Design of Sensorless Field Oriented Control Drives for BLDC Motors

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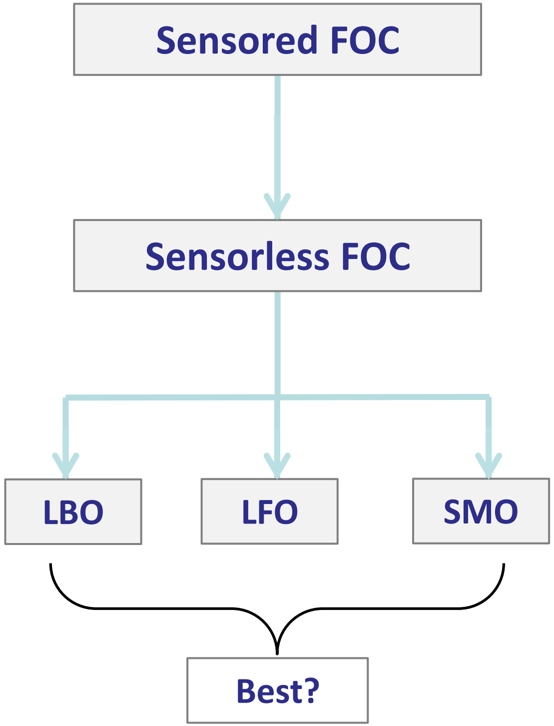
Introduction

- Field Oriented Control (FOC) is currently the best performing motor control algorithm for BLDCs..
- Higher efficiency, virtually non-existent torque ripple, faster dynamic responses etc. over other control algorithms..
- FOC requires the rotor angular position, and can be implemented in either Sensored mode or Sensorless mode..
- Sensorless FOC can be implemented using different kinds of observers..
- A comparison between these observers was not present, indicating a knowledge gap..

Objectives

- Simulating & testing the of the Sensored FOC system..
- Simulating the Sensorless system using different observers
    - *Luenberger BEMF Observer (LBO)*
    - *Luenberger Flux Observer (LFO)*
    - *Sliding Mode BEMF Observer (SMO)*
- Comparing the performance of the different Sensorless systems..
- Recommending an observer type to be used in future developments..



