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Novel Speed Sensorless DT/SC-SVM Scheme for Induction Motor Drives

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Presentation outline

- Introduction
- Direct Torque/Slip Control Method
- Field Weakening Operation
- Flux and speed estimation
- Experimental Results
- Final Conclusions

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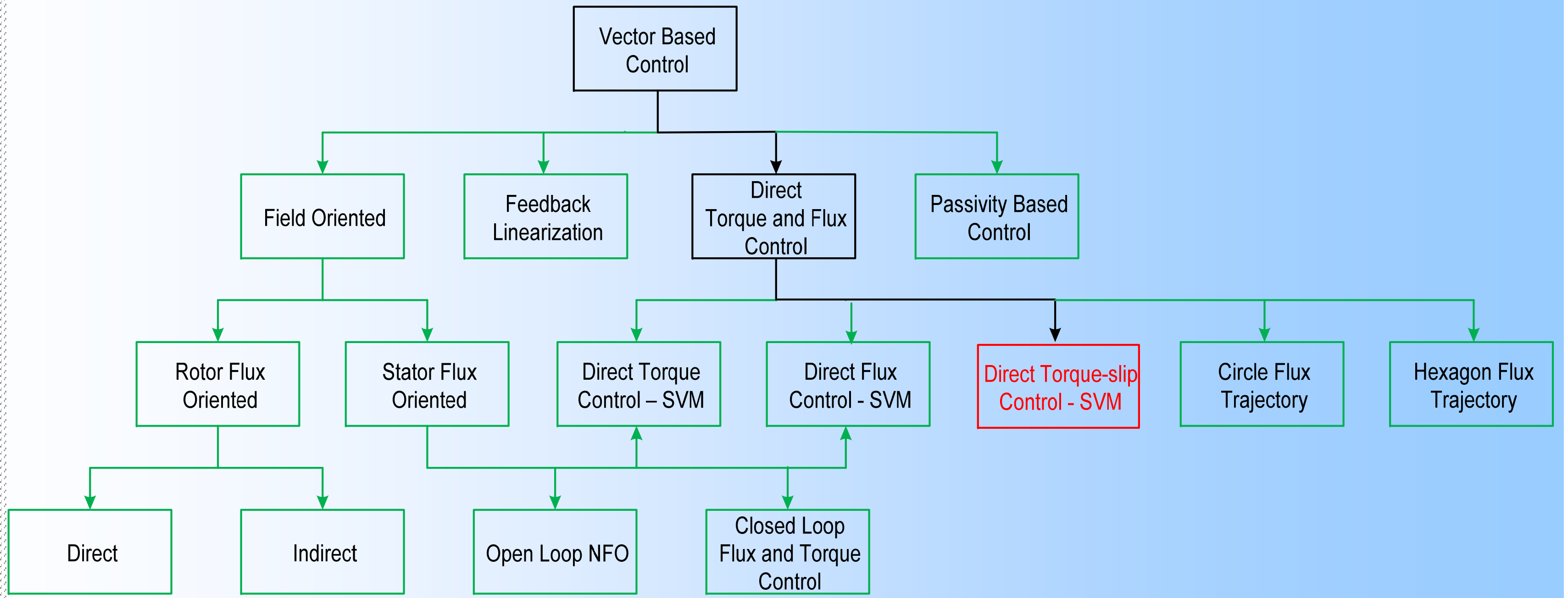
Requirements

Main conditions what should be met to achieve good IM drive for trams and metro:

- wide range of speed control,
- high dynamic of flux and torque,
- high starting torque,
- maximum use of available torque in flux weakening region,
- low sensitivity to motor parameters changes,
- low torque ripples,
- minimization of switching losses :
  - constant and low switching frequency,
  - unipolar inverter output voltage (elimination of +/- Udc) switchings.

Classification of high performance IM control methods



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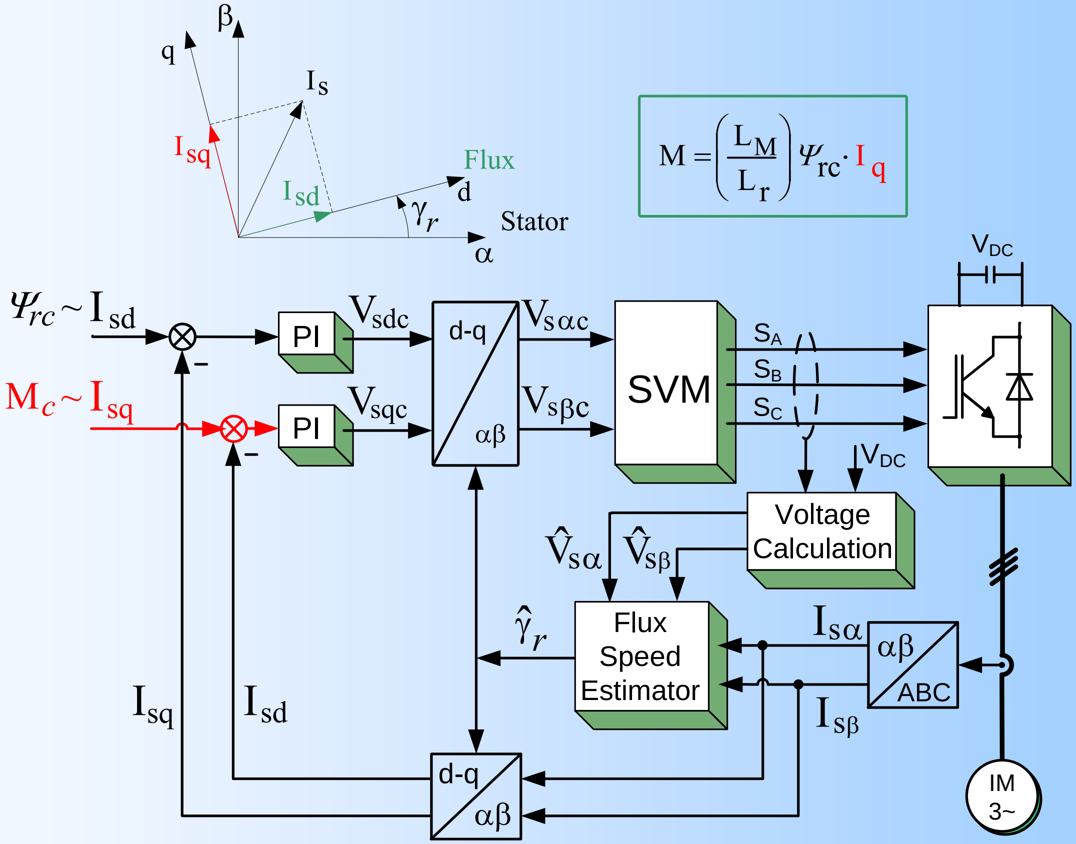
High performance FOC control



Vector diagram and block scheme of rotor FOC. Torque is controlled *indirectly* via torque current I_{sq} control loop

