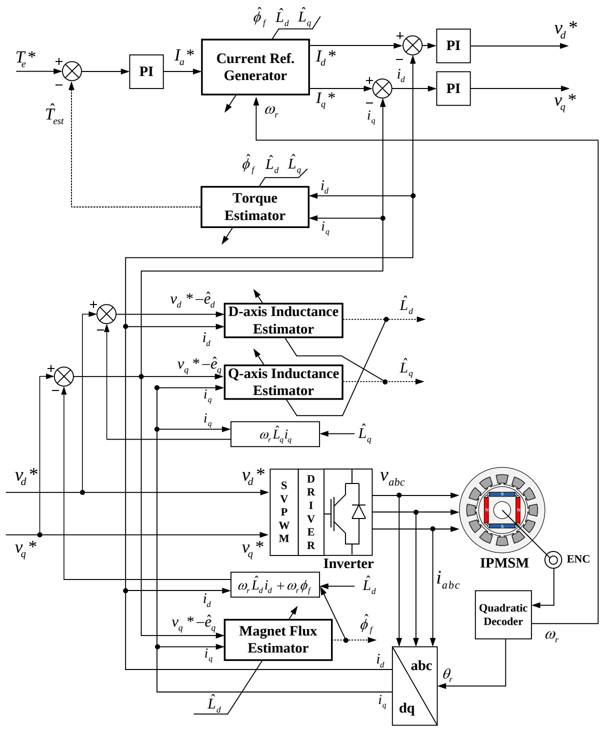

Fig. 3.Proposed torque compensation control scheme

V. Experimental verification of proposed method

To check the validity of the proposed model, the test subject used in the experiment is shown in Fig. 4 with the details in Table 1. It is a three-phase 6-pole 750W internal permanent-magnet synchronous motor (IPMSM) which also serves as a servomotor.

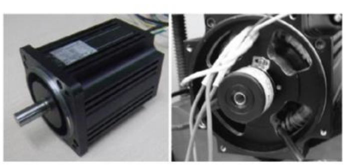

Fig. 4. Picture of IPMSM for experiment

TABLE I
SPECIFICATIONS OF THE TEST MOTOR

Specifications	Value	Unit
Rated output torque	3.58	Nm
Rated Speed(baseRPM)	2000	RPM
DC input voltage	200	V
Peak phase current	6	A
No-load Back EMF	40.4	V/kRPM

To check the validity of the proposed method with respect to rotor temperature change, the back housing of the test subject IPMSM was converted to a duct-shape and a gas torch was used to directly heat the rotor.

To obtain temperature-dependent data, three temperature regions were used: 25degC for room-, between 60~70degC for medium- and 80~90degC for high-temperature region. Temperature was measured using a contact thermometer.

Fig. 5 shows no-load back electromotive force as the rotor magnet temperature changes. No-load back electromotive force at 1000RPM in the room-, medium- and high-temperature condition were measured.

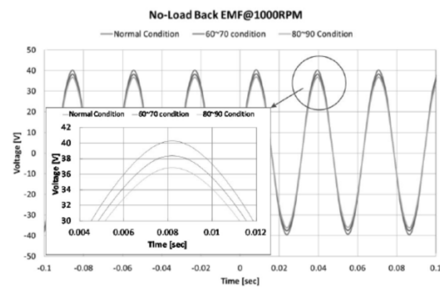

Fig. 5. No-load back E.M.F. at 1000RPM by magnet temperature variation

The rotor magnet temperature condition was divided into the medium- and high-temperature regions of the experiment and the torque compensation of the proposed model was verified by experiment. Fig. 6 shows that in both medium- and high-temperature regions the same torque command (3Nm) causes the proposed model to generate a current vector with a different magnitude and phase for compensating torque.

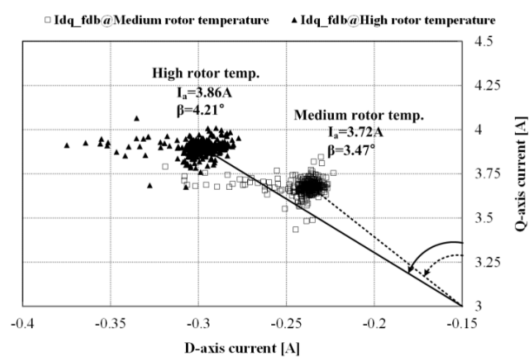

Fig. 6. Traces of current at medium and high magnet temperature condition

VI. Conclusion

A compensation torque control method was proposed using a parameter estimation method which indirectly applies change in rotor magnet temperature, which hinders the reliability of motor torque control. The validity of the proposed control method was experimentally verified.

References

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