Control System – Sensored FOC

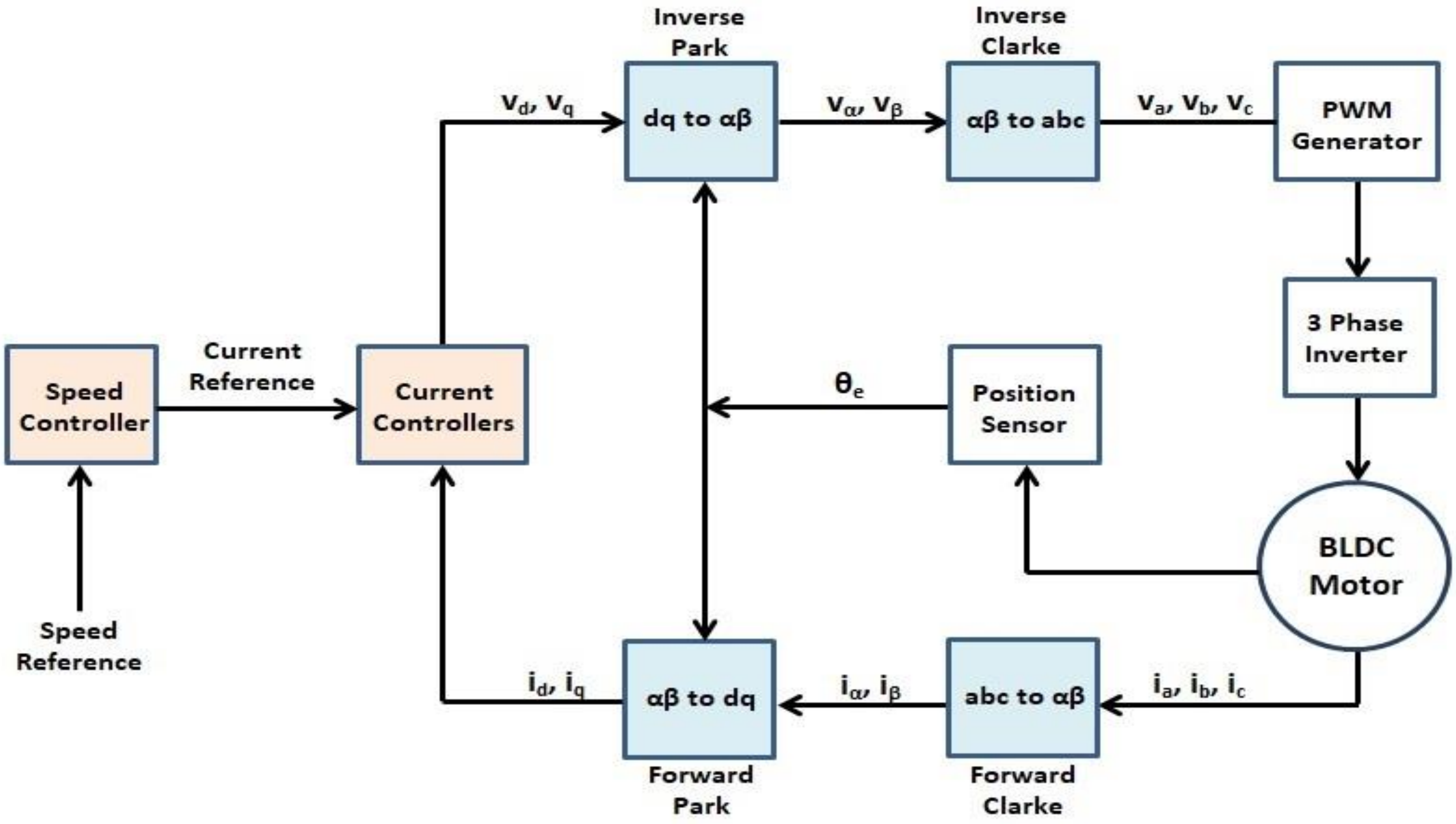


Figure 01: Sensored FOC Block Diagram

Control System – Sensorless FOC

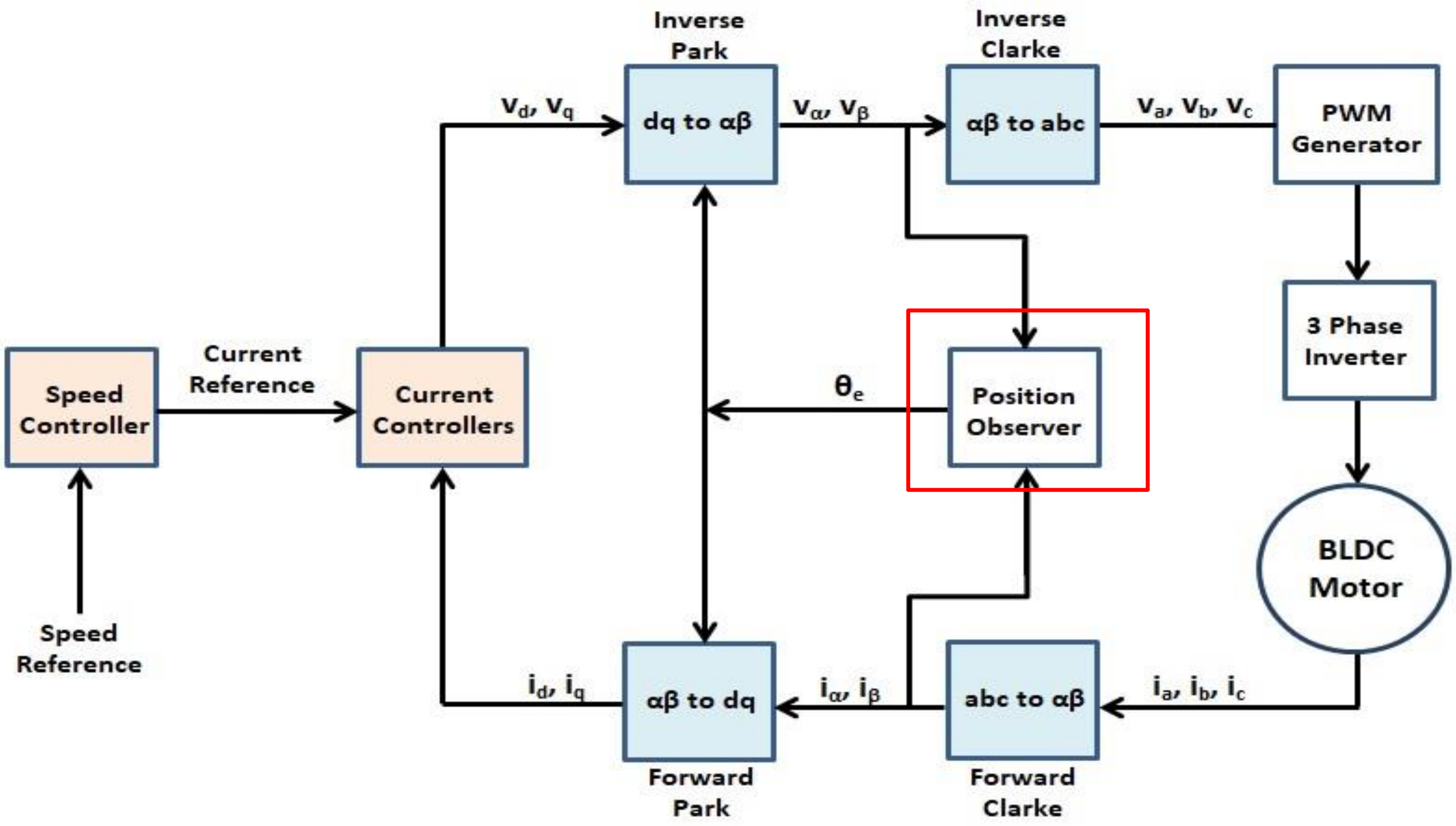


Figure 02: Sensorless FOC Block Diagram

MATLAB Simulink Models – Overall Model

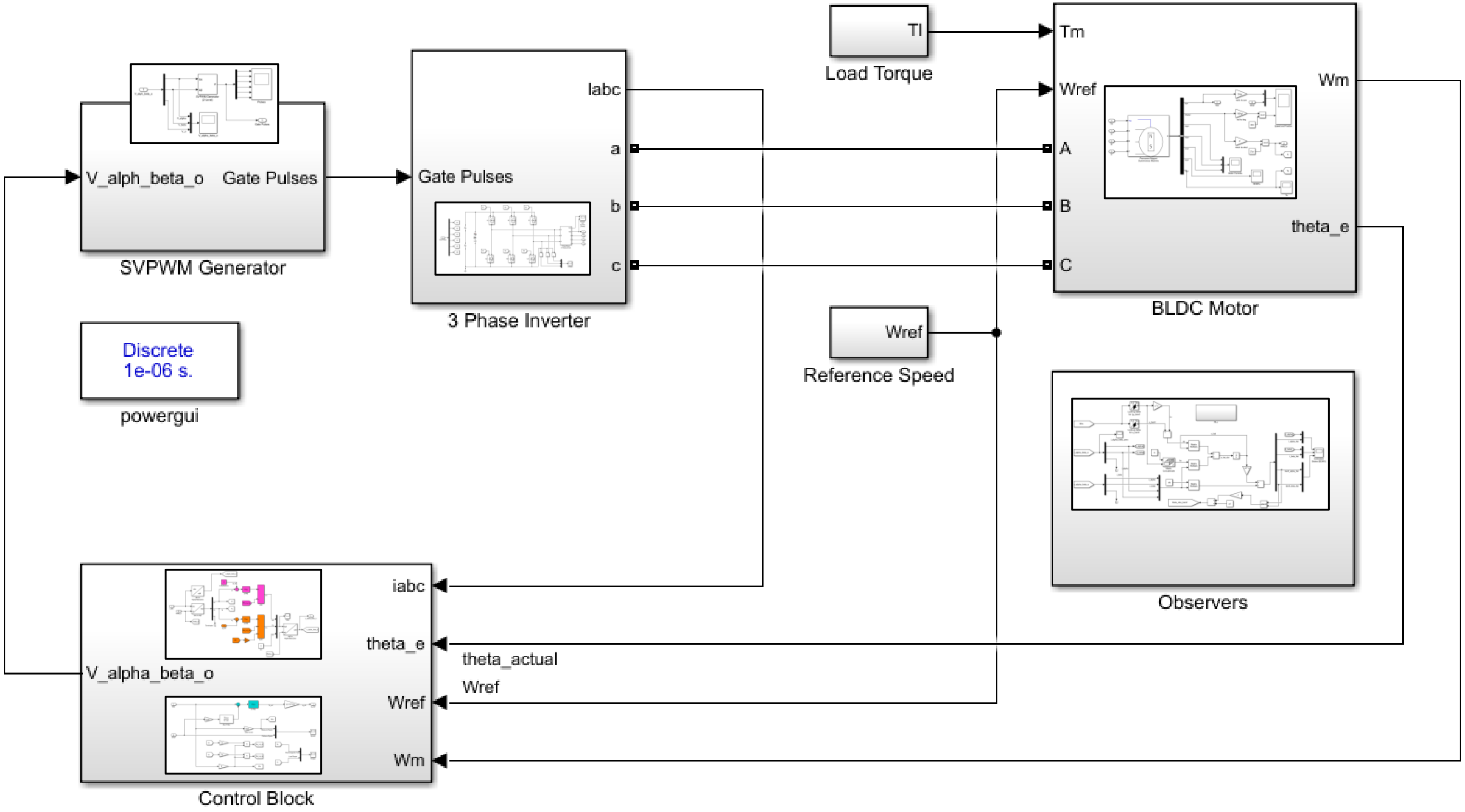