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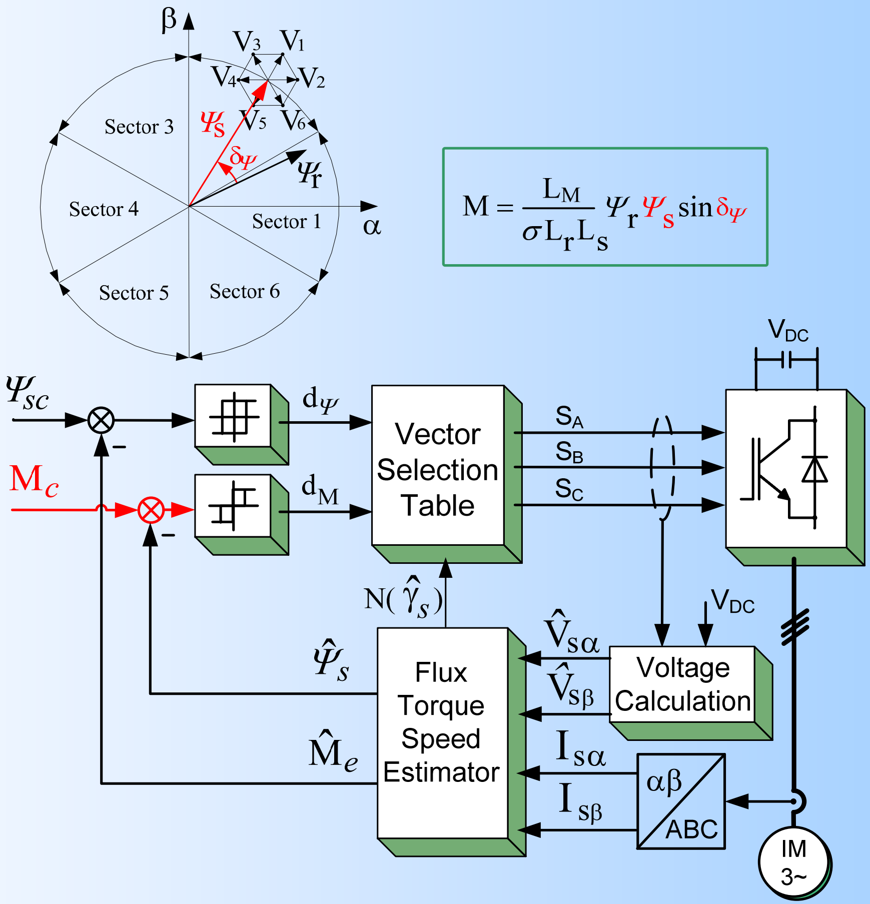
High performance ST-DTC control



In Switching Table based DTC torque is controlled *directly* via stator flux vector movement by selection of appropriate forward/backward active voltage vector (V_1 or V_6) and stops by selection zero voltage vector V_0. Stator flux vector moves on circular path

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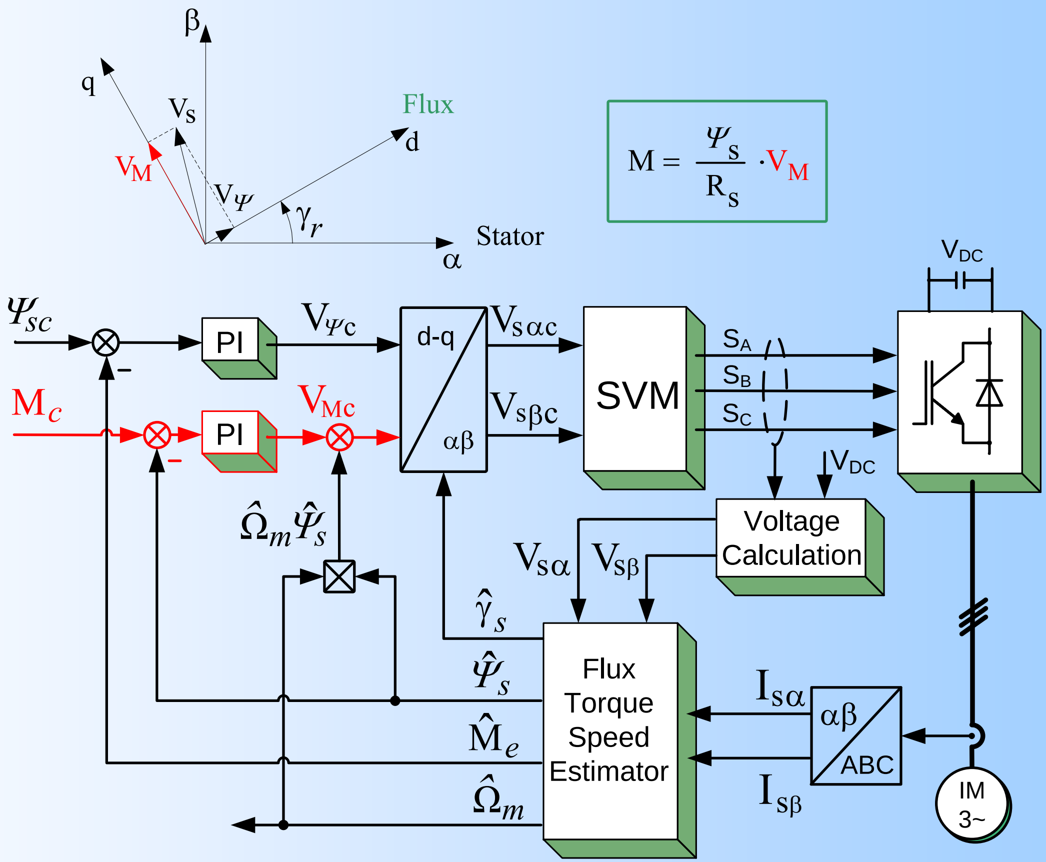
High performance DTC-SVM control



Vector diagram and block scheme of DTC-SVM.
Torque is controlled *directly* via voltage vector component $V\text{-}_M$

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Direct Torque/Slip Control with Space Vector Modulation (DT/SC-SVM)

$$U_{Sy} = R_S \cdot I_{Sy} + \Omega_S \cdot \Psi_S$$

$$M_e = p_b \cdot \frac{m_s}{2} \cdot \Psi_S \cdot I_{Sy}$$

$$\omega_r = \frac{R_R}{\frac{m_s}{2} \cdot p_b \cdot \left|\Psi_R\right|^2} \cdot M_e$$

$$U_{Sy} = \frac{R_S}{p_b \cdot \frac{m_s}{2} \cdot \Psi_S} \cdot M_e + \left(\omega_r + \Omega_m \cdot p_b\right) \cdot \Psi_S$$

