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PDC-Based Hybrid Flux Observer with Flux Error Estimation for Sensorless SPMSM Drives

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Abstract

Parameter mismatch is a major cause of severe position estimation errors in sensorless surface permanent magnet synchronous motor (SPMSM) drives. This article proposes a parallel disturbance controller (PDC)-based hybrid flux observer (HFO) with flux error estimation to enhance robustness against parameter mismatch. The PDC estimates the flux error caused by parameter variations in the current mod-el and compensates for it via a feedback loop, improving rotor position accuracy. Finally, experiments on a 750W SPMSM drive platform validate the effectiveness of the proposed method.

Introduction

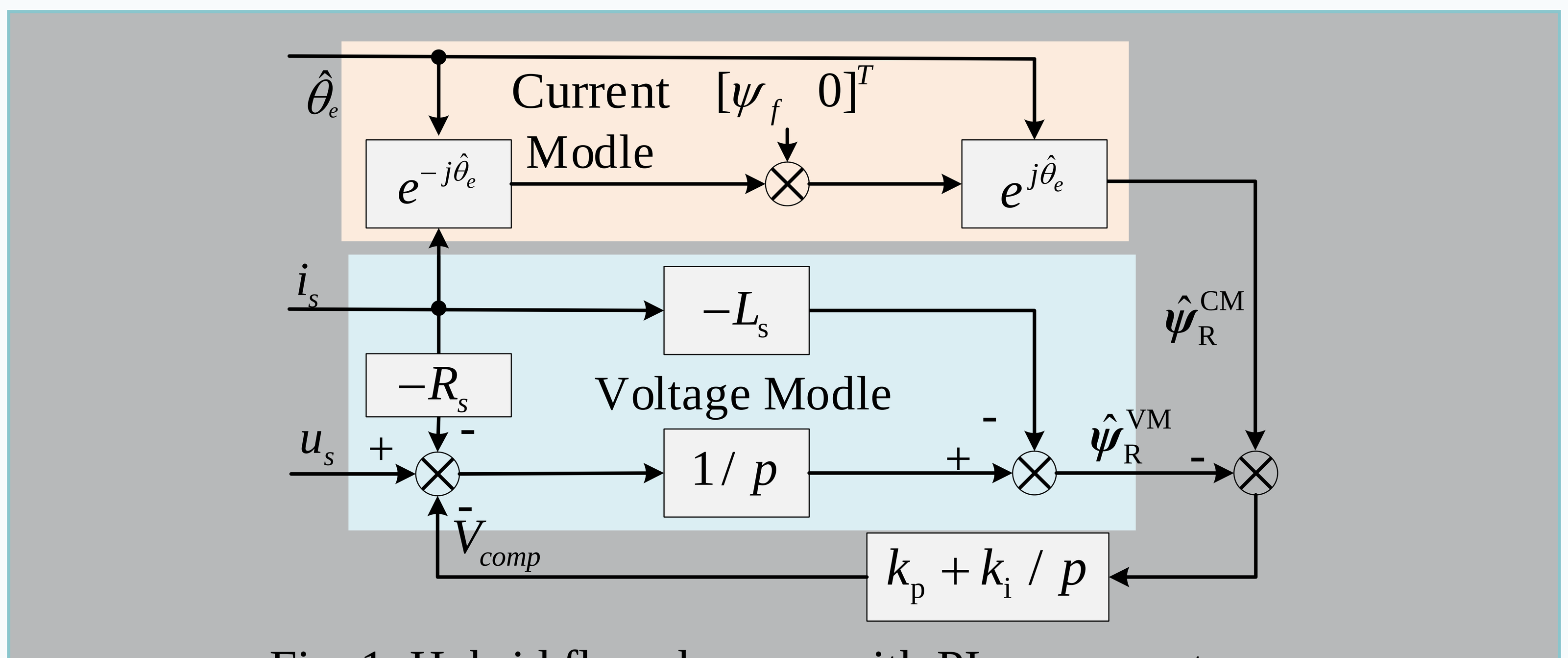

Fig. 1. Hybrid flux observer with PI compensator

The discrepancies between the voltage model and the current model are input into a proportional-integral (PI) controller to generate the compensation voltage. The rotor flux model transforms into an adaptive hybrid flux observer reliant on estimation errors.