Figure 03: Overall MATLAB Simulink model of the system

MATLAB Simulink Models – Overall Model

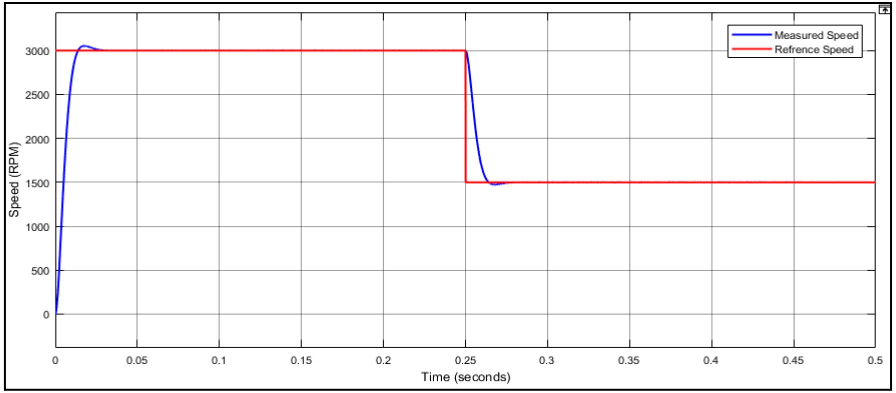


Figure 04: Variation of motor speed with time using Sensored FOC

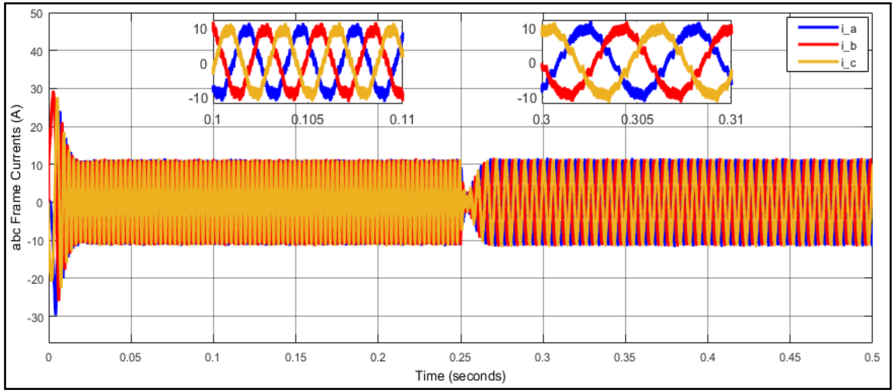


Figure 05: Variation of abc phase currents with time

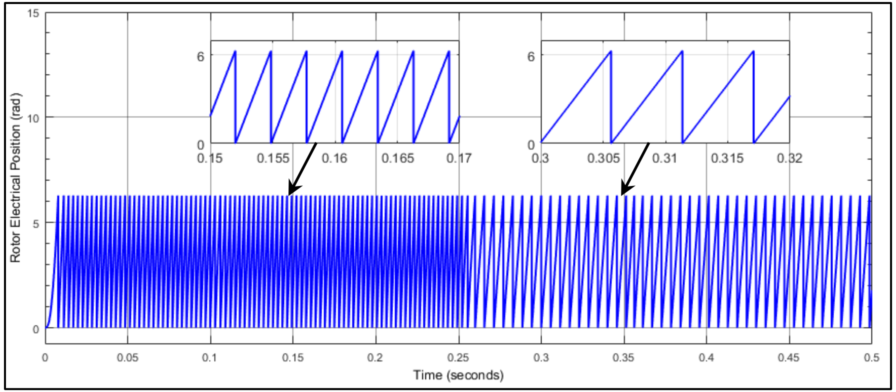