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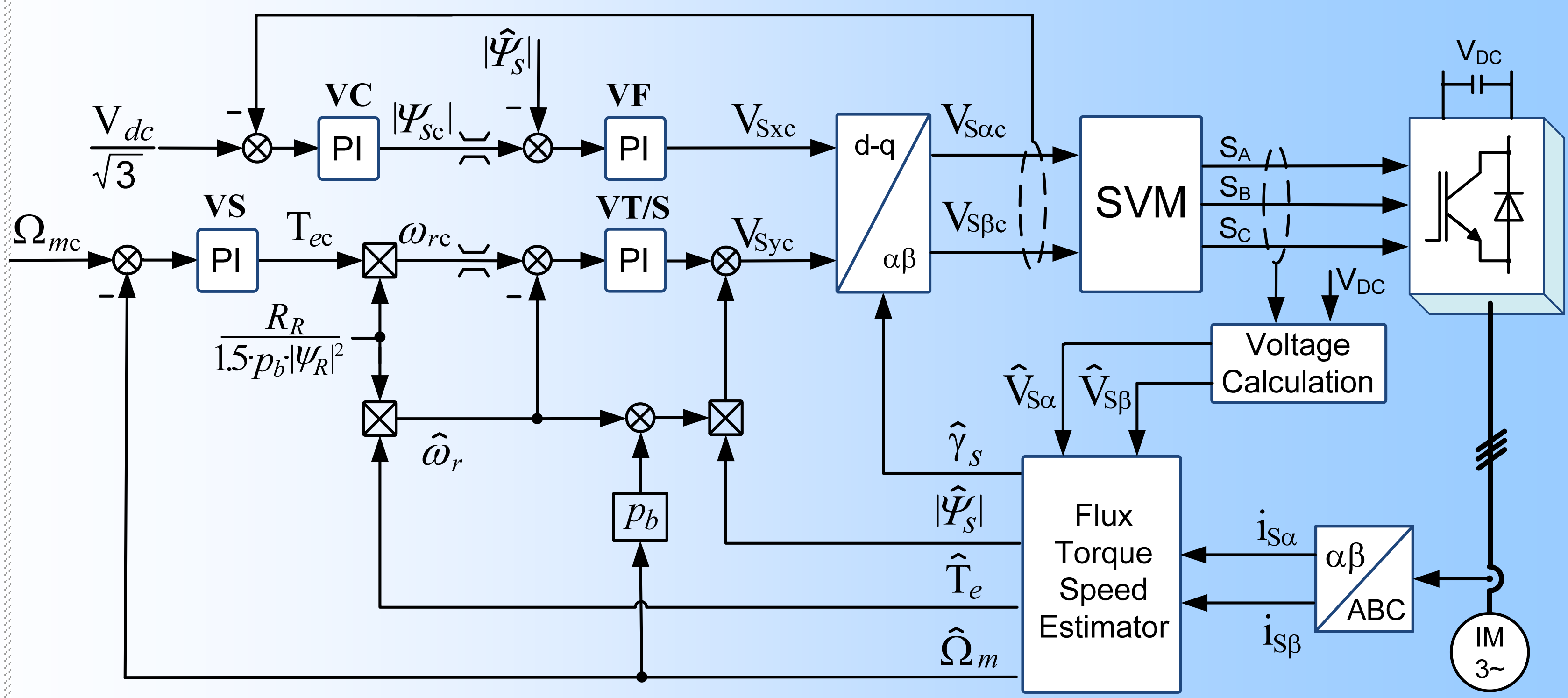
Direct Torque/Slip Control with Space Vector Modulation (DT/SC-SVM)



DT/sC-SVM method with direct torque/slip control and flux weakening. VC – voltage controller, VS – speed controller, VF – flux controller, VT/S – torque/slip controller

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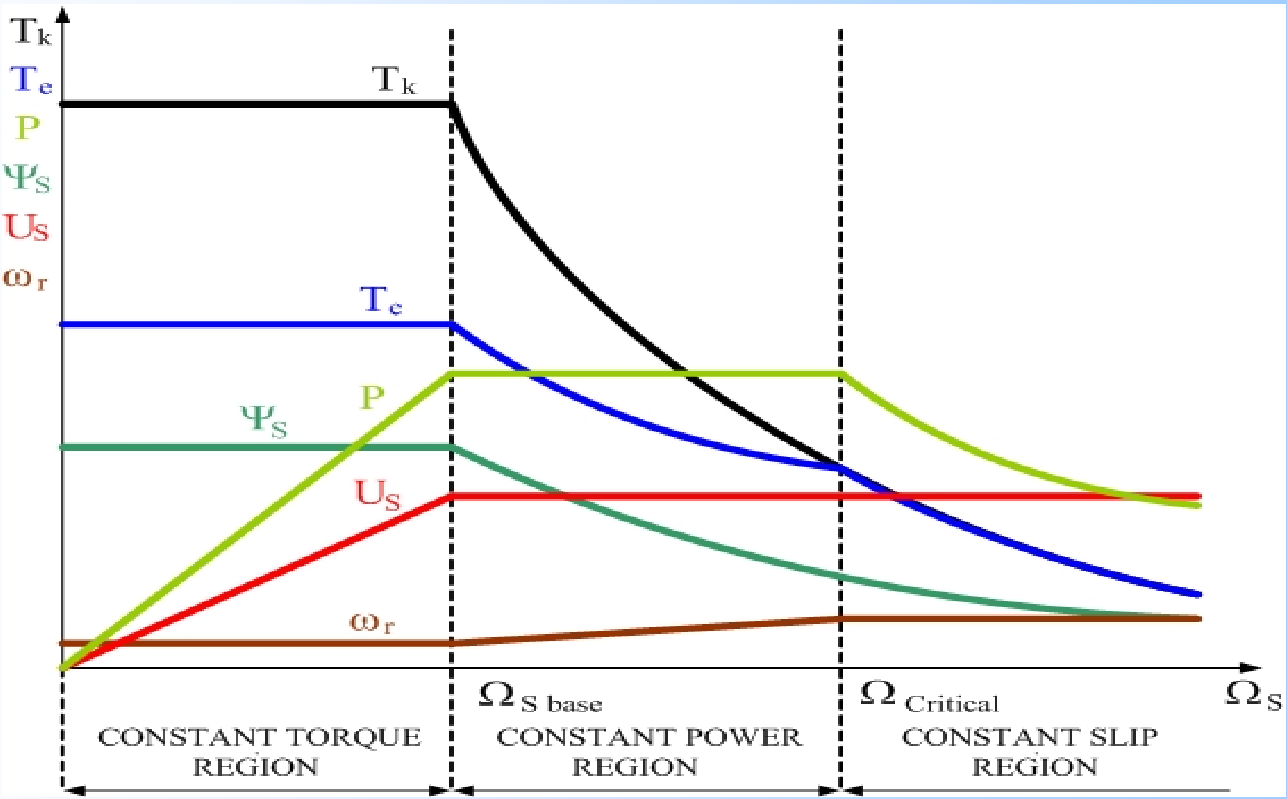
Field Weakening Operation



- operation at constant power and constant slip region ,
- maximum use of available DC voltage,
- high dynamic of torque generation .

