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V-Type Sensorless Field Oriented Control of Induction Motors for low cost applications

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Introduction

- ✓ Scalar V-Type Volt/Hertz (V/Hz) control has a simple structure and it is easily implemented.
- ✓ Vector I-Type Field Oriented Control (FOC) yields good dynamics and accuracy.
- ✓ The proposed sensorless control strategy merges the simplicity of the conventional scalar control with the improvements in the torque delivery capability al low speed and steady state speed precision, both typical features of FOC control.
- ✓ The control algorithm is derived from the conventional FOC equations by successive approximations. Voltage references are calculated instead of derived by the current regulators (V-Type control).

Migration from I-Type to V-Type Control

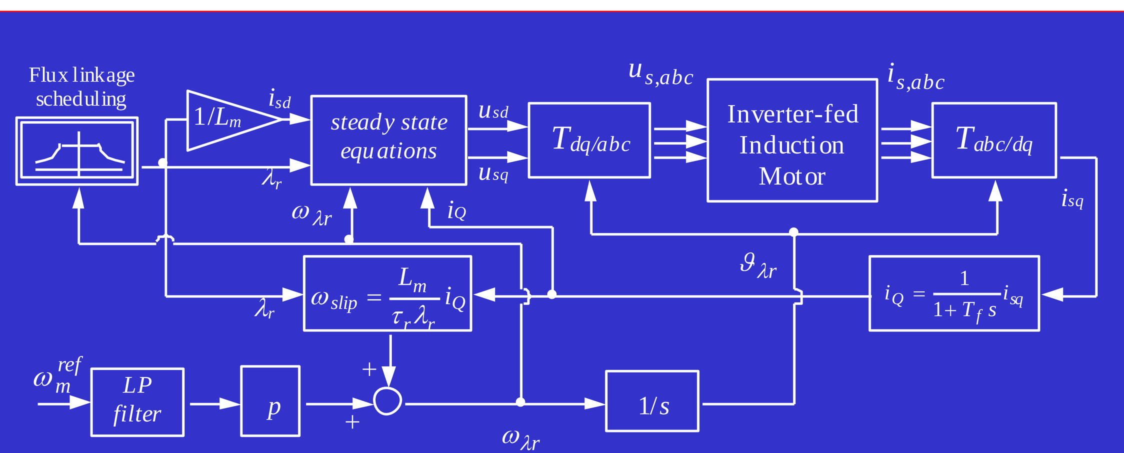
I-TYPE INDIRECT FOC DRIVE:

- ✓ The separation between torque and flux producing components of the stator currents gives excellent dynamic performances.
- ✓ Precise rotor speed measurement is required.
- ✓ The voltage references are delivered by two PID current regulators.

V-TYPE SENSORLESS FOC DRIVE:

- ✓ Elimination of the speed measurement, which compromises the mechanical robustness. The actual speed is approximated by the given speed reference.
- ✓ The current loops are substituted by the IM voltage balance equations, for a given (known) set of motor parameters. The derivative terms are omitted.
- ✓ The control preserves the vector-orientation features. It correctly manages the voltage vector in all working conditions, assuring superior performance.
- ✓ The quadrature current component needs to be filtered to guarantee stability.

Sensorless proposed V-Type Foc Control



Control equations in the reference frame synchronous to the rotor flux. $\Rightarrow$

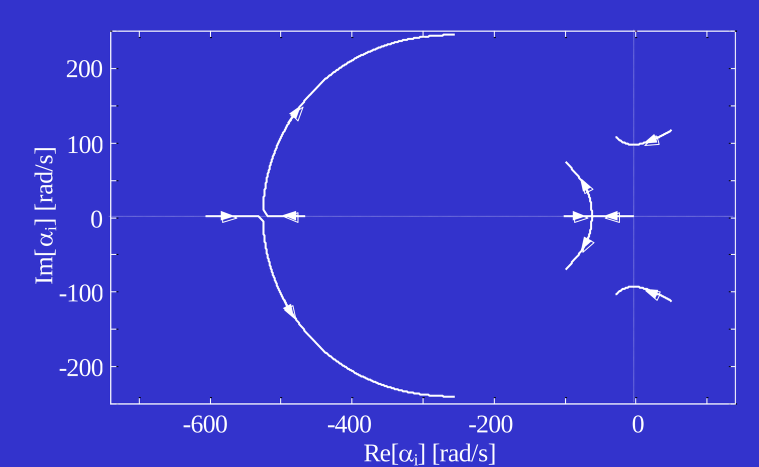
$$\begin{cases} u_{sd} = R_s \dfrac{\lambda_r^{ref}}{L_m} - \omega_\lambda^{ref} L_t i_Q \\ u_{sq} = R_s i_Q + \omega_\lambda^{ref} \dfrac{L_m}{L_r} \lambda_r^{ref} + \omega_\lambda^{ref} L_t \dfrac{\lambda_r^{ref}}{L_m} \end{cases}$$