Figure 06: Variation of rotor position with time

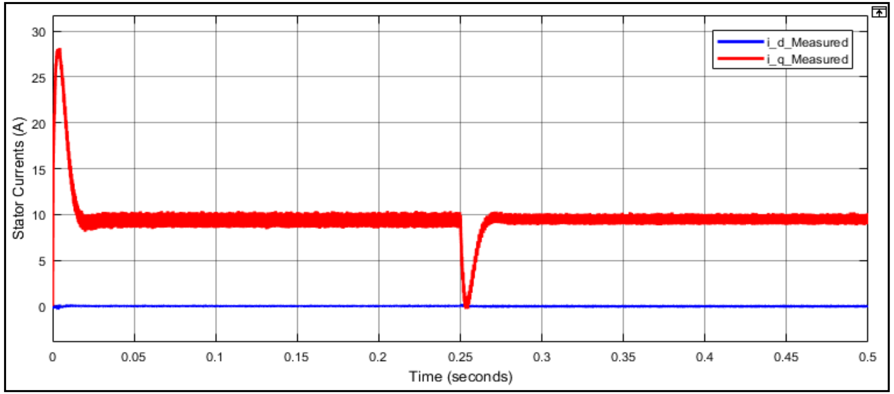


Figure 07: Variation of dq phase currents with time

MATLAB Simulink Models – Luenberger Observers

$$\dot{x} = Ax + Bu$$

$$y = Cx$$

$$\dot{\hat{x}} = (A - LC)\hat{x} + \begin{bmatrix} B & L \end{bmatrix} \begin{bmatrix} u \\ y \end{bmatrix}$$

