Current Control Bandwidth Required for Current Source Type Motor Emulator

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This paper experimentally verifies the current control bandwidth, which is required for a current source type motor emulator (CSTME) to prevent control interference between the CSTME and the inverter under test (IUT). The preferred relationship of the current control bandwidth between IUT and CSTME is verified in this paper. From the experimental results, the stability limit of the current control bandwidth is 2050 Hz when the current control bandwidth of the IUT is set to 500 Hz.

Keywords Motor emulator, Current control bandwidth, Stability analysis

1. Introduction

In recent years, a motor emulator has been introduced for the development of a specific motor drive system. In particular, the current source type motor emulator (CSTME) is suitable as the inverter test system without an actual motor because the CSTME imitates accurate motor current compared with a voltage source type motor emulator. However, the control instability occurs because of the interference with the current control of the inverter under test (IUT) and the one of the CSTME [1]. On the other hand, high performance is required for the power devices and the controller in order to achieve a sufficiently high current control bandwidth of the CSTME and keep the system stable. This paper experimentally verifies the current control bandwidth required for the CSTME in order to prevent control interference between the CSTME and the IUT.

2. Current Source Type Motor Emulator

Fig. 1 shows the system configuration of an inverter test system using the CSTME. The hardware configuration of the CSTME is the same as a PWM rectifier. The CSTME imitates the motor current according to the current command calculated by the motor model. In this paper, the state equation of an interior permanent magnet synchronous motor (IPMSM) as the motor model is implemented. The state equation of an IPMSM based on the dq-axis is expressed as

$$P\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} -\dfrac{R}{L_d} & \omega_{re}\dfrac{L_q}{L_d} \\ -\omega_{re}\dfrac{L_d}{L_q} & -\dfrac{R}{L_q} \end{bmatrix}\begin{bmatrix} i_d \\ i_q \end{bmatrix} + \begin{bmatrix} \dfrac{v_d}{L_d} \\ \dfrac{v_q}{L_q} \end{bmatrix} + \begin{bmatrix} 0 \\ -\dfrac{\omega_{re}\Psi_m}{L_q} \end{bmatrix} \quad \text{..............(1)},$$

where i_d and i_q are the dq-axis current, v_d and v_q are the dq-axis voltage, R is the armature resistance, L_d and L_q are the dq-axis synchronous inductance, ω_{re} is the electric angular frequency, Ψ_m is the flux linkage of the permanent magnet, and P is the differential operator.

Here, the output torque T_{out} and the relationship between the electric angular frequency and the output torque on the dq-axis are expressed as

$$T_{out} = p\{\psi_m i_q + (L_d - L_q)i_d i_q\} \quad \text{..(2)},$$

$$P\omega_{re} = \frac{p}{J}\left(T_{out} - T_L\right) \quad \text{...(3)},$$

where T_L is the load torque, p is the pairs of poles, and J is the inertia of the motor.

The current commands are obtained by solving the differential equation (1), (2), and (3) for the using the backward Eular method in a DSP.

Fig. 2 shows the block diagram of the system shown in Fig. 1. The current control loop of the CSTME is inside the current control loop of the IUT. Thus, the interference occurs between the current

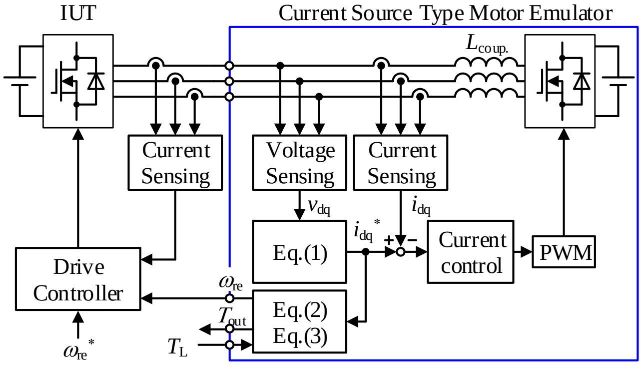

Fig. 1. System Configuration of inverter test system using the current source type motor emulator.

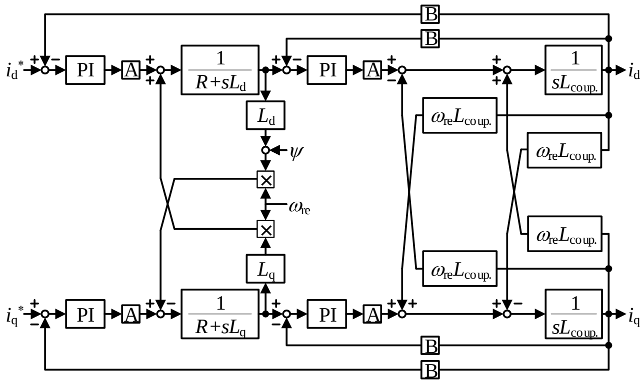

Fig. 2. Block diagram of the system shown in Fig. 1.

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controls, and the system becomes unstable when the current control bandwidth of both the CSTME and the IUT are close. The current control bandwidth of the CSTME must be designed higher than the one of the IUT in terms of prevention for stability.

3. Experimental Results

Table 1 shows the experimental condition. The switching frequency and the DC link voltage of the CSTME should be higher than that of the IUT.

The PI current control and the feed-forward compensation in order to cancel the interference between the inductor on the dq-axis are implemented in the controller of the CSTME. In this paper, note that the voltage command, which is output from the controller of the IUT using a D/A converter, is received by the A/D converter of the CSTME instead of the PWM voltage detection. In contrast, torque control is implemented in the controller of the IUT. In this case, the d-axis current command is set to zero, and the q-axis current command is determined from the torque command.

