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Accurate two-degree-of-freedom discrete-time current controller design for PMSM using complex vectors

Key words: Permanent magnet synchronous machine (PMSM); Discrete-time current controller; Complex vector

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Motivation

1. Permanent magnet synchronous machine (PMSM) drive has received increasing attention for its high power density, high dynamic performance, and advantages in high-speed applications.
2. The common used continuous-time current controller based on the continuous PMSM model will cause inevitable performance degradation because of the intrinsic delay of the digital processor.
3. Using the complex vector notation, the non-salient PMSM can be simplified to a single-input single-output complex vector system, and a simple direct design method in the discrete-time domain can be conducted.

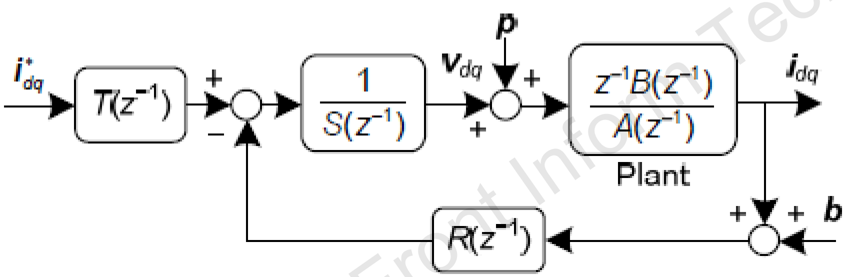
Main idea

1. The integrated accurate hold-equivalent discrete model for PMSM considering the difference between the output of the voltage source inverter and the back electro-motive force can be derived using complex vectors.

2. The accurate two-degree-of-freedom (2DOF) current controller is designed directly in the discrete-time domain, and its performance can be evaluated conveniently via the complex vector root locus and sensitivity functions.

Method

1. Derive the discrete model for PMSM using complex vectors.
2. The accurate 2DOF discrete-time current controller is obtained by integrating polynomials $R(z^{-1})$, $S(z^{-1})$ and $T(z^{-1})$, where the transfer function of the current loop can be designed as desired.



$$H_{\mathrm{cl}}(z^{-1}) = \frac{z^{-1}B(z^{-1})T(z^{-1})}{A(z^{-1})S(z^{-1}) + z^{-1}B(z^{-1})R(z^{-1})} = \frac{z^{-1}B(z^{-1})T(z^{-1})}{P(z^{-1})},$$

$$P(z^{-1}) = (1 - t_1 z^{-1})(1 - p_1 z^{-1})^3 = A(z^{-1})S(z^{-1}) + z^{-1}B(z^{-1})R(z^{-1})$$

$$\Rightarrow \begin{cases} S(z^{-1}) = (1 - z^{-1})(1 + s_1 z^{-1} + s_2 z^{-2}), \\ R(z^{-1}) = r_0 + r_1 z^{-1}, \\ T(z^{-1}) = R(1) \cdot (1 - t_1 z^{-1}) / (1 - t_1), \end{cases}$$

Major results

Position of poles of the current loop can be fully assigned using the 2DOF discrete-time controller.

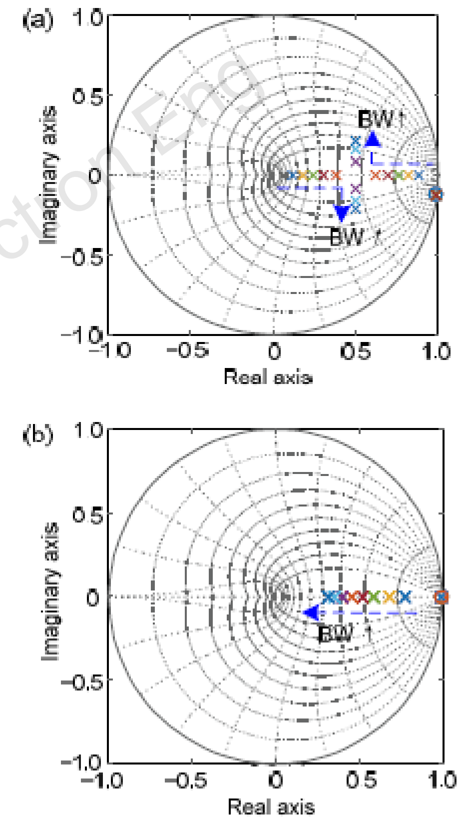


Fig. 9 Migration of the poles of the current loop with the DCV-PI controller (a) and 2DOF discrete-time controller (b) as the closed-loop bandwidth (BW) increases (References to color refer to the online version of this figure)

Major results (Cont’d)