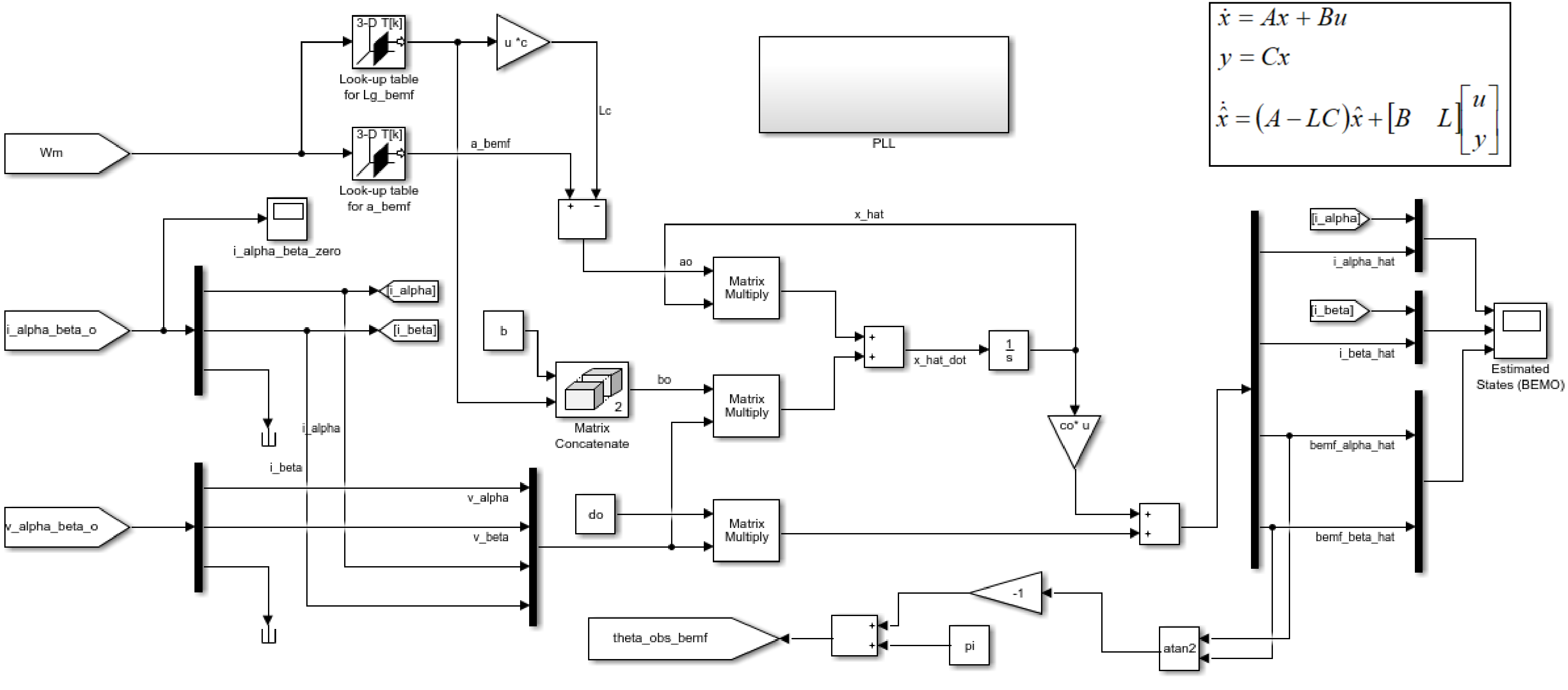


Figure 08: Simulink implementation of Luenberger Observers

MATLAB Simulink Models – Sliding Mode Observer

- Implemented in a similar manner to that given in Qiao et al. (2013)

$$L_s\left(\frac{d\hat{i}_\alpha}{dt}\right) = -R_s\hat{i}_\alpha + u_\alpha - kF(\hat{i}_\alpha - i_\alpha)$$
$$L_s\left(\frac{d\hat{i}_\beta}{dt}\right) = -R_s\hat{i}_\beta + u_\beta - kF(\hat{i}_\beta - i_\beta).$$

$$\frac{d\hat{e}_\alpha}{dt} = -\hat{\omega}_r\hat{e}_\beta - l(\hat{e}_\alpha - e_\alpha)$$
$$\frac{d\hat{e}_\beta}{dt} = \hat{\omega}_r\hat{e}_\alpha - l(\hat{e}_\beta - e_\beta)$$
$$\frac{d\hat{\omega}_r}{dt} = (\hat{e}_\alpha - e_\alpha)\hat{e}_\beta - (\hat{e}_\beta - e_\beta)\hat{e}_\alpha$$