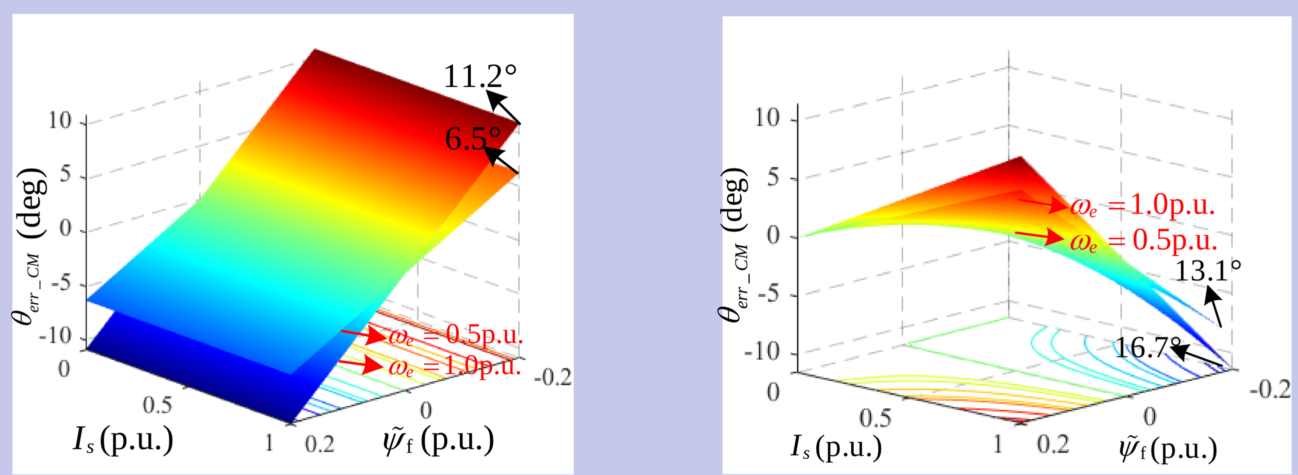

Fig. 2. Analysis Results of Position Estimation Error Due to Flux Linkage Parameter Mismatch

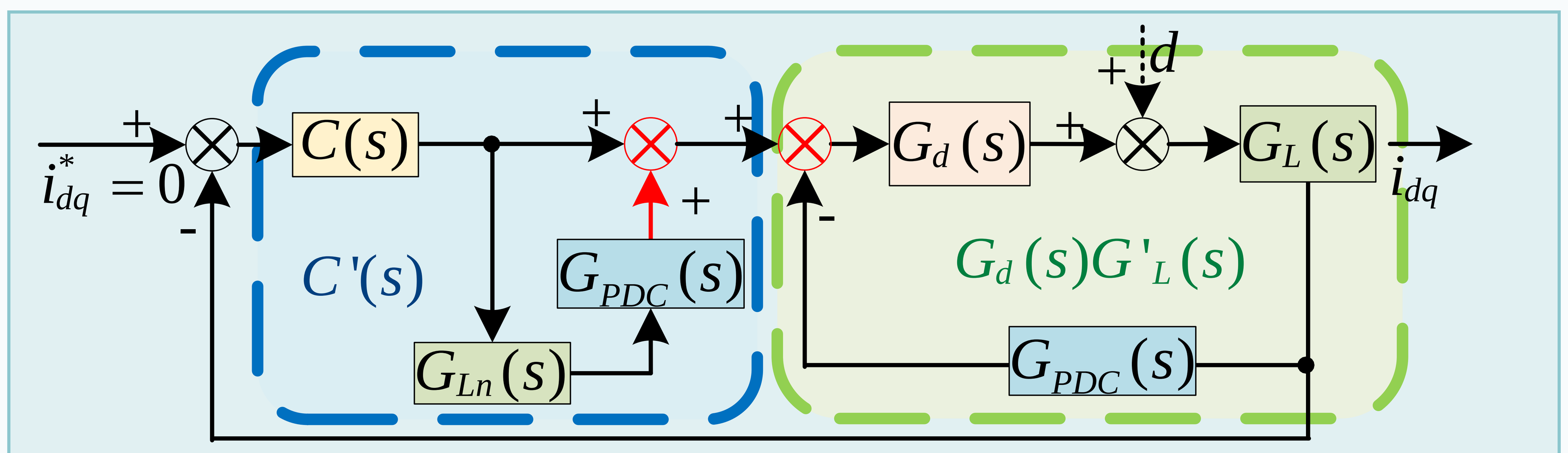

Fig. 3. Block diagram of PDC structure.

Analyzing the disturbance transfer function of the parallel disturbance controlled current loop system under zero-current command conditions (idq*=0) with only disturbances considered, the cur-rent loop block diagram can be equivalently represented by the control structure shown in Fig. 7.

