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A Robust Induction Motor Control Firmware based on TI HV Developer's Kit

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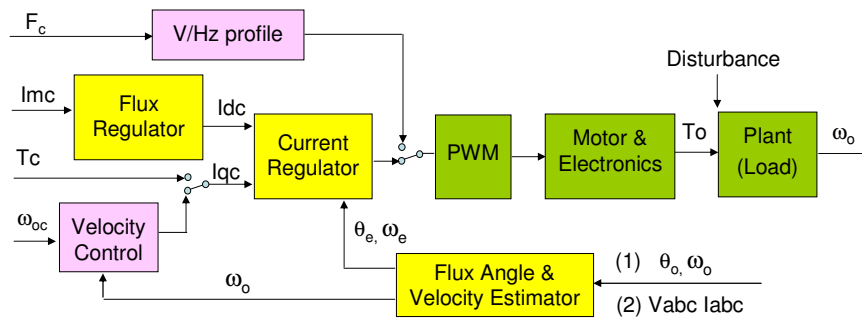
Overview

- **Robust Induction Motor Control Firmware**
 - Field Oriented Control and V/Hz Inverter Mode
 - Supports both Encoder and Sensorless Modes
 - **Customizable for Application-specific requirements**
- **Enhanced from TI controlSUITE software**
 - Host communication via Serial Communication
 - Parameter Storage, Setup and Tuning Aid
 - Improved Safety and Protection
 - Backed by MATLAB/SIMULINK simulation
 - Improved Control Algorithm
 - Dead-time compensation, Anti-windup,
 - Torque and Power calculation
 - Runs at 280XX or 283XX platform

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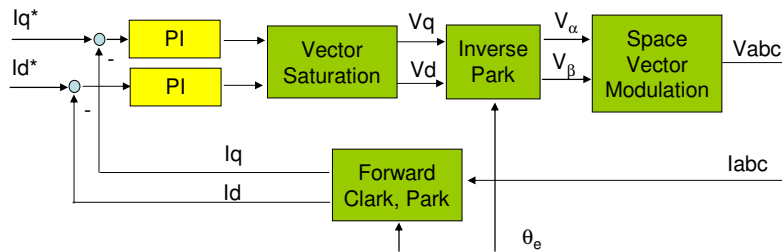
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Induction Motor Drive System



- Designed for Versatile Induction motor applications
- Room for Application-specific functions and features

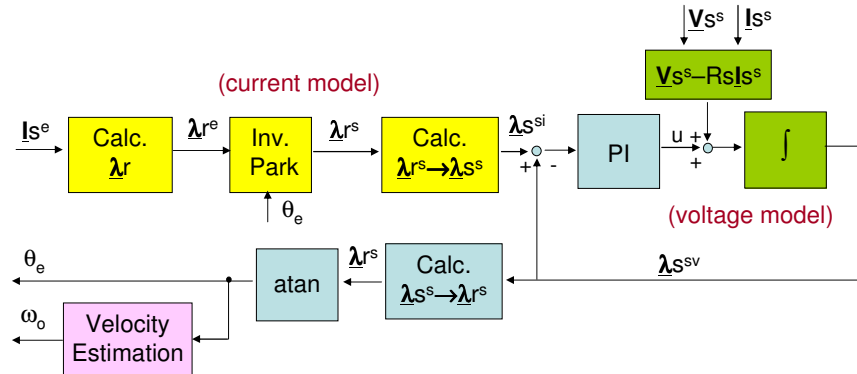
Basic Synchronous Current Regulator



- Effective current source within linear region
 - No steady-state phase delay
- Capable of feed-forward terms (V_{emf} and cross-coupling)
- Vector saturation algorithm

Hybrid Rotor Flux Angle Estimator

- Low frequency – dominated by current model
- High frequency – dominated by voltage model
- PI controller determines threshold frequency and mid-frequency characteristics



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Sensorless Technologies and Challenges