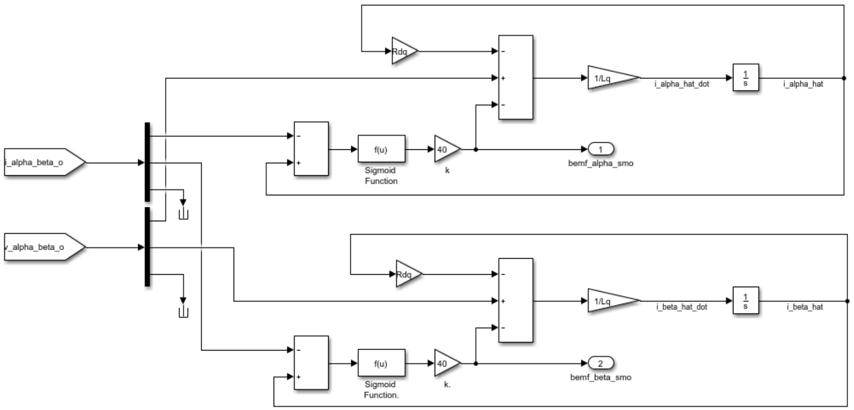


Figure 09: Sliding Mode Observer – Stage 1

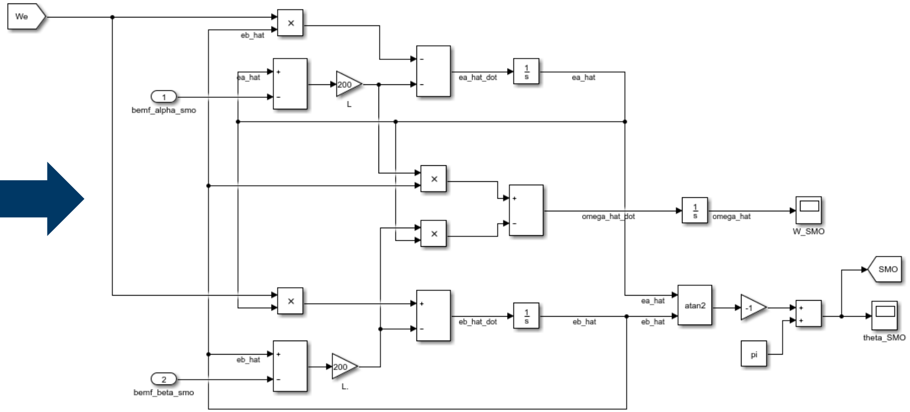


Figure 10: Sliding Mode Observer – Stage 2

Results – Sensorless FOC (Position Variation)

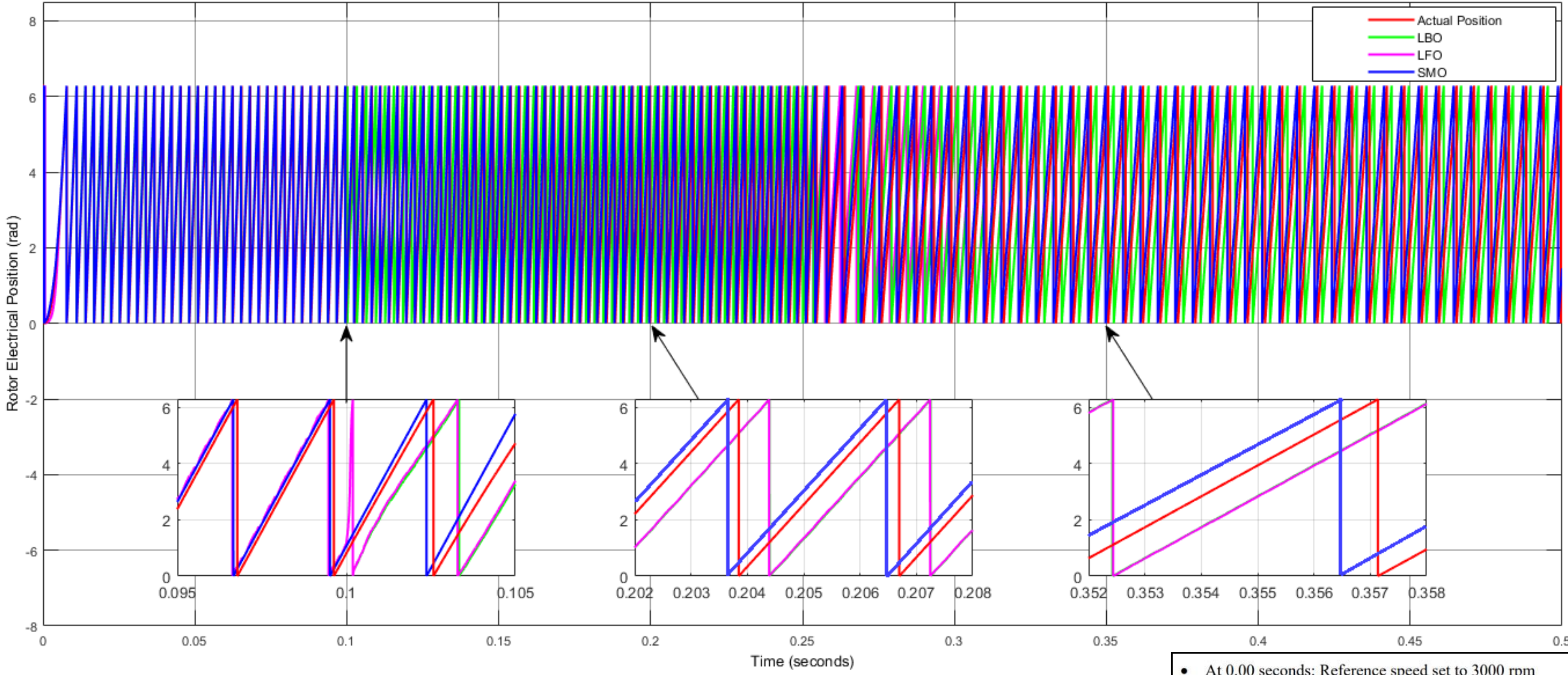


Figure 11: Variation of rotor angular position with time using Sensorless FOC

- At 0.00 seconds: Reference speed set to 3000 rpm
- At 0.00 seconds: Full load torque of 0.1432 Nm applied
- At 0.10 seconds: Switching from sensored to sensorless mode
- At 0.25 seconds: Reference speed decreased to 1500 rpm