Method

Flux Linkage Error Compensation with PDC

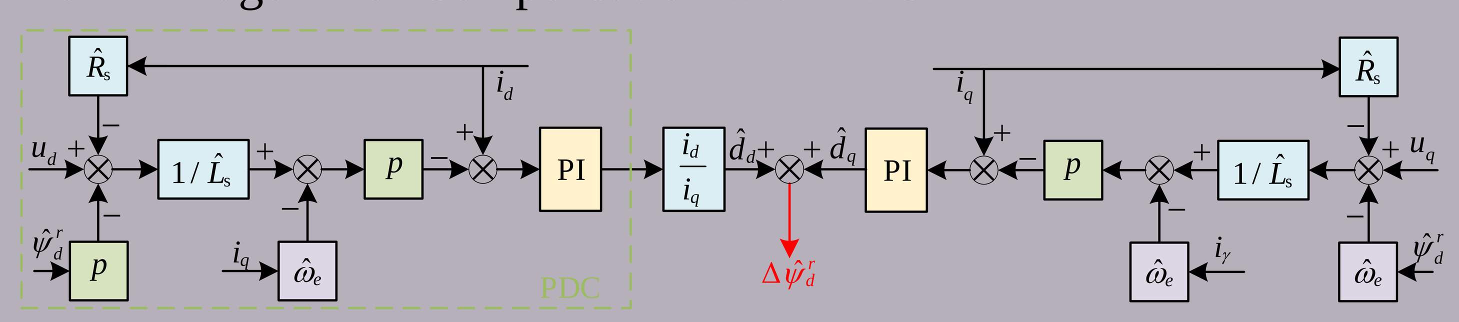

Fig. 4.Block diagram of proposed PDC with flux error estimation

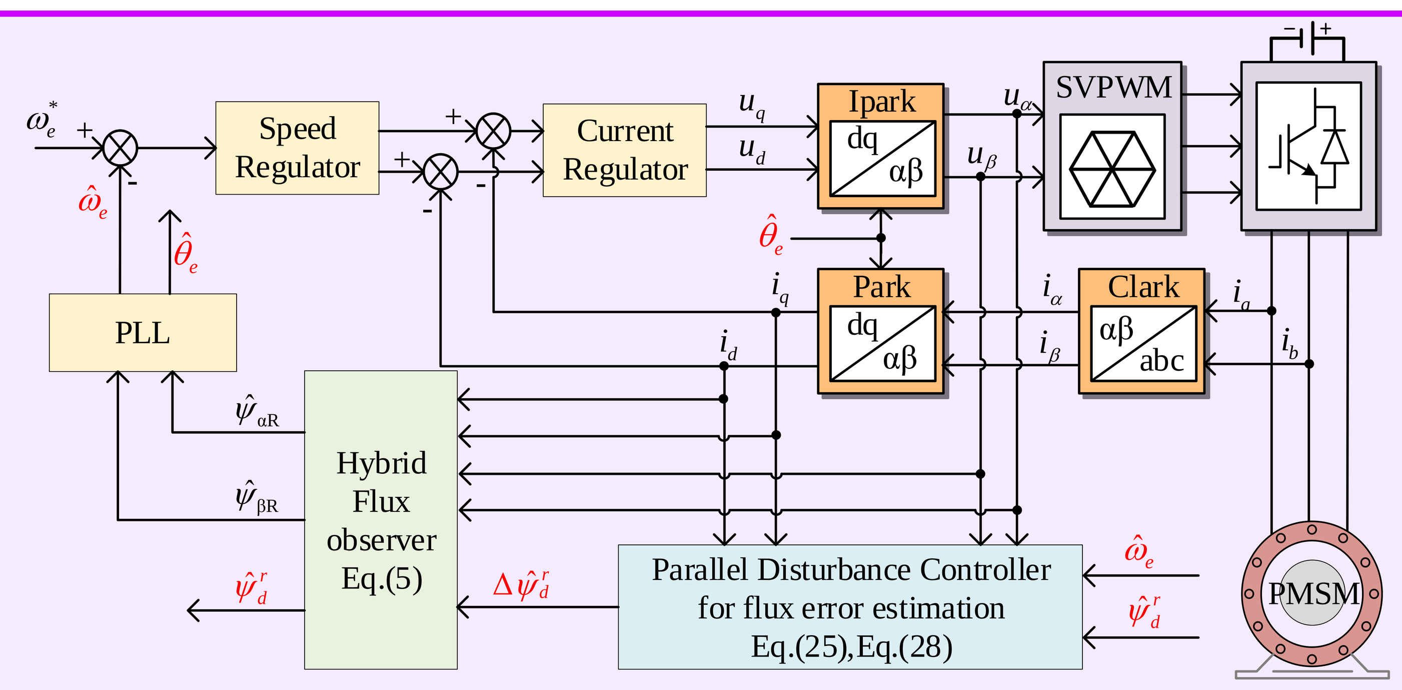

Fig. 5.Block diagram of proposed PDC with flux error estimation

Motor equations can be reformulated as:

