Control of Brushless Doubly-Fed Reluctance Wind Generators

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Presentation Outline

- Motivation.
- Applications.
- Description of the BDFRG.
- Dynamic Model of BDFRG.
- Preliminary Results.
- BDFRG Test Rig.
- Conclusions and Perspectives.

Motivation

- "Slip power recovery" machine – smaller inverter – **cost effective** (especially large units).
- No brush gear – robust, **reliable** and **maintenance-free** (crucial for off-shore applications).
- 'Cold' reluctance rotor – **high efficiency** and **simple control.**
- Superior **low-voltage-fault-ride-through** capability.
- **Operational mode flexibility** – can also operate as an induction or adjustable field synchronous machine.

Main Applications

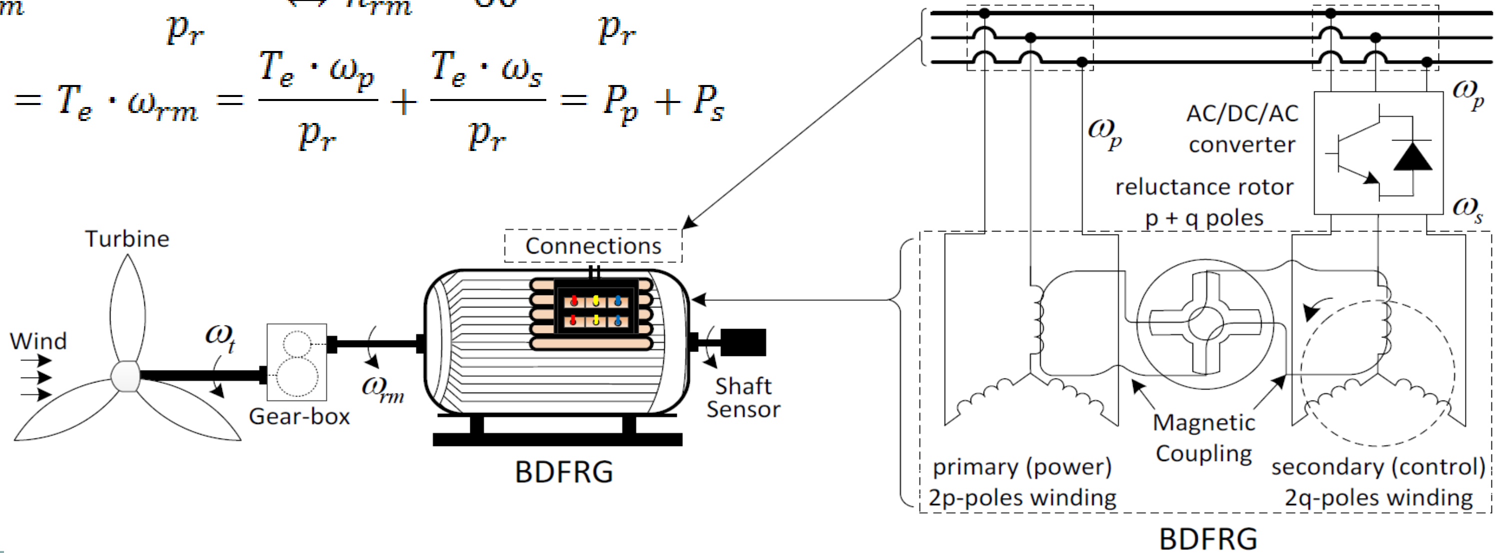
- **Target:** Variable speed constant frequency (VSCF) grid connected wind turbine generators (off-shore or on-shore).
- Large pumps and similar adjustable speed drives (e.g. compressors, fans etc.) for commercial and industrial heating, ventilation and/or air-conditioning.

BDFRG Wind Turbine

- 2 stator windings with different pole numbers & applied frequencies + cage-less reluctance rotor having half the total number of stator poles.
- Rotor provides position dependent magnetic coupling between stator windings – a pre-requisite for torque production.
- Primary connected directly to mains supply & Secondary fed from bi-directional (back-to-back) power electronics converter for control.

$$\omega_{rm} = \frac{\omega_p + \omega_s}{p_r} \Leftrightarrow n_{rm} = 60 \cdot \frac{f_p + f_s}{p_r}$$

$$P_m = T_e \cdot \omega_{rm} = \frac{T_e \cdot \omega_p}{p_r} + \frac{T_e \cdot \omega_s}{p_r} = P_p + P_s$$