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Field Weakening Techniques

- V/Hz adjustment (Scalar Control)
- Flux Program Reference $1/\Omega_m$ (Vector Control)
- Maximum Torque Capability (Vector Control)
- Operation at Voltage limit
- Sensorless Voltage Controller

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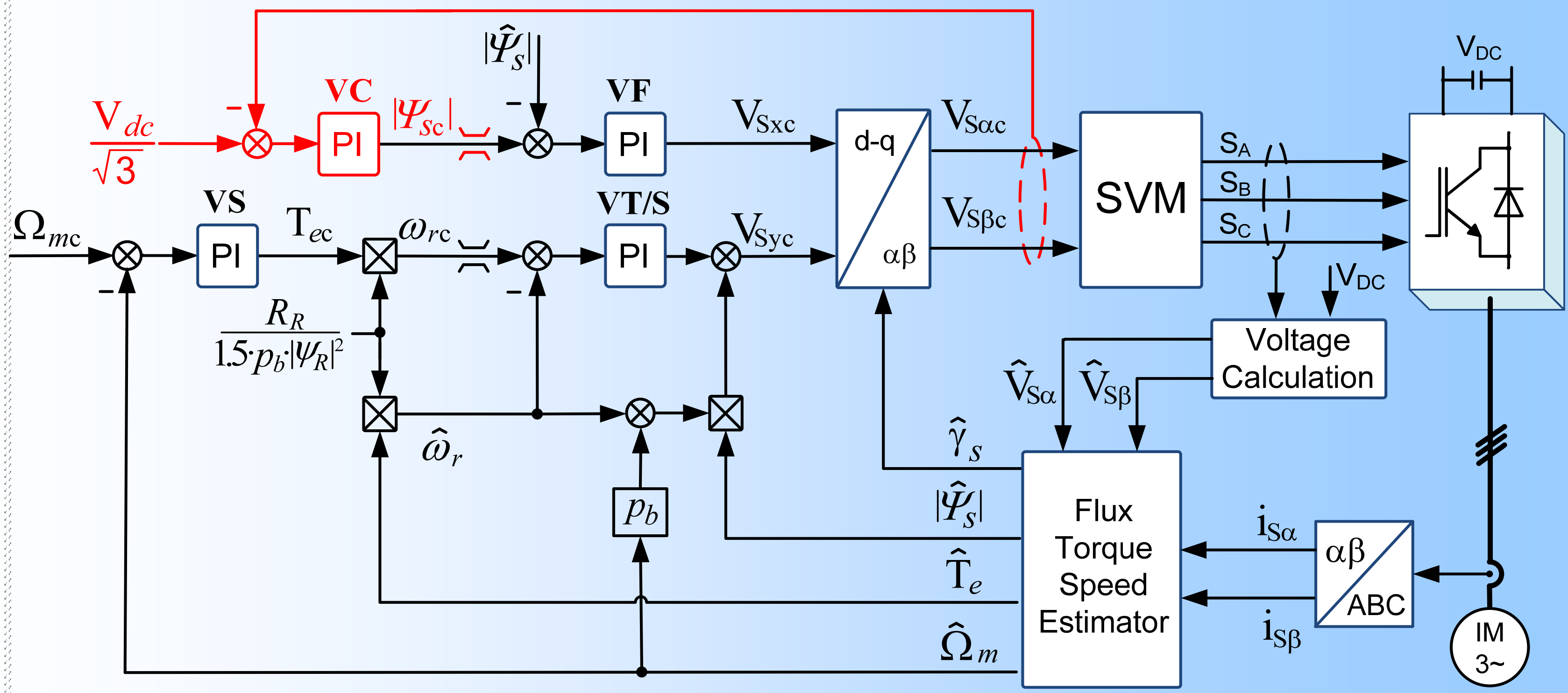
Field Weakening in DT/S-SVM Control Method



DT/SC-SVM scheme operates in three drive ranges:
constant torque (M_e = const.), constant power (P = const.)
and constant slip (ω_r = const)

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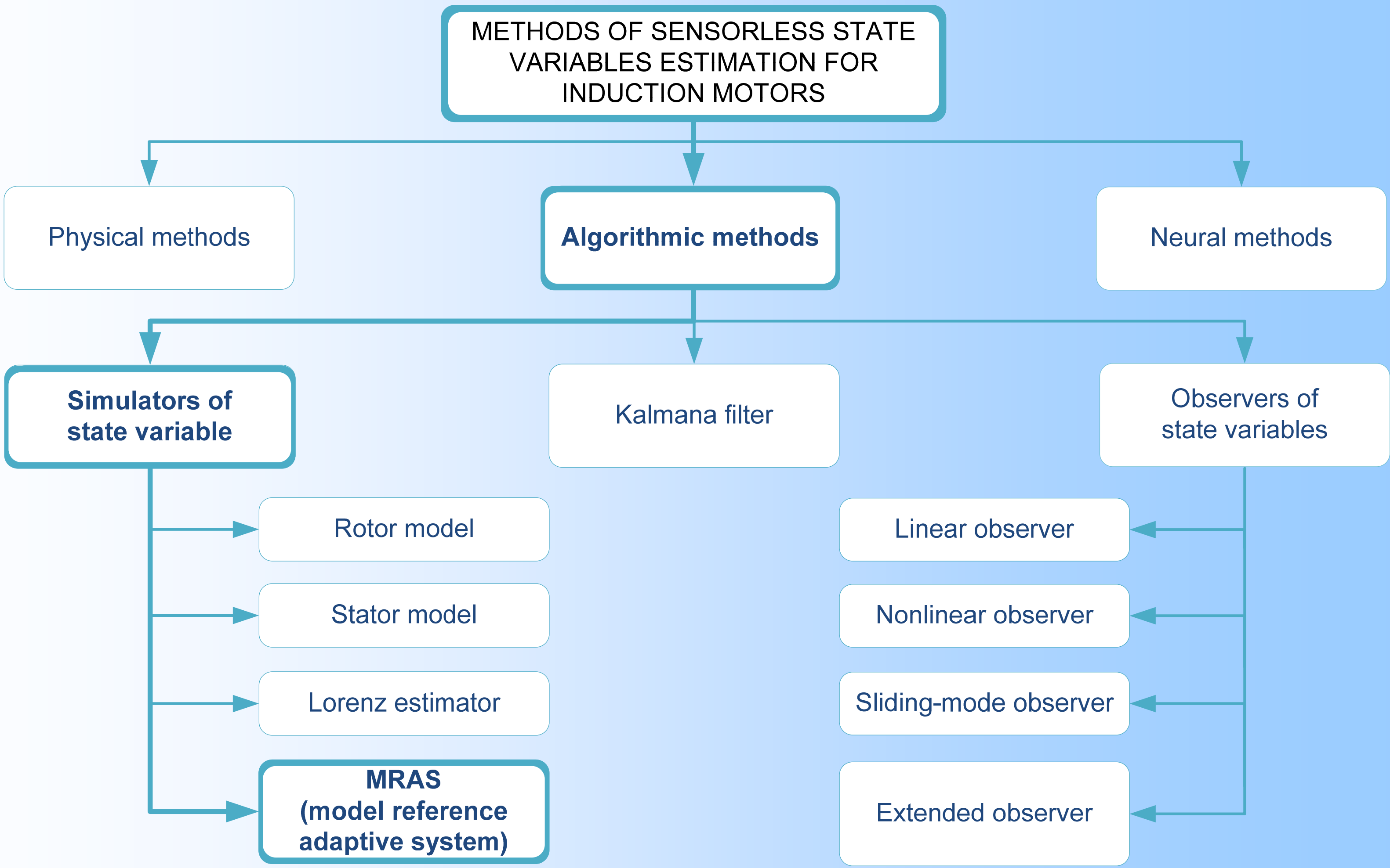
Classification of flux & speed estimators



