Flux-based Cascade Vector Control for xEV Applications Reducing Calibration Time

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Permanent Magnet Synchronous Motors (PMSM) are applied to main traction motor for xEVs. Current control is usually utilized for torque control of PMSM. However, it takes long time to calibrate current controller's parameters because of PMSM's magnetic saturation. Though step-response is required for precise torque response calibration, it occurs unstable condition if setting parameters are not proper.

To cope with this problem, this paper proposes flux-based cascade vector control. It utilizes flux instead of current for torque control.

Flux-based voltage equations of PMSM is shown as Eq.(1).

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \frac{R}{L_d L_q - L_{dq} L_{qd}} \begin{bmatrix} L_q & -L_{qd} \\ -L_{dq} & L_d \end{bmatrix} \begin{bmatrix} \phi_d - K_e \\ \phi_q \end{bmatrix} + s \begin{bmatrix} \phi_d \\ \phi_q \end{bmatrix} + \omega_1 \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} \phi_d \\ \phi_q \end{bmatrix} \tag{1}$$

Where v_d, v_q are dq-axis voltage, R is stator resistance, L_d, L_q are dq-axis inductance, L_{dq}, L_{qd} are mutual inductance between dq axis, φ_d, φ_q are dq-axis flux, K_e is magnetic flux, and $\omega 1$ is rotor speed.

Assuming L_{qd} and L_{dq} are sufficiently smaller than L_d and L_q, Eq.(1) is changed as Eq.(2).

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} \frac{R}{L_d} & 0 \\ 0 & \frac{R}{L_q} \end{bmatrix} \begin{bmatrix} \phi_d - K_e \\ \phi_q \end{bmatrix} + s \begin{bmatrix} \phi_d \\ \phi_q \end{bmatrix} + \omega_1 \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} \phi_d \\ \phi_q \end{bmatrix} \tag{2}$$

Eq.(2) can consider magnetic saturation of PMSM if φ_d, φ_q are changed according to current. On the other hand, all parameters (R, φ_d, φ_q, L_d, L_q, K_e) can be calibrated by steady-state test. The proposed controller is shown in Fig.1. The proposed method bases on Eq.(2). Therefore it can consider magnetic saturation. In addition, it requires only steady-state test for torque-response calibration instead of step-response test.

The proposed method is verified by experiment of EV motor. Fig.2 shows experimental results of step-response test from zero to maximum torque. Cut-off frequency of torque controller is set as rising time is 3ms. It can be seen that the proposed method operates well. Fig.3 shows the rising time of every parameter vs. step torque. It shows the errors of rising time is within +/- 0.6 ms (that is +/- 20 %).

As above, the proposed flux-based cascade vector control realizes the reduction of calibration time with keeping precise torque control response.

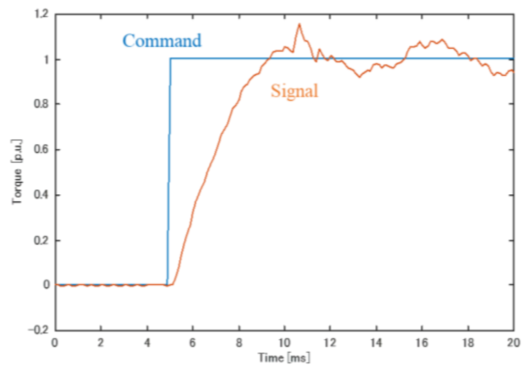

Fig.2 Experimental result of maximum torque step

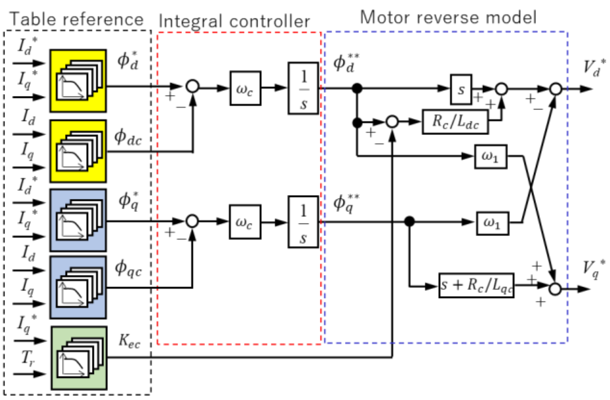

Fig.1 Block diagrams of proposed flux-based cascade vector control

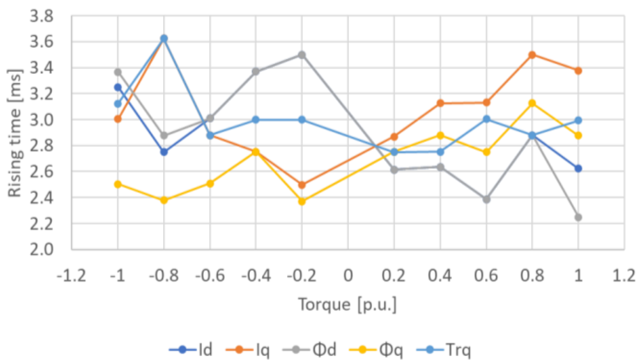

Fig.3 Experimental results of rising time