BDFRG Dynamic Model

The primary and secondary winding voltage space-vectors in the respective rotating reference frames can be represented as:

$$\begin{cases} \underline{v}_p = R_p \underline{i}_p + \dot{\underline{\lambda}}_p + j\omega_p \underline{\lambda}_p \\ \underline{v}_s = R_s \underline{i}_s + \dot{\underline{\lambda}}_s + j\omega_s \underline{\lambda}_s \end{cases}$$

where the flux-linkages are:

$$\begin{cases} \underline{\lambda}_p = L_p \underline{i}_p + L_{ps} \underline{i}_s^{\,*} \\ \underline{\lambda}_s = L_s \underline{i}_s + L_{ps} \underline{i}_p^{\,*} \end{cases}$$

Electro-magnetic torque expression:

$$T_e = \frac{3 P_r L_{ps}}{2 L_p} (\lambda_{pd} i_{sq} + \lambda_{pq} i_{sd})$$

Mechanical equation:

$$\frac{d\omega_{rm}}{dt} = \frac{1}{J} (T_e - T_l)$$

Control Principles

$$P_{p_{foc}} = \frac{3}{2}\omega_p \lambda_{ps} i_{sq} = \frac{3}{2}\frac{L_{ps}}{L_p}\omega_p \lambda_p i_{sq}$$

$$Q_{p_{foc}} = \frac{3}{2}\frac{\omega_p \lambda_p}{L_p}\left(\lambda_p - L_{ps} i_{sd}\right) = \frac{3}{2}\omega_p \lambda_p i_{pd}$$

$$T_e = \frac{3p_r L_{ps}}{2L_p}\lambda_p i_{sq} = \frac{3p_r}{2}\lambda_{ps} i_{sq} = \frac{3p_r}{2}\lambda_p i_{pq}$$