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Flux and speed estimator

Flux estimation

$$\frac{d\widehat{\Psi}_{S\alpha}}{dt} = V_{S\alpha} - \hat{I}_{S\alpha} R_S + e_{I\alpha}$$

$$\frac{d\widehat{\Psi}_{S\beta}}{dt} = V_{S\beta} - \hat{I}_{S\beta} R_S + e_{I\beta}$$

$$\frac{d\widehat{\Psi}_{R\alpha}}{dt} = \left(\frac{R_S L_S}{L_M}\right) \hat{I}_{S\alpha} - \frac{R_R}{L_M \widehat{\Psi}_{S\alpha}} - p_b \Omega_m \widehat{\Psi}_{R\beta}$$

$$\frac{d\widehat{\Psi}_{R\beta}}{dt} = \left(\frac{R_S L_S}{L_M}\right) \hat{I}_{S\beta} - \frac{R_R}{L_M \widehat{\Psi}_{S\beta}} + j p_b \Omega_m \widehat{\Psi}_{R\alpha}$$

$$\hat{I}_{S\alpha} = \frac{\left(L_R \widehat{\Psi}_{S\alpha} - L_M \widehat{\Psi}_{R\alpha}\right)}{(L_R L_S \sigma)}$$

$$\hat{I}_{S\beta} = \frac{\left(L_R \widehat{\Psi}_{S\beta} - L_M \widehat{\Psi}_{R\beta}\right)}{(L_R L_S \sigma)}$$

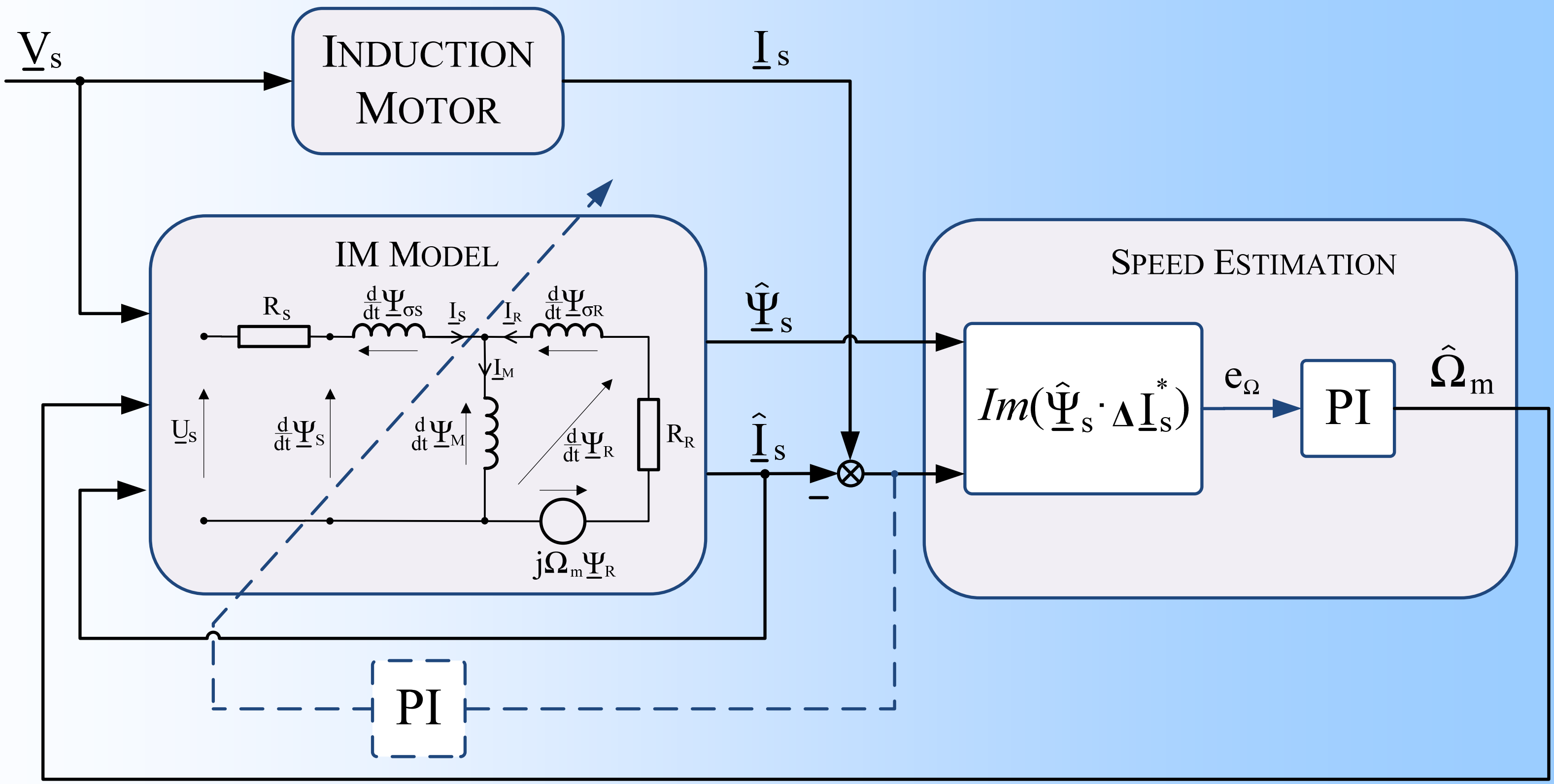
Speed estimation

$$\Delta I_{S\alpha} = I_{S\alpha} - \hat{I}_{S\alpha}$$
$$\Delta I_{S\beta} = I_{S\beta} - \hat{I}_{S\beta}$$

$$e_\Omega = \widehat{\Psi}_{S\beta} \cdot \Delta I_{S\alpha} - \widehat{\Psi}_{S\alpha} \cdot \Delta I_{S\beta}$$

$$\Omega_m = K_P e_\Omega + K_P / T_I \int e_\Omega \, dt$$

Flux and speed estimator



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Advantages and disadvantages of proposed solution

Advantages:

- elimination of speed sensor,
- low complexity of flux and speed estimator,
- direct slip control,
- wide range of speed operation,
- low sensitivity of field weakening to motor parameter changes,
- adaptation of field weakening method to available voltage in DC link, speed and load torque,
- high dynamic of flux and torque generation.