Fig. 3 shows the waveform when the torque step applies to the IUT. The current control bandwidth of the IUT is set to 500 Hz. As shown in Fig. 3, torque and current oscillations are smaller when the current control bandwidth of the CSTME is higher. In addition, torque and current oscillations are occurring in Fig. 3 (b) and Fig. 3 (c). However, the oscillation is decreasing only in Fig. 3 (c). Thus, the stability limit of the current control bandwidth of the CSTME is between 2000 Hz and 2050 Hz. Therefore, the CSTME requires the current control bandwidth that is approximately four times the current control bandwidth of the IUT.

4. Comparison with simulation results

In this section, the required bandwidth is obtained by simulation containing the delay factors. The simulation model is implemented by a continuous system, and the delay factors are implemented as the first-order delay. Adding delay factors are as follows:

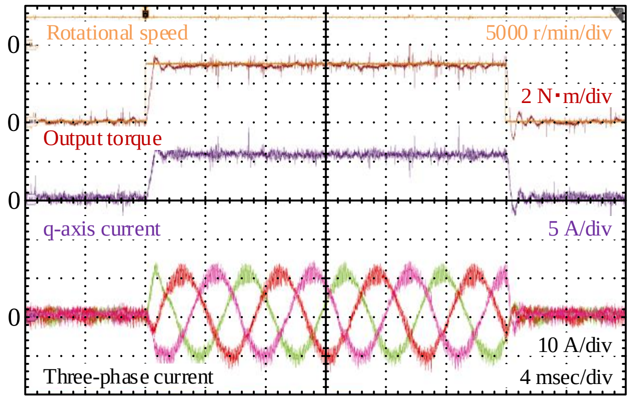
1) output of PI (caused by voltage command update) (A in Fig. 2)
2) current feedback (caused by sampling delay) (B in Fig. 2)

In this simulation, the different sampling delay is added to the CSTME and the IUT because the switching frequency of the CSTME is different from that of the IUT.

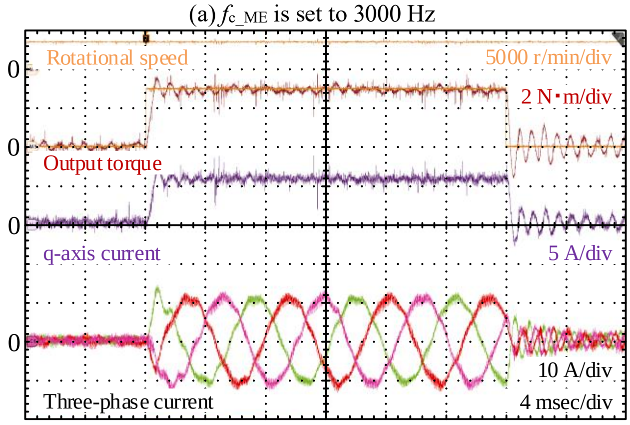
Table 2 shows the error rate between the stability limit obtained by simulation and one of the experiments. In this case, the stability limit of the CSTME obtained by experiments is 2050 Hz. The stability limit without the delay factor is 991 Hz with an error rate of 51.6% compared to the experimental result. In the case of adding the delay factor of 1), the stability limit is 1501 Hz with an error rate of 26.8%. Furthermore, adding the delay factor of 2), an error rate decreases to 16.4%. In this case, the stability limit is 2386 Hz, which is higher than the experimental limit because the experimentally limit is lower due to the damping factor, which is losses of the circuit. From these results, the stability limit of the CSTME is estimated with high accuracy by containing the delay factors 1) and 2).

Table 1. Experimental condition.

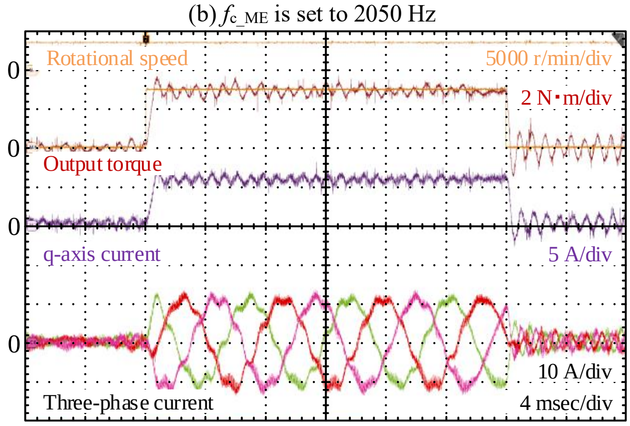
Parameter	Symbol	Value
DC link voltage of IUT	V_{dc_IUT}	280 V
DC link voltage of ME	V_{dc_ME}	320 V
Coupling inductor	$L_{coup.}$	1.73mH
Current control bandwidth of IUT	f_{c_IUT}	500 Hz
Switching frequency of IUT	f_{sw_IUT}	10 kHz
Switching frequency of ME	f_{sw_ME}	40 kHz



(a) f_{c_ME} is set to 3000 Hz



(b) f_{c_ME} is set to 2050 Hz



(c) f_{c_ME} is set to 2000 Hz

Fig. 3. Waveforms of torque step response when f_{c_IUT} is set to 500 Hz.

Table 2. Relationship between stability limit and delay factor.

condition	Stability limit	Error
Without delay factor	993 Hz	51.6%
With delay factor of A in Fig. 2	1501 Hz	26.8%
With delay factor of A and B in Fig. 2	2386 Hz	16.4 %

References

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