Primary Flux (Field) Oriented Control **(FOC)**

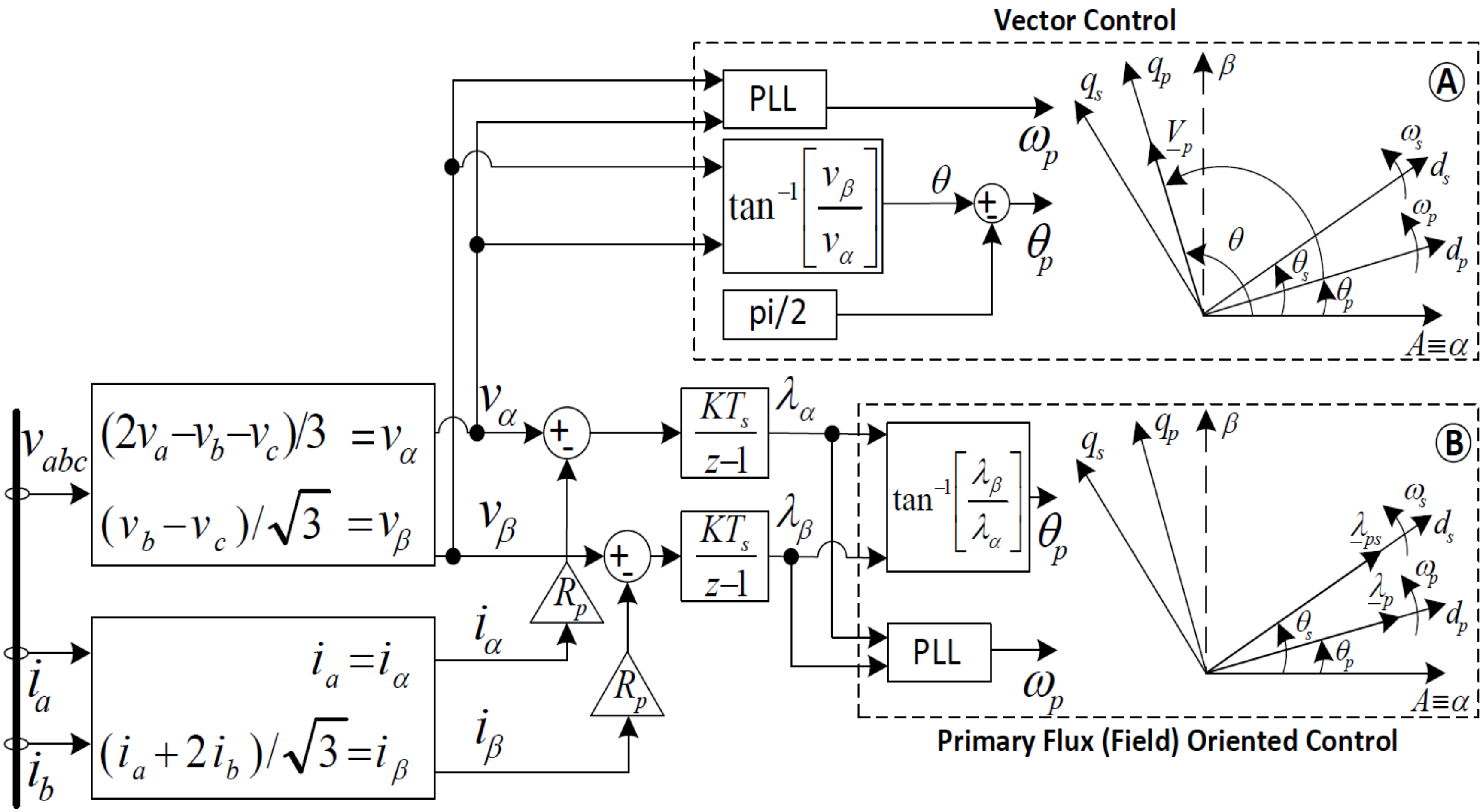
Coupling terms

$$P_{p_{vc}} = P_{p_{foc}} - \frac{3}{2}\omega_p \lambda_{ps_q} i_{sd}$$

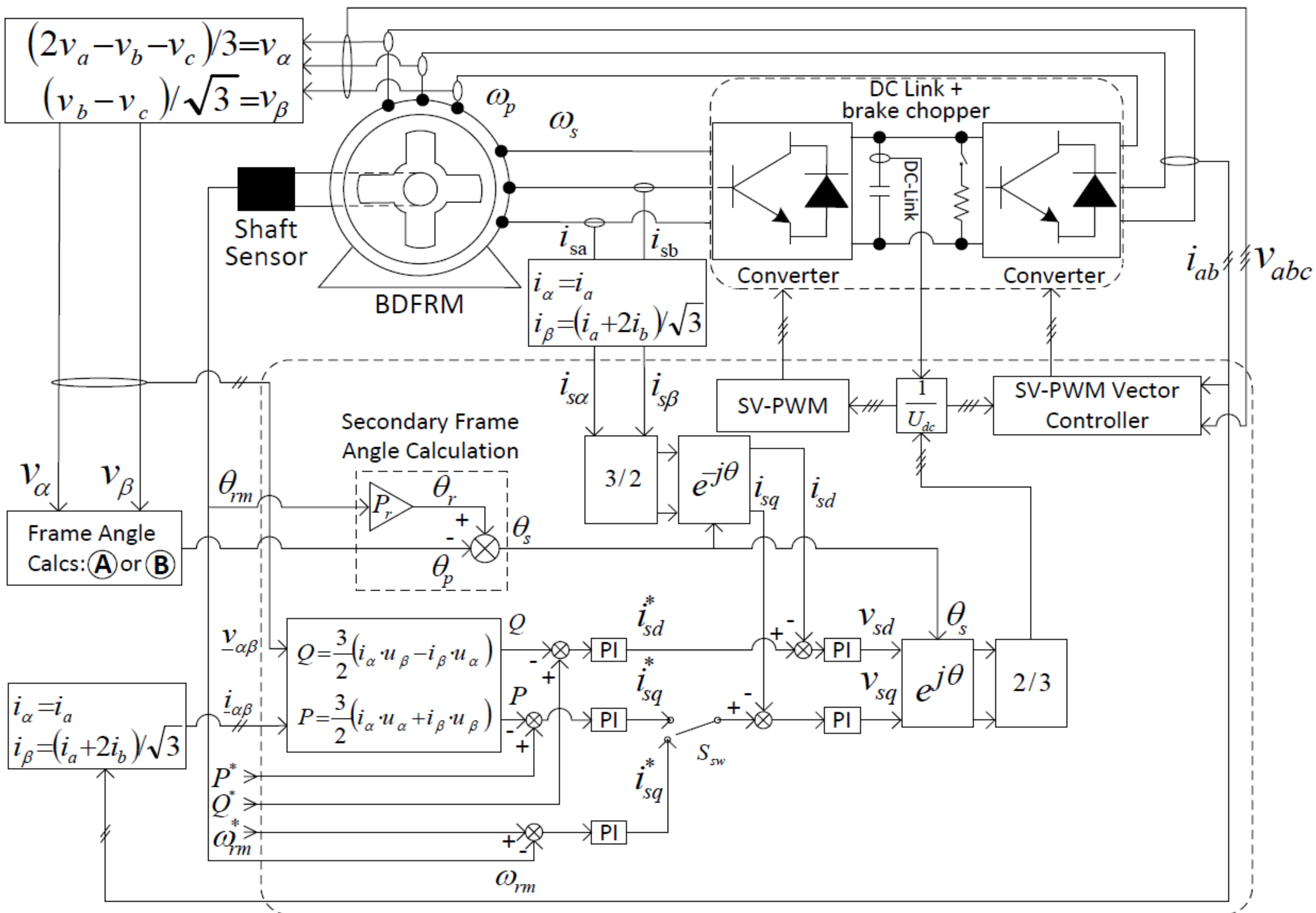
$$Q_{p_{vc}} = Q_{p_{foc}} - \frac{3}{2}\omega_p \lambda_{ps_q} i_{sq}$$