$$p\boldsymbol{i}_{dq} = \bar{\boldsymbol{U}}_{dq} + d_{dq}$$

$$\bar{\boldsymbol{U}}_{dq} = (\boldsymbol{u}_{dq} - R_s\boldsymbol{i}_{dq} - \hat{\omega}_e\boldsymbol{J}\hat{L}_s\boldsymbol{i}_{dq} - \hat{\omega}_e\boldsymbol{J}\hat{\boldsymbol{\psi}}^{r}_{dq} - p\hat{\boldsymbol{\psi}}^{r}_{dq}) / \hat{L}_s$$

$$d_{dq} = (-\tilde{L}_s p\boldsymbol{i}_{dq} - \hat{\omega}_e\boldsymbol{J}\tilde{L}_s\boldsymbol{i}_{dq} - \hat{\omega}_e\boldsymbol{J}\Delta\hat{\boldsymbol{\psi}}^{r}_{dq} - p\Delta\hat{\boldsymbol{\psi}}^{r}_{dq}) / \hat{L}_s$$

The intermediate variables i_{dq} and $u_{dq}G_{Ln}(s)$ are represented as i_{dq} and $\boldsymbol{U}_{dq}/p$, within PDC architecture incorporating the stator flux error estimation algorithm.

$$\hat{d}_{dq} = (k_{p\_pdc} + k_{i\_pdc} / p)e_{PDC}$$

$$e_{PDC} = \boldsymbol{i}_{dq} - \bar{\boldsymbol{U}}_{dq} / p$$

the disturbance d_{dq} can be designed as the output of the parallel disturbance controller. Thus, the PDC on the d-q axes can be expressed as:

$$\hat{d}_{dq} = (-\hat{\omega}_e\boldsymbol{J}\tilde{L}_s\boldsymbol{i}_{dq} - \hat{\omega}_e\boldsymbol{J}\Delta\hat{\boldsymbol{\psi}}^{r}_{dq}) / \hat{L}_s$$

Experimental Verification

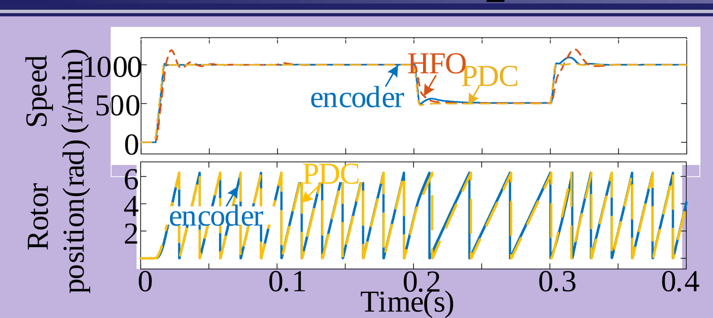

Fig. 6.Acceleration/Deceleration experiments.