The slip angular frequency is obtained by the estimated flux linkage and the filtered quadrature current. $\Rightarrow$

$$\omega_\lambda^{ref} = \omega_{me}^{ref} + \omega_{slip}^{ref} = \omega_{me}^{ref} + \frac{L_m i_Q}{\tau_r \lambda_r^{ref}}$$

Stability Analysis

- ✓ The stability depends on the constant time T_f of the low pass filter in the quadrature current measurements.
- ✓ To investigate the stability of the non-linear system, the Lyapunov theorem is used. It states that if all eigenvalues of the Jacobian matrix have negative real parts, than the equilibrium state is asymptotically stable.

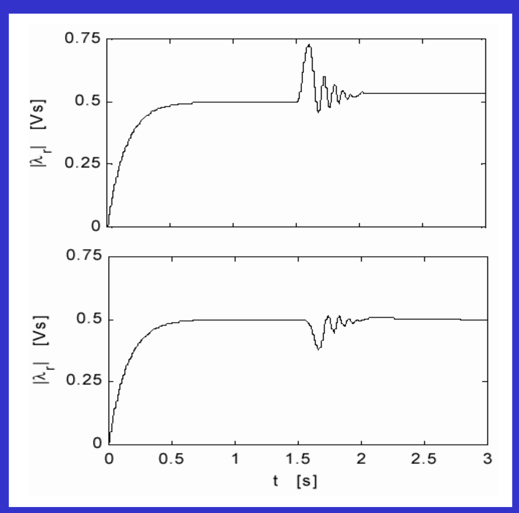


Real and Imaginary part of eigenvalues α_i for different T_f.

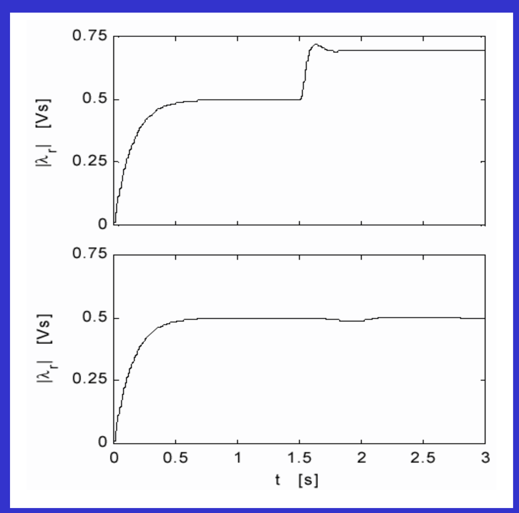
- ✓ Low values of T_f leads to instability.
- ✓ High values of T_f slow down the system dynamics.
- ✓ A trade-off has to be accepted.
- ✓ It has been found that the system sensitivity to T_f is rather low. The tuning of T_f is quite simple.

Simulation Results

- ✓ The V-Type FOC scheme tends to regulate the flux to its rated value. It avoids possible performance degradation due to iron saturation, which could arise with conventional V/Hz.
- ✓ Flux behaviour to a speed ramp from t=1.5s to t=2s.
- ✓ Upper side plot: Conventional V/Hz. Bottom plot: Proposed V-Type control.



Speed ramp from 0 to nominal speed Ω_n.



Speed ramp from 0 to $\Omega_n/10$.

Experimental Results on Drive Prototype

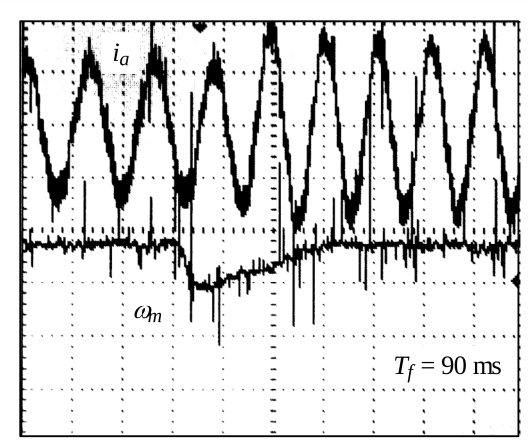
- ✓ The performances of the proposed control strategy have been tested on two IMs.