Primary Voltage Oriented (Vector) Control **(VC)**

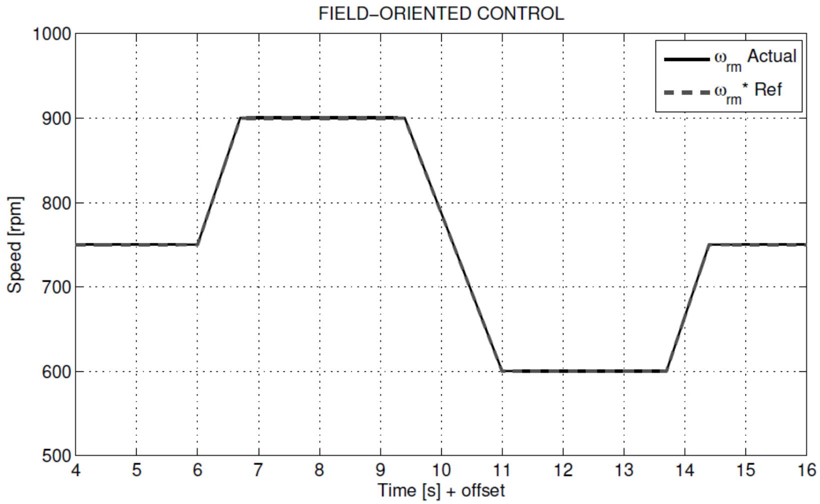
Primary Voltage/Flux Vector Identification