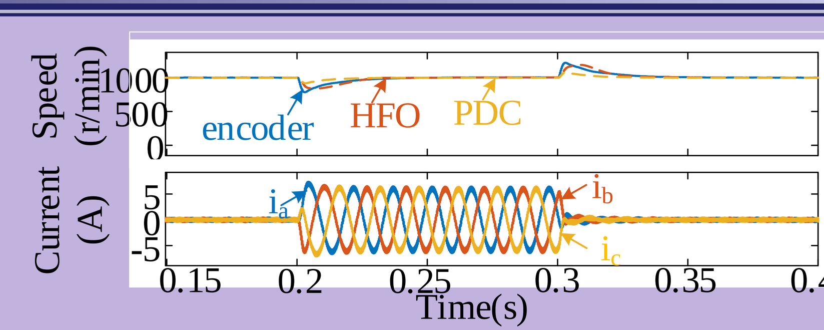

Fig. 7.Experiment of loading/unloading at 1000rpm

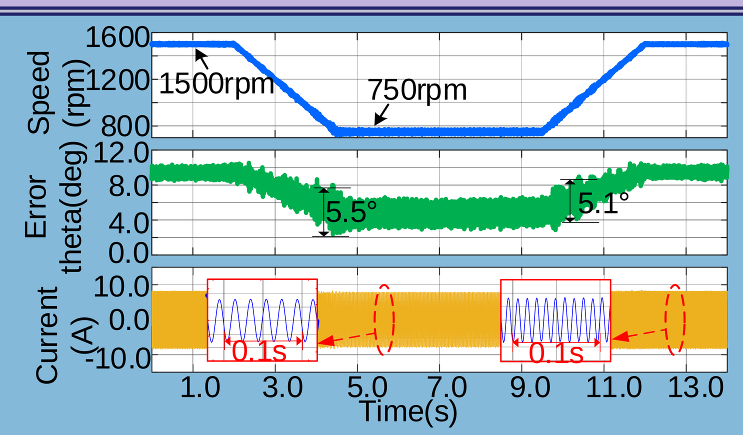

Fig. 8. Acceleration/Deceleration experiments

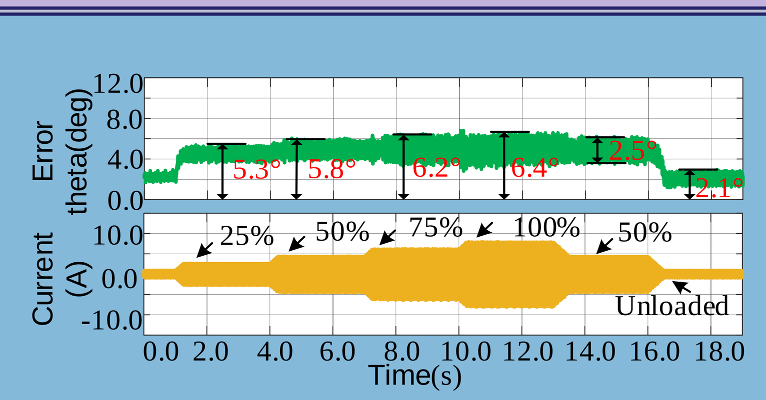

Fig. 9. Experiment of loading/unloading at 750rpm

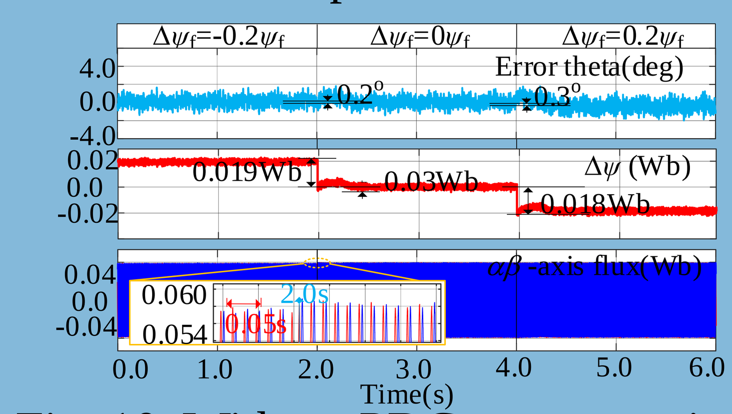

Fig. 10. Without PDC compensation

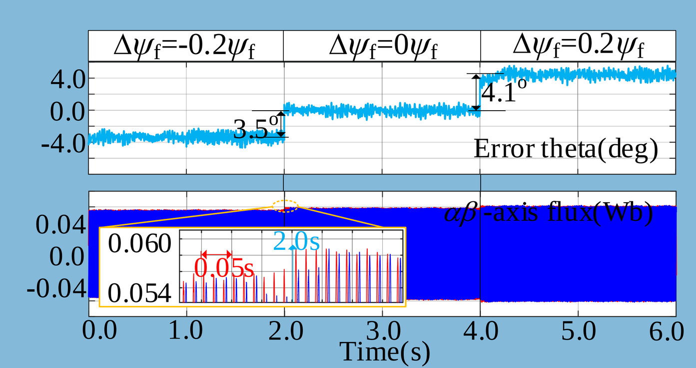

Fig. 11. With PDC compensation

Conclusion

After introducing the fundamental concept of HFO, this paper integrates PDC to propose a PDC-based hybrid flux observer. Experimental results indicate that compared with conventional HFO, the proposed method improves rotor position estimation accuracy by 25% and enhances robustness against parameter mismatch. The compensation mechanism effectively reduces flux estimation errors, ensuring stable motor operation under ±20% flux parameter disturbances. Testing on a 750W sensorless SPMSM drive verified the method's effectiveness, demonstrating position tracking errors not exceeding 0.3° under time-varying pa-rameter conditions, confirming its industrial applicability.