	IM #1	IM #2
rated voltage	195 V	220 V
rated current (λ-conn.)	5 A	5 A
nominal speed	2864 rpm	1391 rpm
max speed (flux weak.)	18000 rpm	4000 rpm
rated torque	2.7 Nm	4.6 Nm
pole pairs	2	1

- ✓ The algorithm has been implemented on a low cost Hitachi H8/3687 tiny series 16 bit µP.
- ✓ Stator current sampling time 300 µs.
- ✓ Speed loop service routine 15 ms.

Measurements on IM#2

- ✓ Speed response to a load torque step variation of 60% of the rated torque at $\omega_m^{ref} = 1/6\ \Omega_n$.
- ✓ Best tuning is T_f = 90 ms, obtained by a trial-and-error procedure.



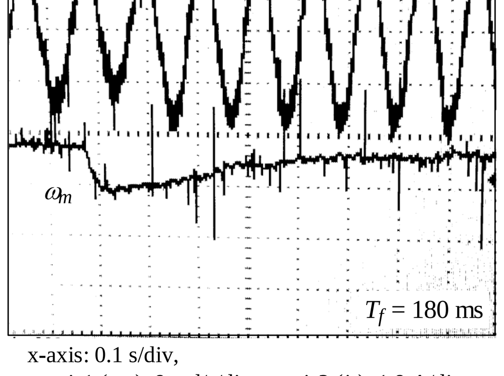
x-axis: 0.1 s/div,
y-axis1 (ω_m): 9 rad/s/div, y-axis2 (i_a): 1.9 A/div

Experimental Results: T_f Tuning

- ✓ Measurements on IM#2. Speed response to a load torque step variation of 60% of the rated torque with different value of T_f at $\omega_m^{ref} = 1/6\ \Omega_n$.

Effect of filter time constant T_f tuning:

- Increasing T_f up to 180 ms yields to both a bigger settling time and a significant speed error, after the load torque application.
- Reducing T_f leads to speed overshoot. For T_f =22.5 ms stability limit is reached.



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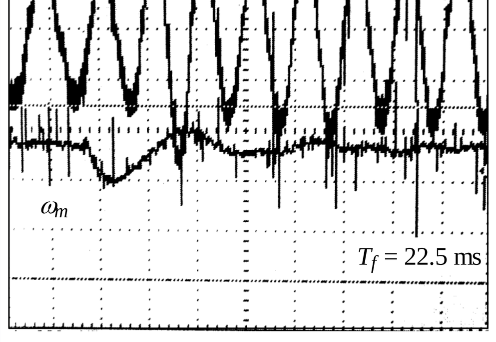

x-axis: 0.1 s/div,
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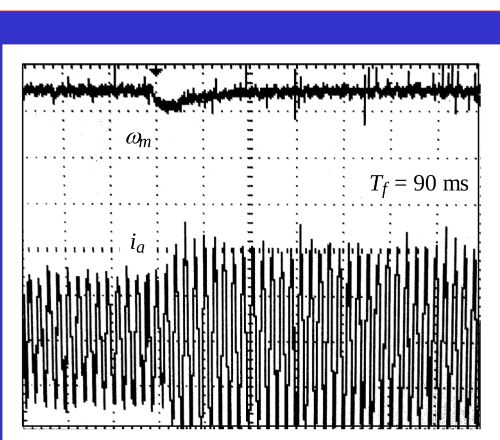
Experimental Results / Conclusions

Measurements on IM#2

- ✓ Speed response to a load torque step variation of 60% of the rated torque with best tuning for T_f at $\omega_m^{ref} = \Omega_n$.
- ✓ Null steady state speed error and fast transient. It has been experienced that the higher speed, the larger the T_f range for stability.



x-axis: 0.1 s/div, y-axis1 (ω_m): 22.5 rad/s/div, y-axis2 (i_a): 1.9 A/div

CONCLUSIONS:

- ✓ The control scheme derives from a FOC control.
- ✓ The control algorithm is simple, inexpensive, without any current closed loop.
- ✓ Matching between simulation and experimental test proves the work accuracy.
- ✓ The steady state speed error is maintened several time lower the nominal slip.
- ✓ The proposed sensorless V-Type control achieves a fair compromise between cost and performances. It is oriented to low-cost IM drives market.

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