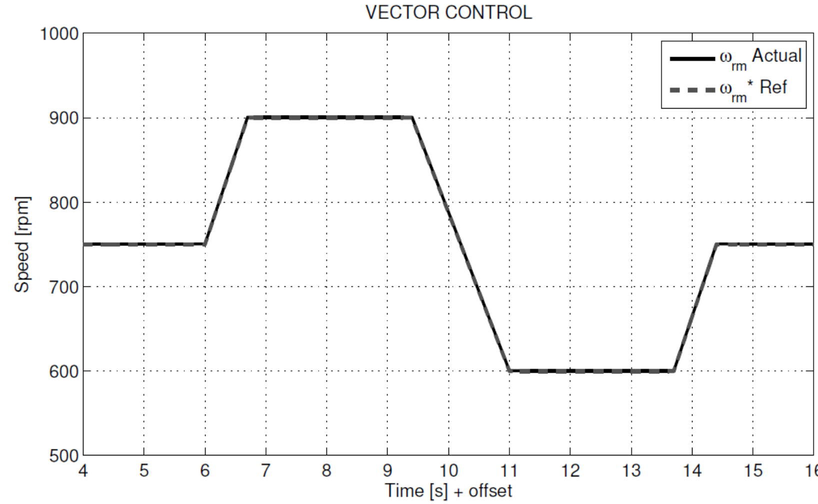


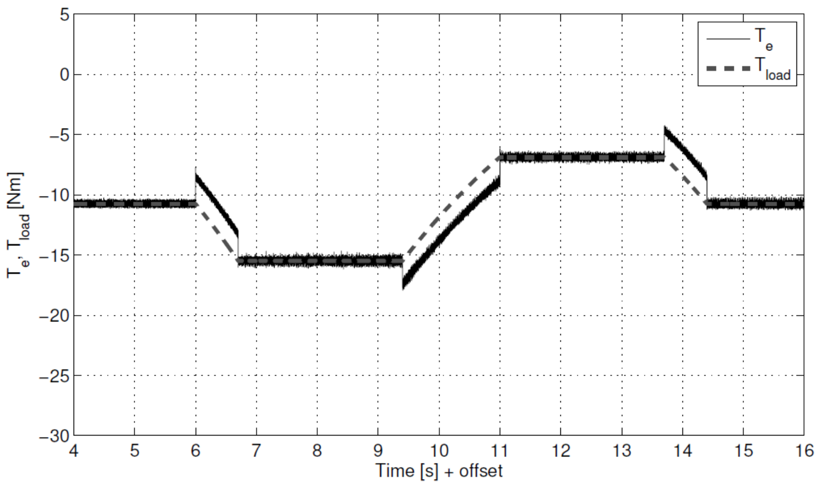
BDFRG Drive Setup