Disadvantages:

- higher sensitivity to motor parameters changes than with speed sensor use,
- additional PI controller in field weakening path

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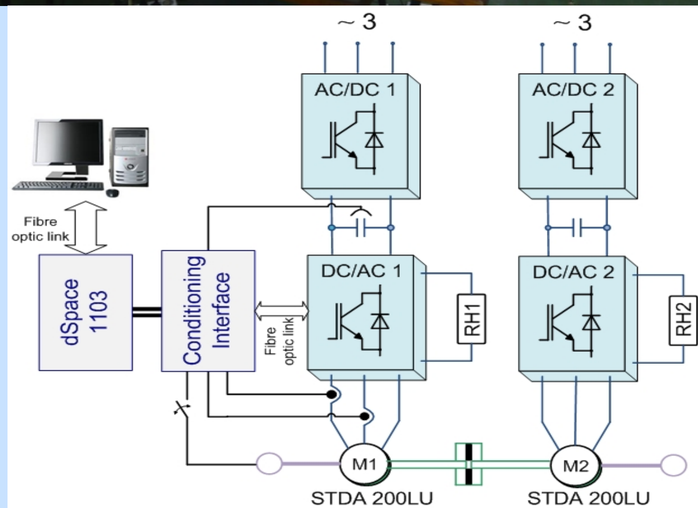
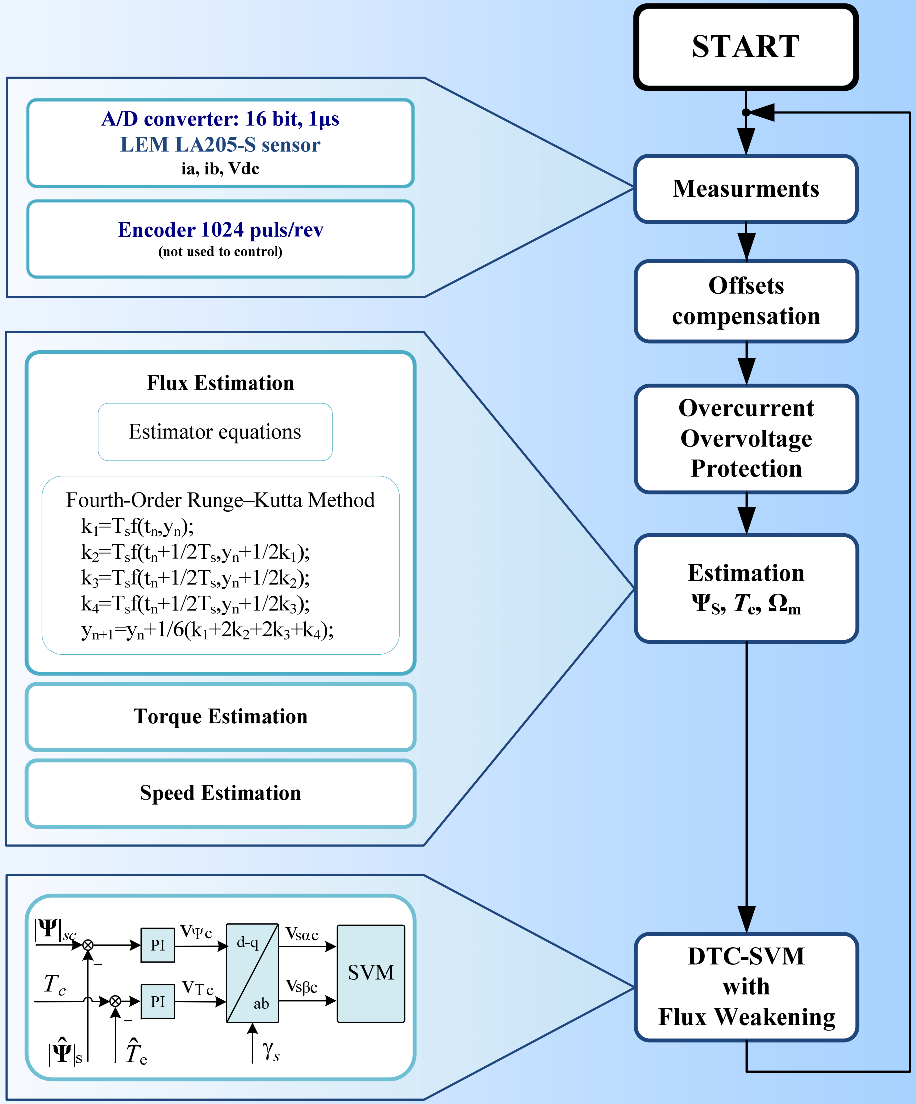
Laboratory setup

IM type STDA 200LU			
P_N	50 kW	R_S	64,5 mΩ
U_N	3 x 380	R_R	46,3 mΩ
I_N	88 A	L_S	25,217 mH
f_N	65 Hz	L_R	25,137 mH
M_{eN}	249 Nm	L_M	24,75 mH
p	2	J	10 $kg \cdot m^2$

Power converter AC/DC and DC/AC	
P_N	55 kW
I_N	98 A
U_N	3x400 50Hz
f_{imp}	4 kHz



Flow diagram of control algorithm



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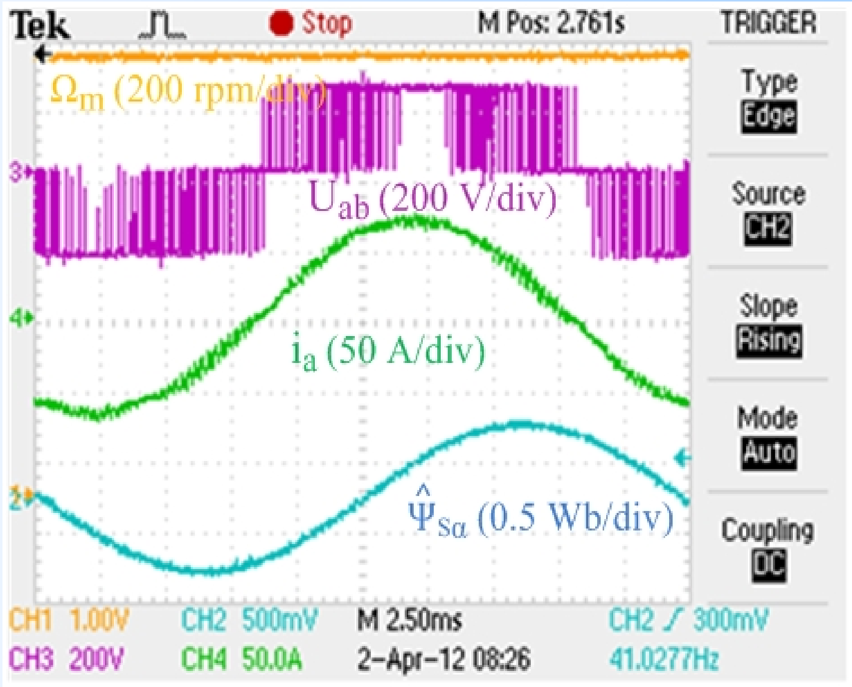
Experimental Results