Results – Sensorless FOC (Speed Variation)

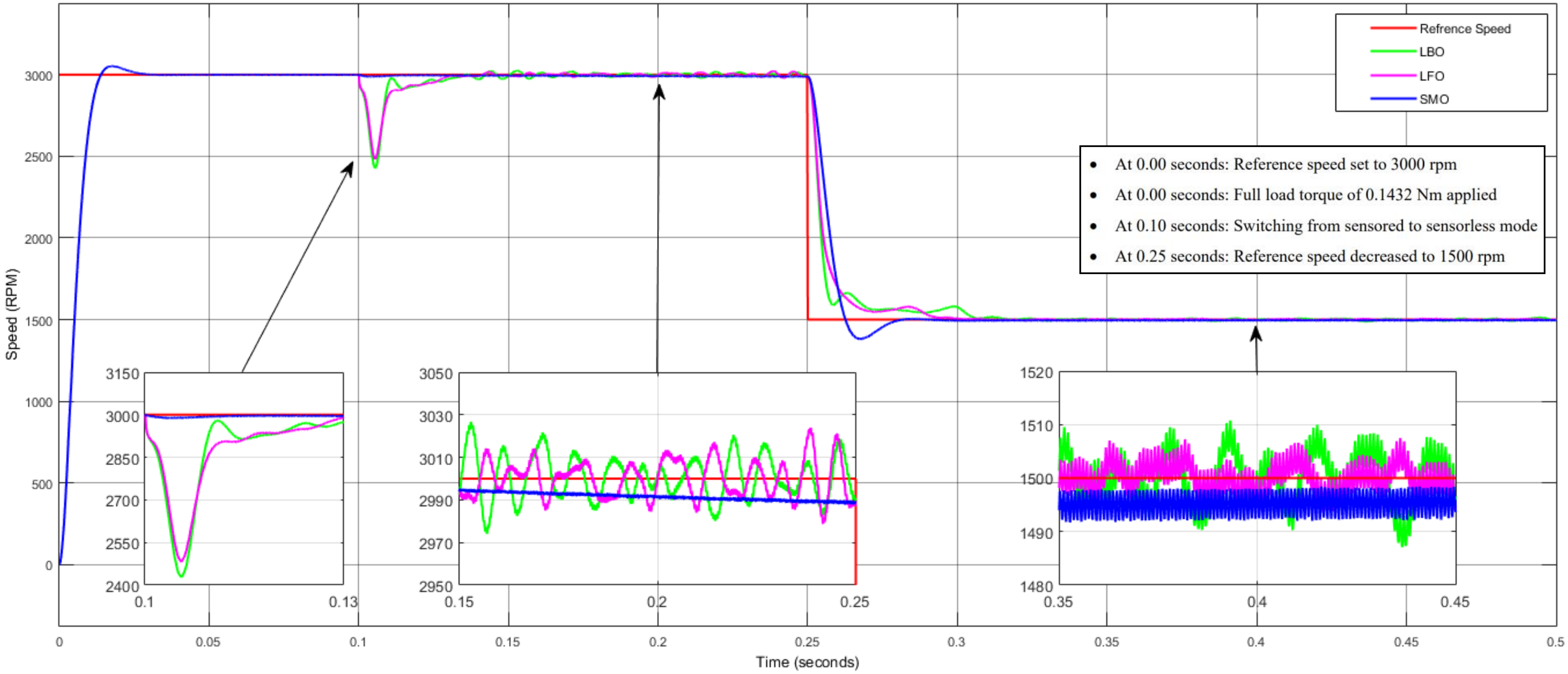


Figure 12: Variation of motor speed with time using Sensorless FOC

Results – Sensorless FOC (Sliding Mode BEMF Observer)