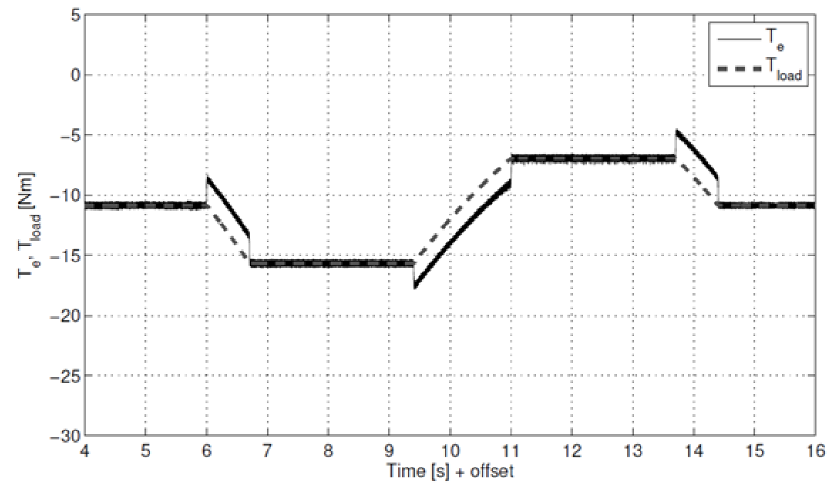


Preliminary Results: Speed and Torque

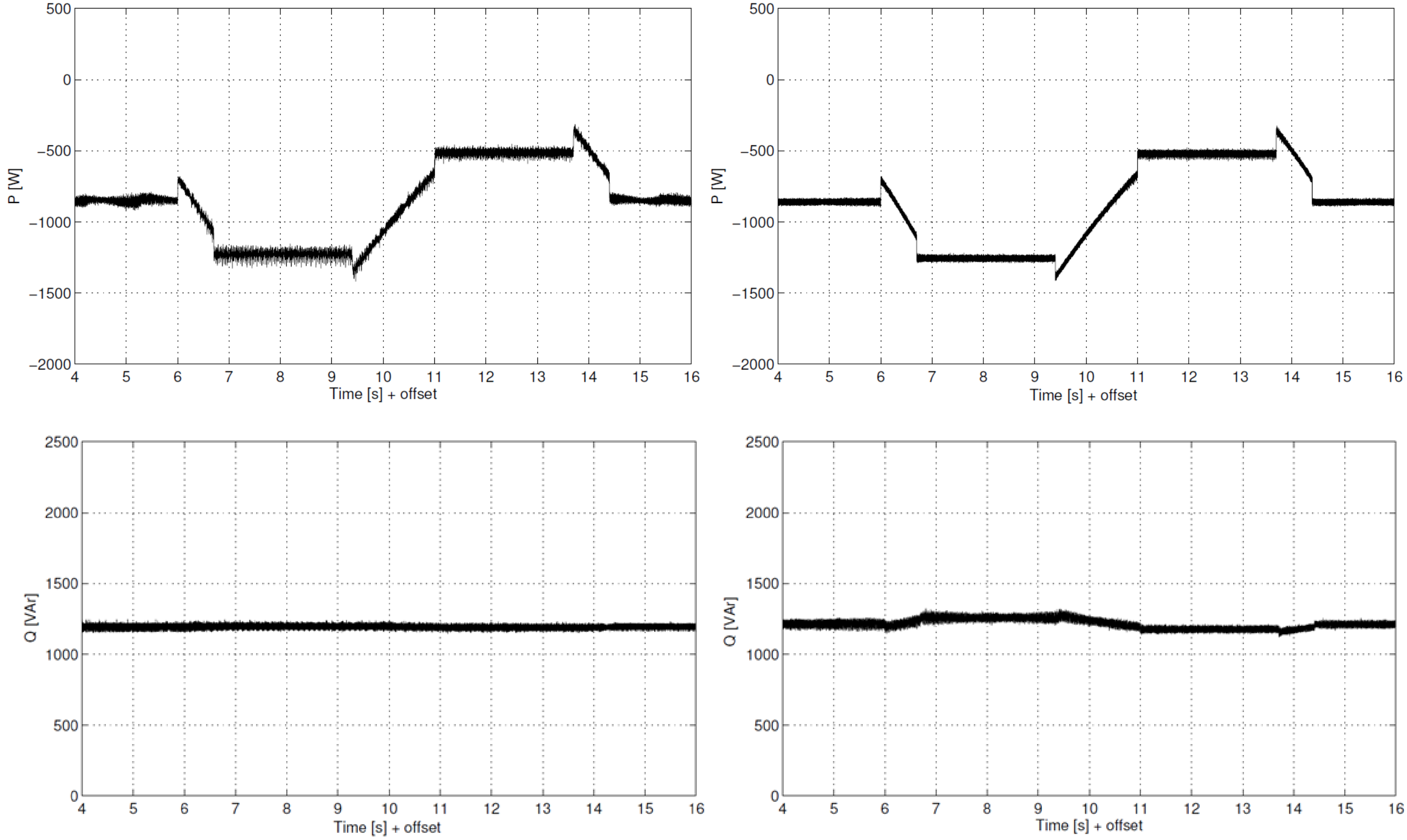