Sady state operation



Steady state operation in field weakening region at 100 Nm load torque

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Experimental Results

Steady state operation

Measurement of the stator current THD
GOSSEN type Mavowatt 50 M816A
Current probe Metraflex 3003

Experimental Results

Stator current THD

Lp.	U_{dc} [V]	f_S [Hz]	I_A [A]	THD [%]	Comments
1	625	30	26	5.8	No load
2	625	30	88	1.9	Rated load
3	625	50	28	5.4	No load
4	625	50	88	1,9	Rated load

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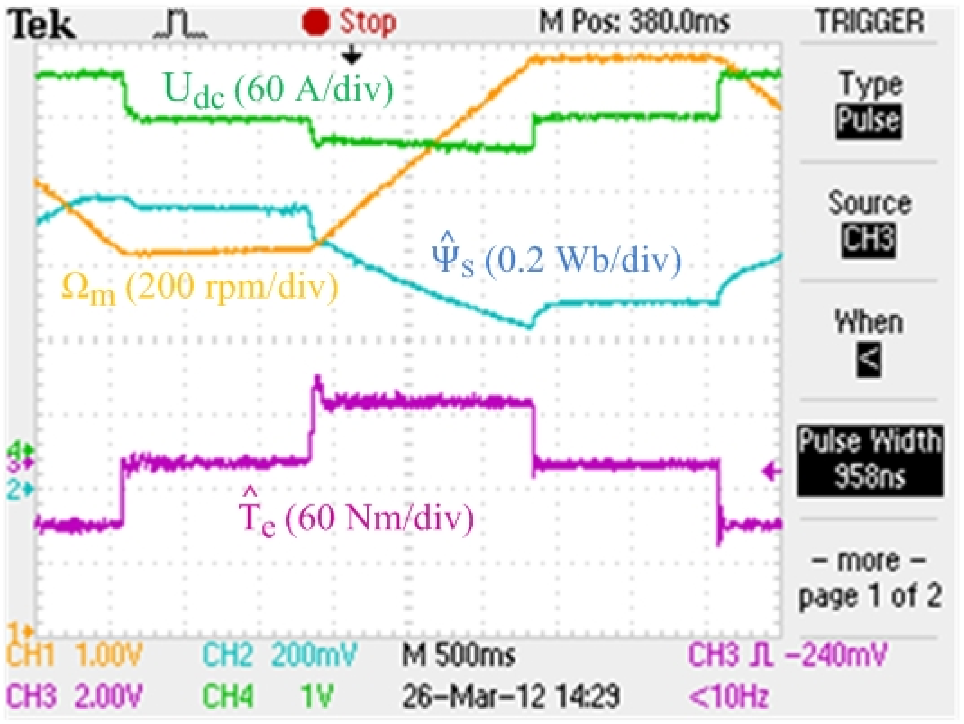
Experimental Results
Constant torque and field weakening region



Operation in torque/slip control mode:
torque reference changes +/-50 Nm
Speed changes from 1000 rpm to 1500 rpm

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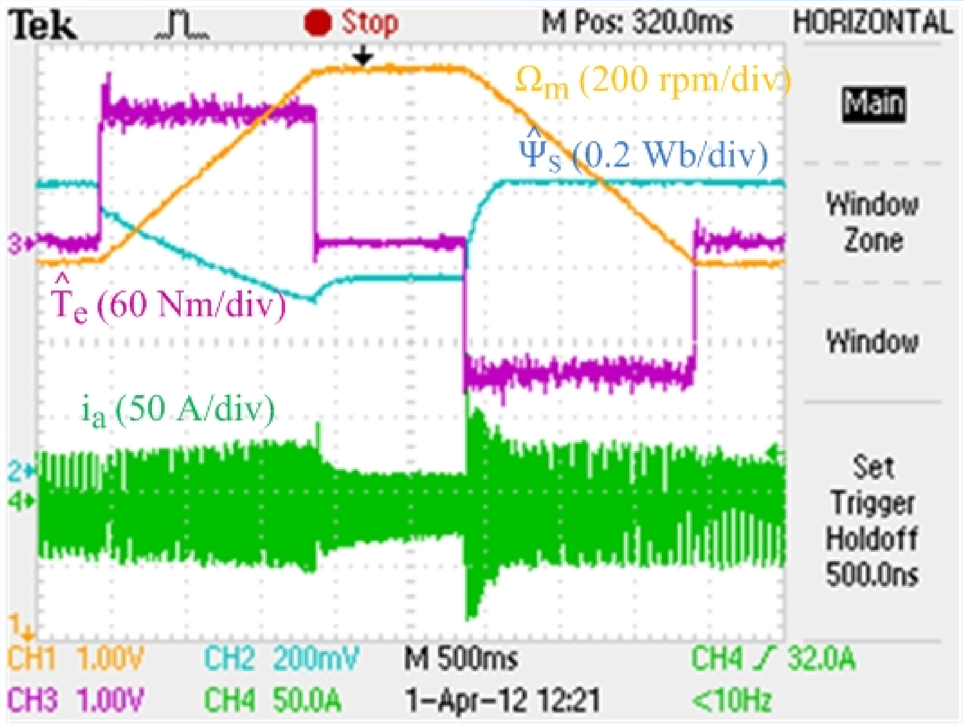
Experimental Results
Constant torque and field weakening region



Operation in torque/slip control mode:
torque reference changes +/-100 Nm
Speed changes from 1000 rpm to 1500 rpm