- Estimation of Flux Angle & Velocity
 - from terminal voltages and currents
- Performance in general
 - Challenges at startup and near-zero speed, high torque application
 - BW limited, limited accuracy
- **Key to Improved Sensorless Techniques**
 - Compensation of Nonlinearities (dead-time, voltage drop, etc.)
 - Algorithm selection – Hybrid Angle Estimator
 - Accurate Parameter Model
 - Intelligent Tuning
 - Safeguard and Protection

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Nonlinearities in Voltage Measurement

- **Dead-time effect**
 - Effect is determined by direction of current
 - Fundamental component voltage
$$\Delta V_x = (4/\pi) (T_d/T_s) V_{bus}$$
- **Semiconductor drop**
$$\Delta V_y = \Delta V_o + R_y I_s$$
$$R_{s\#} = R_s + R_y + R_{cable}$$
- Compensation can be done at synchronous frame
- Tuning
 - Direct - Calculated and Datasheet parameters
 - Verify with short circuited terminal.

Torque and Power Calculation

- Instantaneous Power
$$P = V_a I_a + V_b I_b + V_c I_c = 3 V_p I_p \cos\theta$$
Constant power in balanced 3 phase system
- In transformed 2-phase system
$$\mathbf{P} = (3/2) (\mathbf{V}_{ds} \mathbf{I}_{ds} + \mathbf{V}_{qs} \mathbf{I}_{qs})$$
$$P = (3/2) (V_{\alpha s} I_{\alpha s} + V_{\beta s} I_{\beta s})$$
(3/2) due to Clarke transform convention
- Torque
$$P = T (\omega_o P_p)$$
$$\mathbf{T} = (3/2) \mathbf{P}_p (\lambda_{ds} \mathbf{I}_{qs} - \lambda_{qs} \mathbf{I}_{ds})$$

Per Unit System (IQ-math)

- Advantages
 - **Use of low-cost microcontroller**
 - **Maximize fixed-point resolution in calculation**
 - **Fast calculation speed**
 - Most unit conversions can be performed during initialization
- Base quantities defined for each variable
- Example:
 - $I_b = I_{max}$, $V_b = V_{max}$
 - $V_u V_b = R_s I_u I_b$
 - $V_u = (R_s I_b / V_b)$ $I_u = R_s' I_u$
 - For internal calculation in per-unit system, R_s' should be used.

Parameter Commissioning

- Based on IEEE Standard 112
- DC low voltage injection
 - Dead-time and voltage drop
 - $R_s^{\#}$
- No-load Voltage test
 - L_s
 - Rotor and load inertia
 - Encoder direction
- Locked-rotor test (or single phase injection)
 - L_l , L_r , R_r
 - $L_m = L_s - L_l$

Auto-tuning and Parameter Adjustments

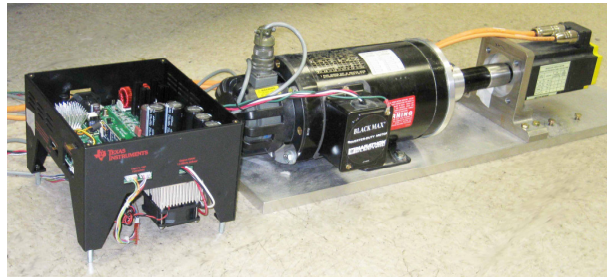
- **Current Control**
 - Current measurement Filter
 - Current loop PI
 - **Sensorless FOC**
 - Hybrid PI controller
 - Voltage Integrator LPF Corner Frequency
 - **Velocity Control**
 - Velocity Estimation Filter Frequency
 - Velocity loop PI
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- Model-based analytic tuning and allows fine tuning
 - Currently under development

Safeguard and Protection

- **Shut-down Protection**
 - Over-current protection
 - Over-temperature
 - Over-speed protection
- **Safeguard**
 - Slip, Voltage and Current saturation
 - Anti-wind-up and integrator limit for PI regulator
 - Validity of parameters and overflow
 - Under & over voltage (bus)
 - Abnormal field orientation check**
 - Abnormal speed or frequency detection
 - Accumulated regulator error check