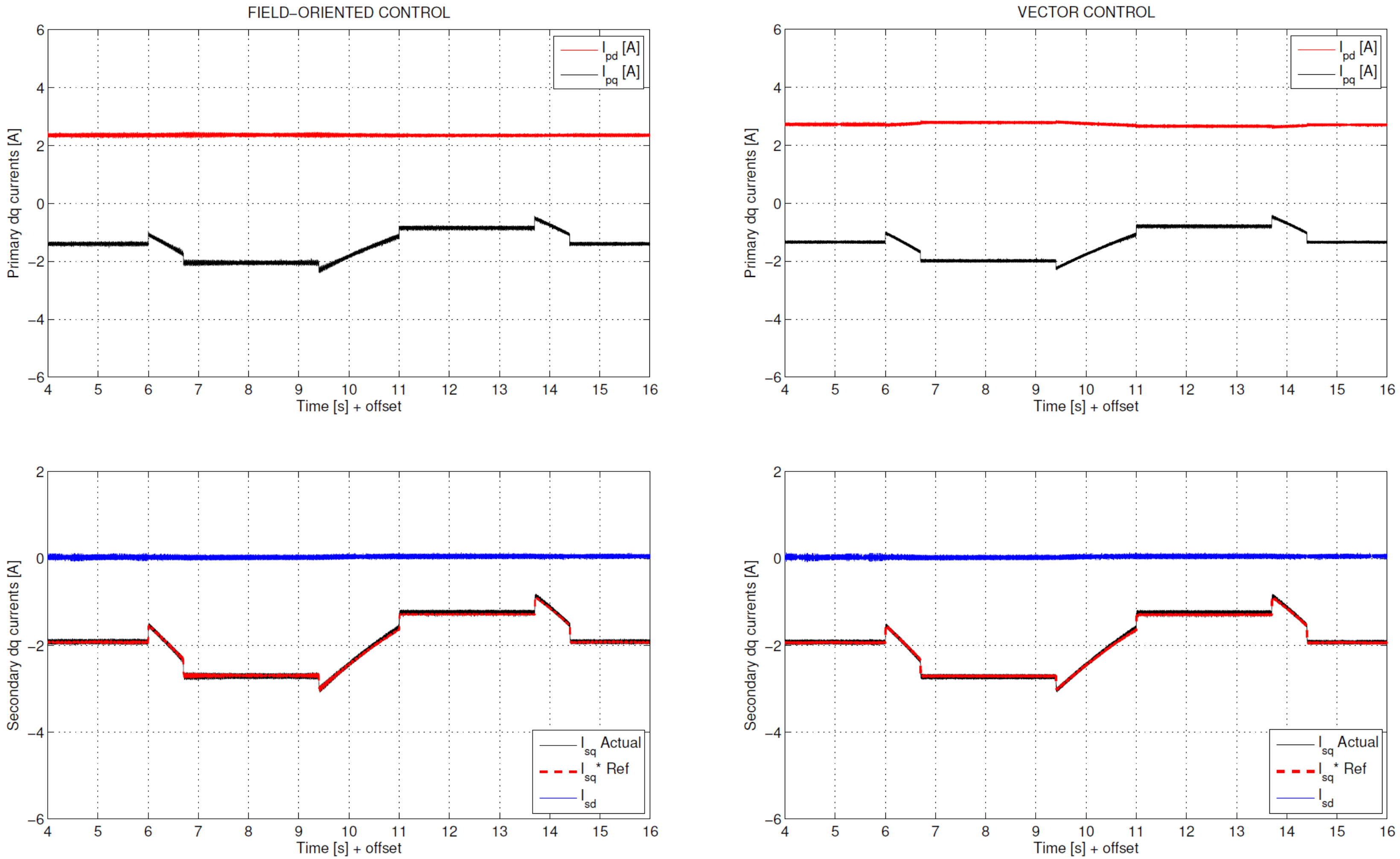




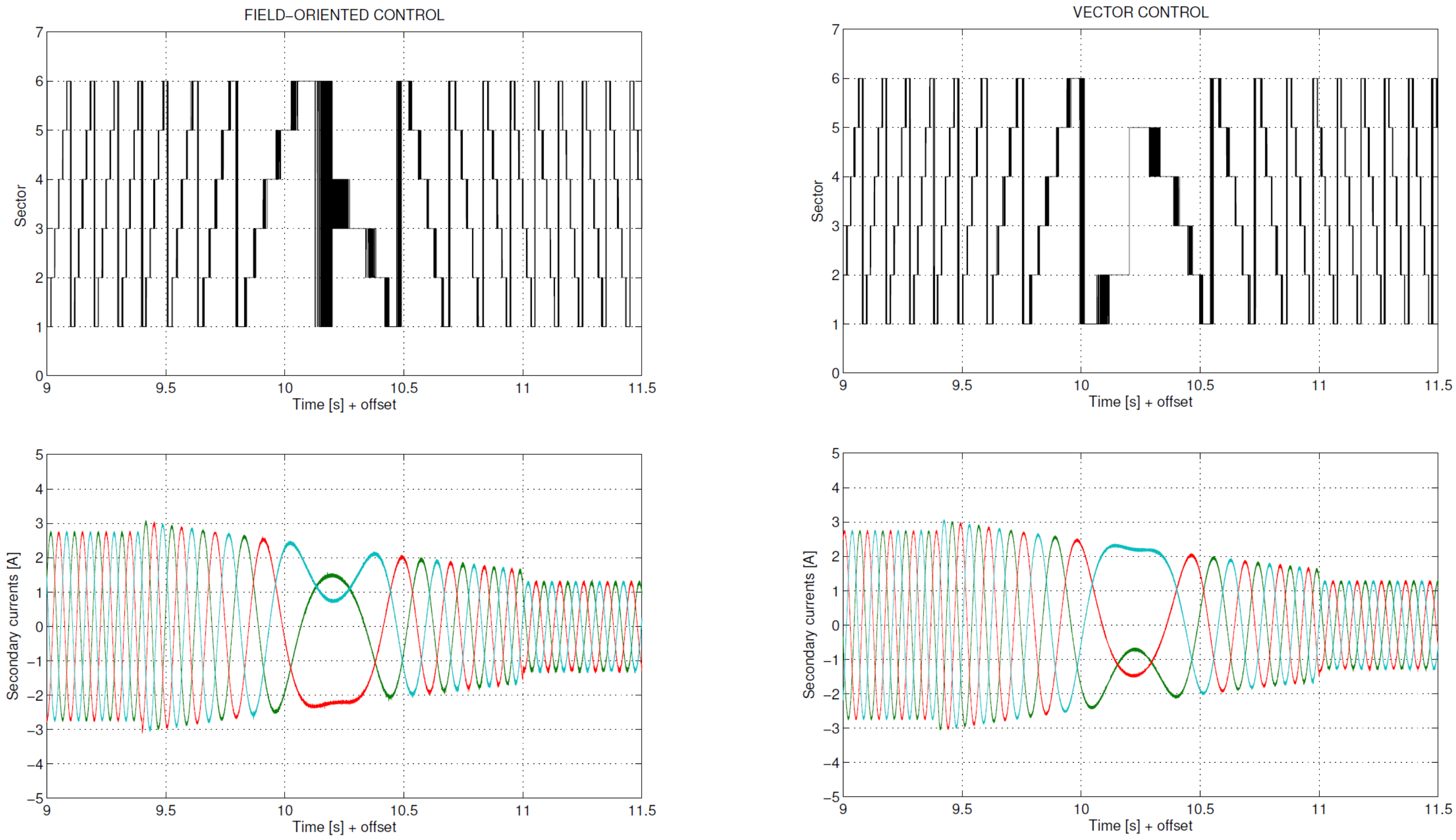
… Preliminary Results: Real and Reactive Power