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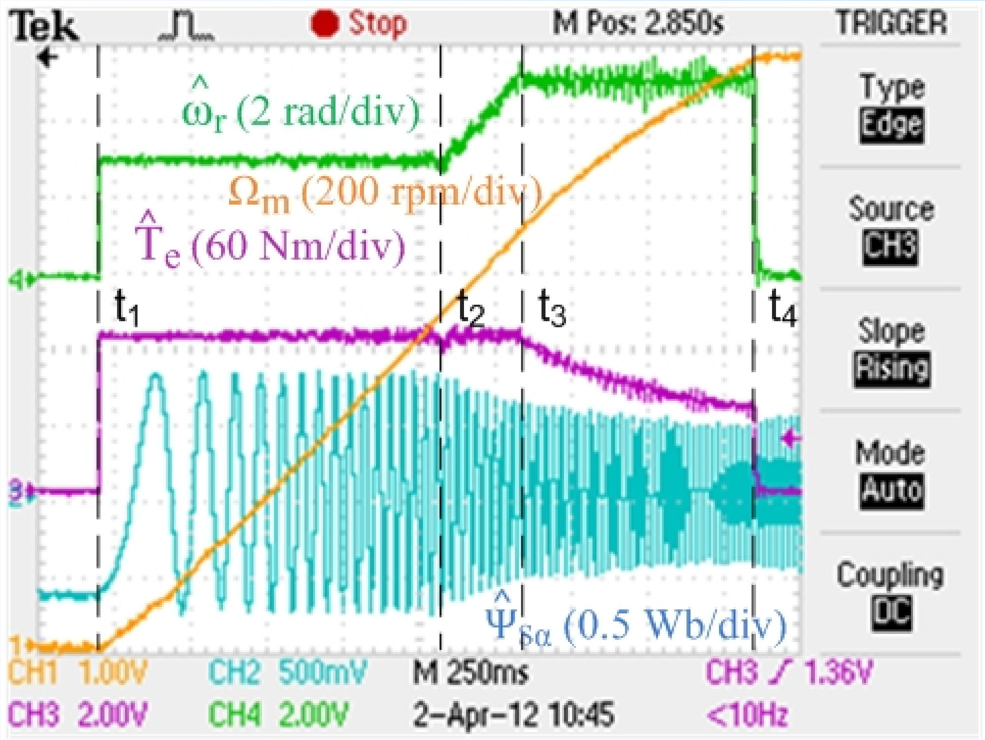
Experimental Results

Constant torque and field weakening region



Start up from 0 up to 1580 rpm

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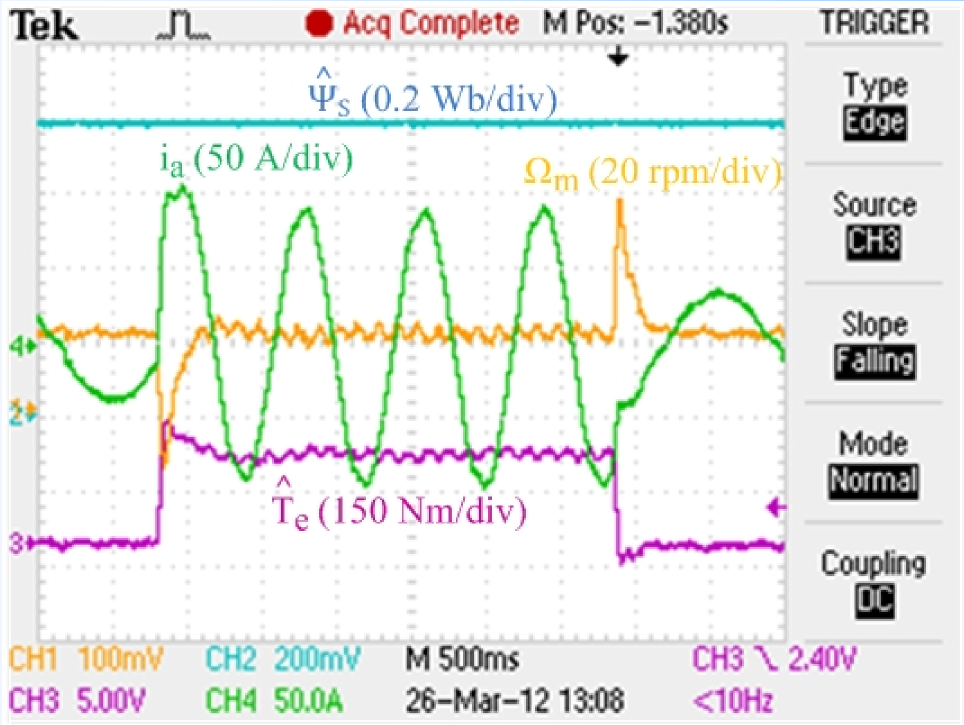
Experimental Results

Speed response



Speed response to the load step change
in speed control mode
Speed 20 rpm/min, Load torque 120 Nm

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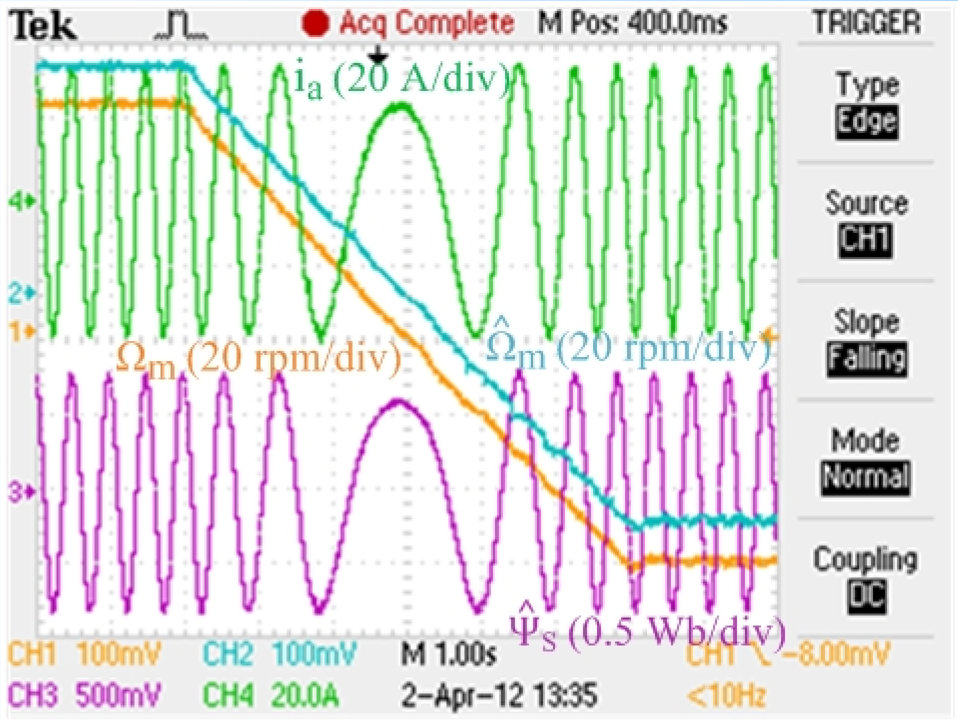
Experimental Results

Speed reversal



Speed tracking performance for
slow reference changes +/-60 rpm
in the time period of 6s

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Final Conclusions

- Presented control method allows for direct slip control
- Simple flux weakening method allowing for adaptation to all conditions of speed, load torque and available voltage in DC link
- Maximum use of available DC voltage
- High dynamic of torque generation
- Proposed simple flux and speed estimator operates in wide range of speed
- Elimination of speed sensor
- Whole control system was tested on 50 kW tram IM motor

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