Test Setup

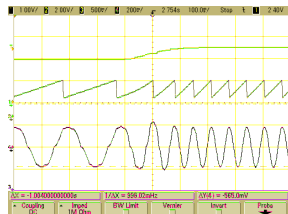
- Motor Marathon 1 HP induction motor (with encoder for test)
- Drive Modified **TI Motor Control & PFC Developer's Kit**
DC 300V bus common with load motor drive
- Load Baldor brushless servo motor, Resolver feedback
Drivetech Servo Drive



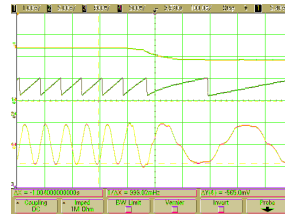
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Dynamic speed change and low frequency test

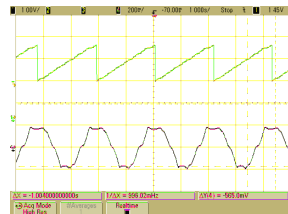


(1) 5 Hz to 15 Hz Speed change



(2) 13 Hz to 3 Hz speed change

Red: A-phase current, Yellow: actual speed, Green: estimated stator angle



(3) Low speed < 1 Hz



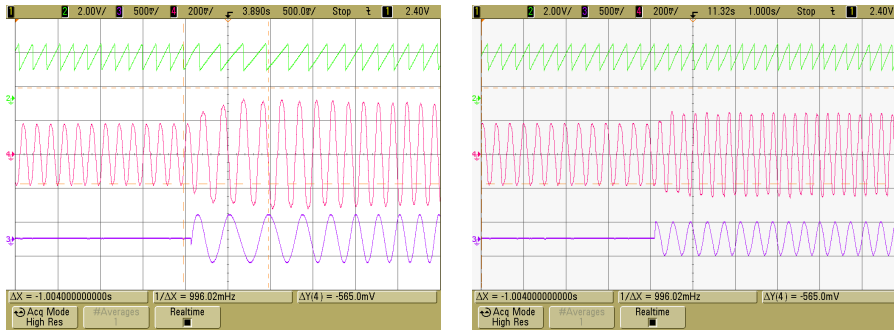
(4) Actual and est. angle after tuning

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Red: A-phase current, Yellow: actual stator angle, Green: estimated stator angle

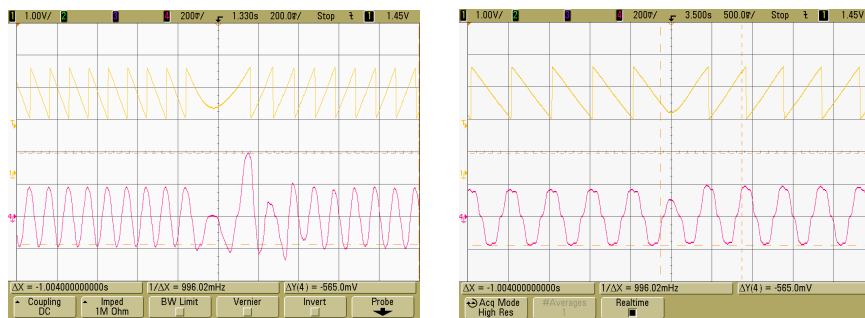
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Step Load Torque Change



(5) 3Nm Step Torque at 6 Hz (6) 2Nm Step Torque at 3 Hz
 Red: A-phase current, Purple: load motor current, Green: calculated stator angle

Fast Speed Reversal



(7) -10Hz to +10Hz speed reversal (8) -2Hz to +2Hz speed reversal
 Red: A-phase current, Yellow: calculated stator angle

Conclusion

- Robust Sensorless FOC Control algorithm
 - Fast execution (runs at 10kHz sampling on 60 MHz 280xx)
 - **283XX micro for high pwm rate, or for more features**
- **Performance verified with load test**
 - Robust performance down to a few Hz
 - Stable torque disturbance response and Quick speed reversal
- **Excel** table support for parameter calculation
- Serial communication with PC – parameter change, control and status, data logging
- Enhanced features under development
 - Auto-commissioning
 - Similar firmware for **PM Motor sensorless FOC**