… Preliminary Results: Currents

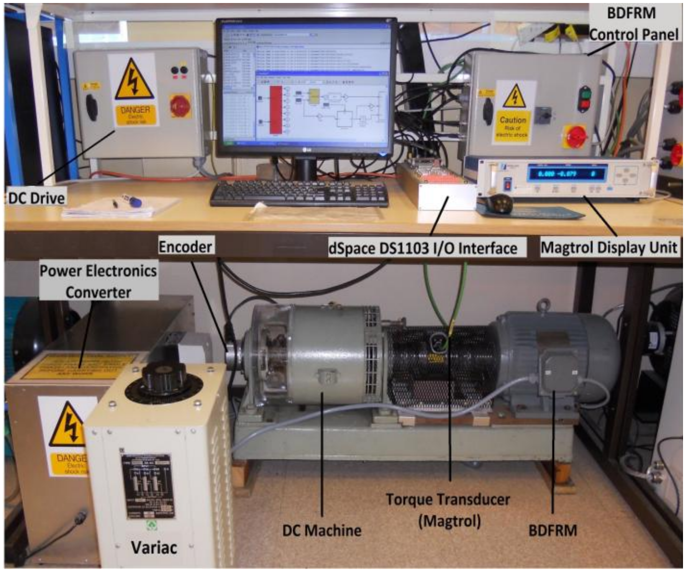


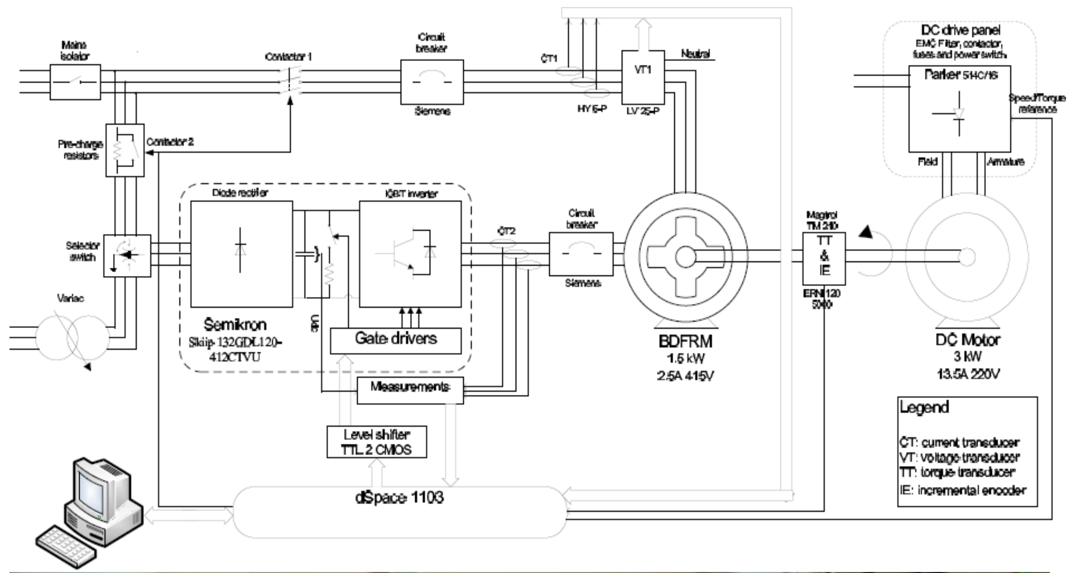
… Preliminary Results: Phase Sequence Reversal



BDFRG inferred secondary voltage positions & current waveforms showing a phase sequence reversal during transition from super-to-sub-synchronous speed.

BDFRG Test Rig

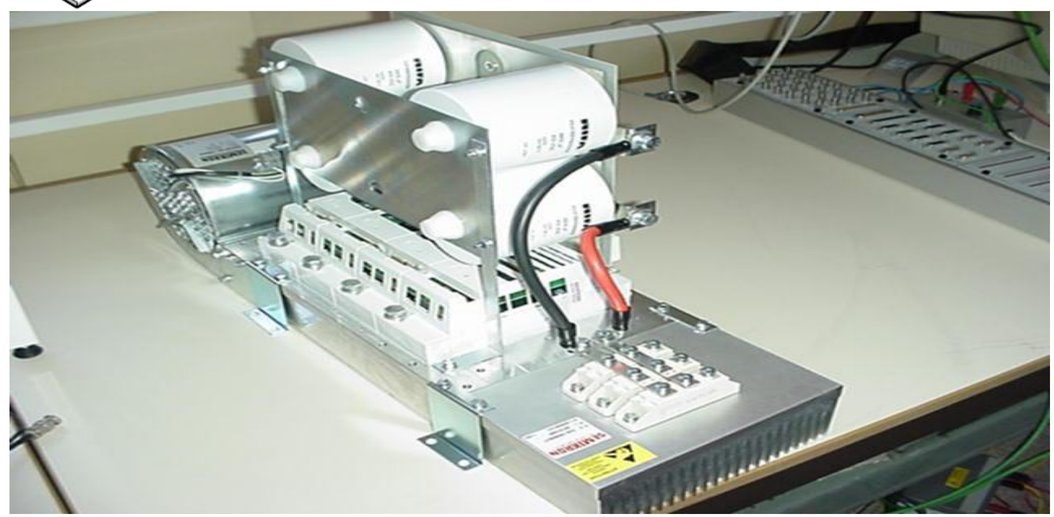




Stator: 6/2-pole

Rotor: 4-pole Axially-Laminated

Data: 1.5-kW, 750-rpm, 415-V, 2.5-A



Conclusions

- ***<u>Main contribution</u>***: Performance evaluation of the two robust, parameter independent control algorithms on a custom-made BDFRG under MTPIA conditions for efficiency improvement.

- The FOC and VC schemes considered generic in nature and equally applicable to small as well as large scale BDFRG or (with little modifications) to conventional doubly-fed induction generators (DFIGs).

- Future work (currently being in progress) should experimentally verify the effectiveness of the proposed methods as demonstrated by realistic simulation studies presented in this paper.


Thank you for your attention!