1. Disturbance rejection properties of two kinds of 2DOF discrete-time controllers and the DCV-PI controller.

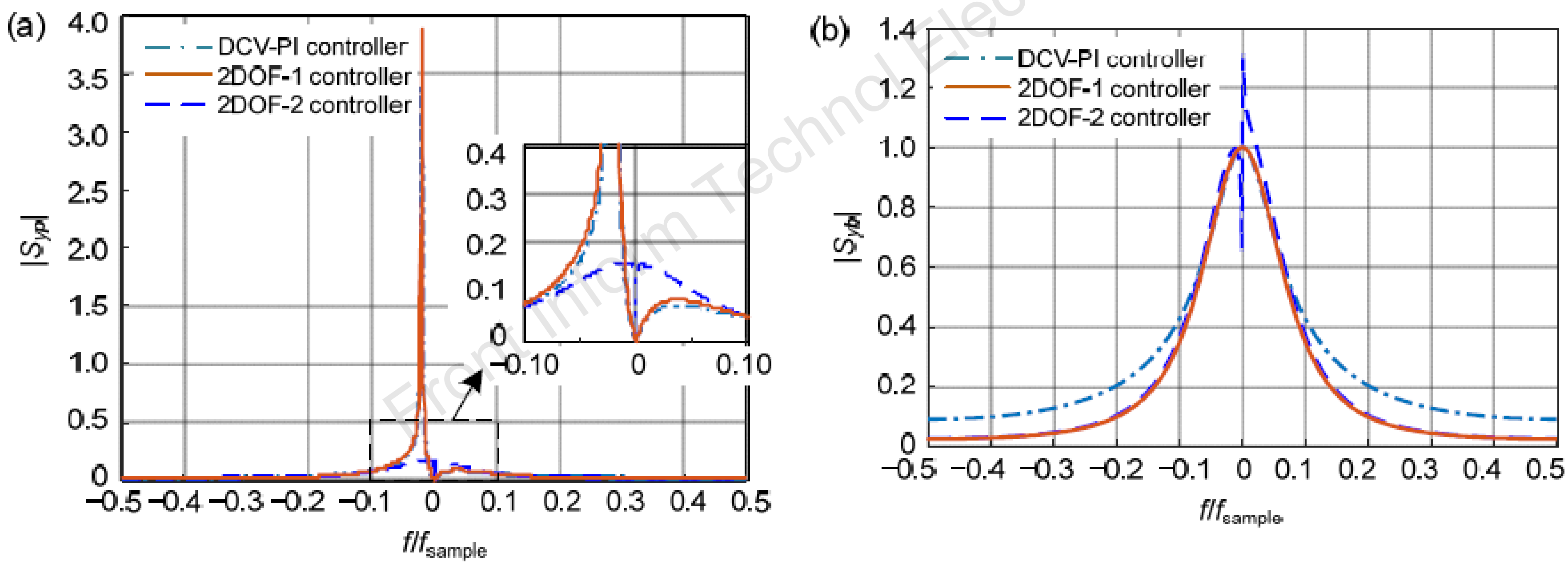


Fig. 10 Frequency characteristics of the modulus of the sensitivity function from the disturbance (a) or noise (b) to the output

Major results (Cont’d)

2. Sensitivity to parameter variation of the two 2DOF discrete-time controllers.

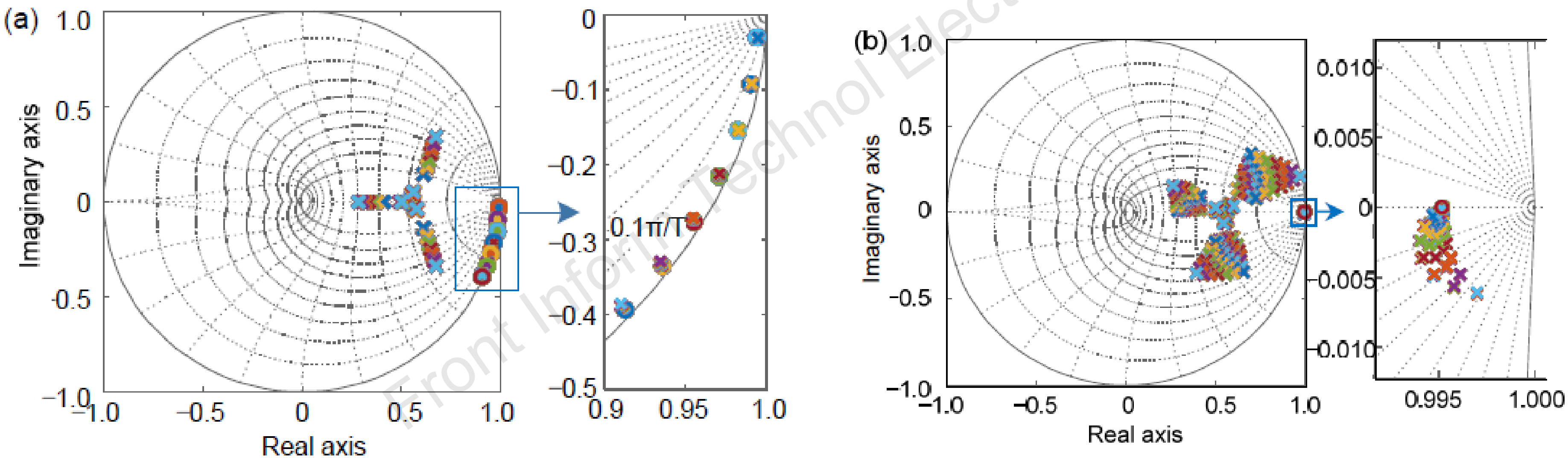


Fig. 11 Robust root locus of the current loop with the 2DOF-1 (a) or 2DOF-2 (b) controller when parameters change from 0 to 40% and $\omega \in [2\pi \cdot 50, 2\pi \cdot 800]$ rad/s (References to color refer to the online version of this figure)

Conclusions

1. With the accurate integrated hold-equivalent discrete model for the PMSM, the current controller can be designed directly in the discrete-time domain utilizing the complex vector root locus and sensitivity functions.

2. The 2DOF discrete-time accurate decoupling controller has preferred disturbance rejection property and transient response without oscillation to disturbances.

3. In fact, the 2DOF discrete-time controller is a more general controller structure that has more freedom in design. It can be configured like the state-feedback PI controller or the complex vector PI controller.