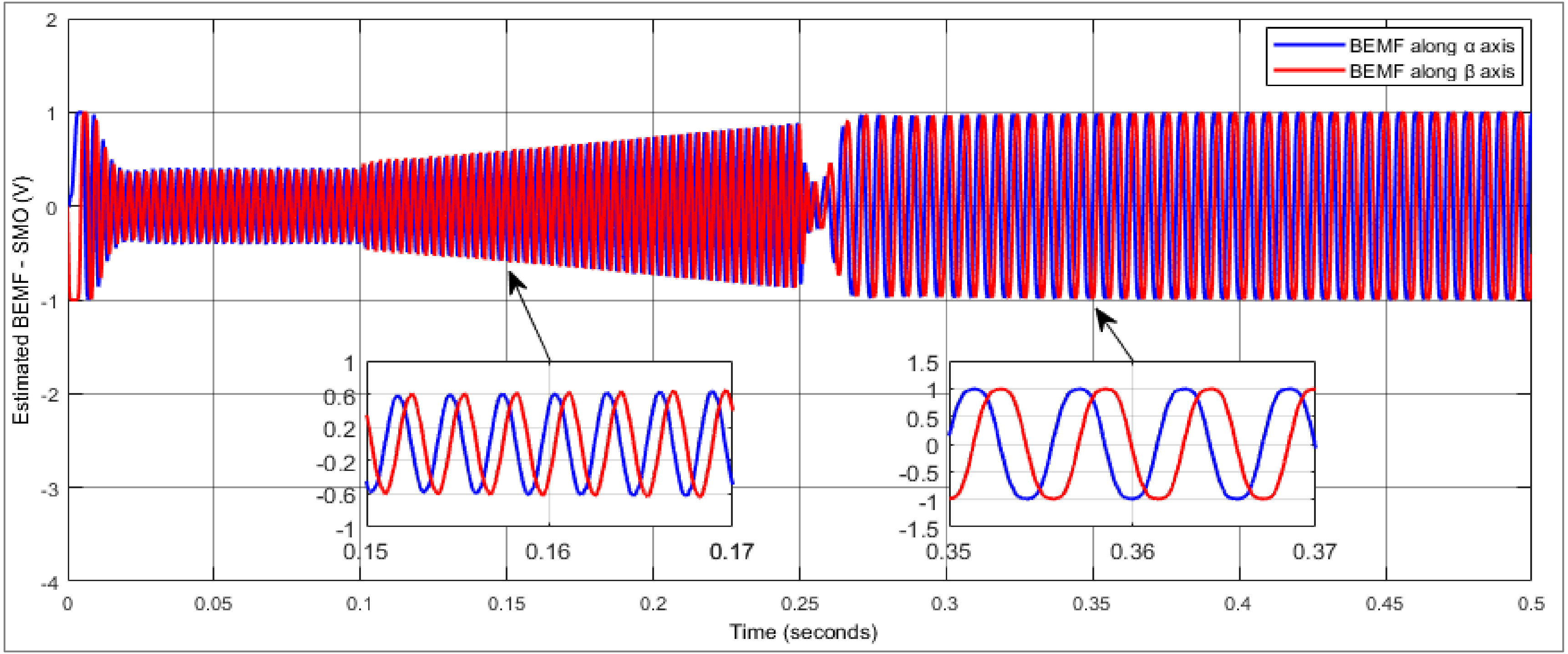


Figure 13: Estimated BEMF waveforms by the Sliding Mode Observer

- At 0.00 seconds: Reference speed set to 3000 rpm
- At 0.00 seconds: Full load torque of 0.1432 Nm applied
- At 0.10 seconds: Switching from sensored to sensorless mode
- At 0.25 seconds: Reference speed decreased to 1500 rpm

- After switching to sensorless mode, BEMF magnitude keeps increasing even during constant speed regions

Results – Sensorless FOC (Summary)

Table 01: Summary of observer performance characteristics

Parameter		LBO	LFO	SMO
Speed fluctuation during switching		-600 rpm	-500 rpm	-10 rpm
Settling time after switching		0.03 s	0.04 s	0.02 s
Steady state speed ripple	3000 rpm	±10 rpm	±15 rpm	Negligible
	1500 rpm	±5 rpm	±10 rpm	±6 rpm
Mean steady state speed error	3000 rpm	0	0	-62 rpm/s
	1500 rpm	0	0	-5 rpm
Steady state position error	3000 rpm	1.2 rad	1.2 rad	-0.3 rad
	1500 rpm	1.1 rad	1.1 rad	-0.9 rad

Discussion

- Overall, the Luenberger BEMF observer and Flux observer yielded similar results..
- In both cases a considerable ripple in the speed waveform was observed, which is most likely caused by the steady state position error..
- The speed waveform of the Sliding Mode BEMF observer was significantly smoother..
- However, a steady state speer error was observed which is most likely caused due to anomalies in the estimated BEMF waveforms..

Conclusions

Table 02: Quantitative comparison of observer performance characteristics

	Luenberger BEMF Observer	Luenberger Flux Observer	Sliding Mode BEMF Observer
Implementation Complexity	High	High	Low
Transient Performance	Satisfactory	Satisfactory	Excellent
Steady State Performance	Satisfactory	Satisfactory	Needs Improvement
Robustness	Low	Low	High

- Considering the above factors, the **Sliding Mode BEMF Observer** is recommended for future developments..

Future Work

- The immediate next step of this project will be to optimize the performance of the Sliding Mode BEMF observer..

- Afterwards, hardware implementation and real world testing can be carried out..

Acknowledgments

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Thank You

Q&A