Power 'n Motors

Critical aspects in power applications
design, proper component selection
& experimental results

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Agenda

9:00	**Introduction**
9:15	**HV Motors (BLDC) & 3PHs Inverters** • Architectures & components • New Intelligent Power Modules (IPM) from ST 1. Experimental results: Performance Benchmark 2. Guidelines to minimize EMI
11:00	Coffee break
11:15	**IPM simulation tool**
11:45	**HV driving with isolation** • Driving an isolated 60kW HB driver: experimental results
12:15	**LV Motors (DC & BLDC)** • Architectures & components
12:30	Lunch
13:30	**LV Motors (DC & BLDC)** • Choosing right MOSFET for LV Motor Control (1h) 1. Relationship between MOSFET parameters & EMI behavior 2. Experimental results: Performances of new F7 Technology
14:30	**ST solutions to drive three phases permanent magnet motors** • ST MCU Portfolio for Motor Control • Software & Firmware • Evalboard demonstration
16:00	**Conclusions**

ST solutions to drive three phases permanent magnet motors

Software & Firmware

Evaluation boards

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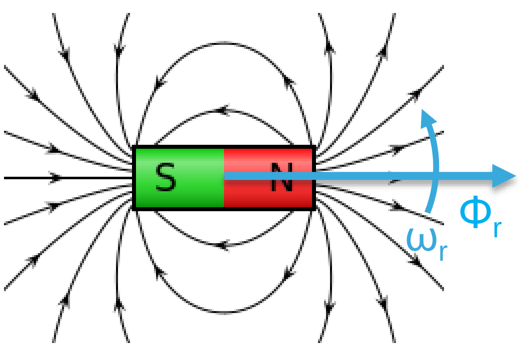
G. Forte
Systems Lab

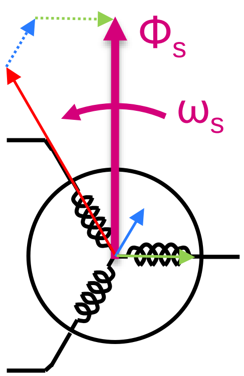
What is FOC?

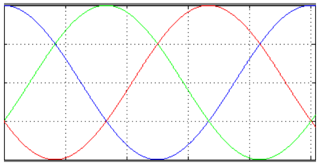
- FOC is the acronym of ***Field Oriented Control.***
- The purpose of the FOC is to maximize the electro-magnetic torque provided by the motor keeping the two magnetic fields (rotor and stator) always at 90 electrical degrees.

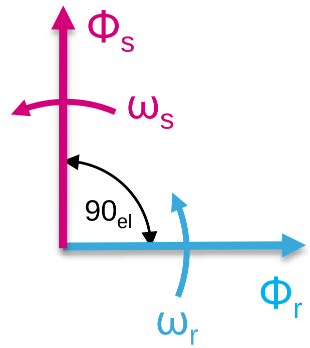
Rotor magnetic field



Stator magnetic field







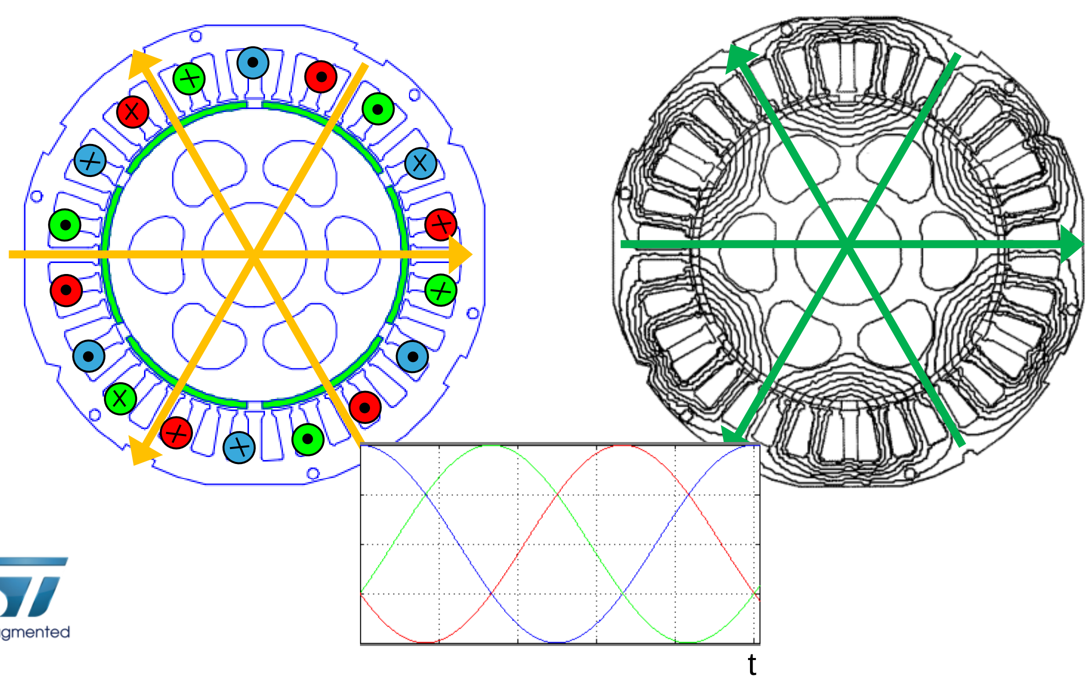
Torque T_e is maximized if the two field are kept at 90°

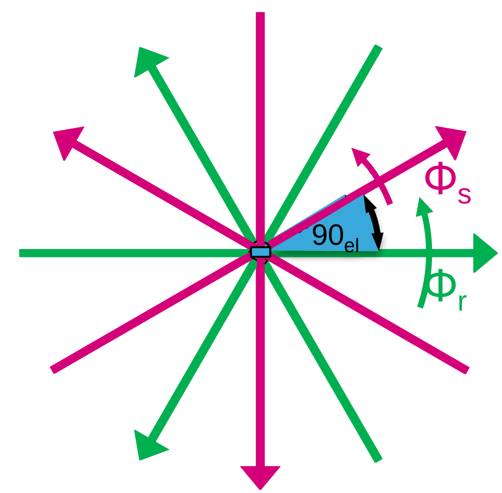
Benefits of FOC

- Best energy ***efficiency*** even during ***transient operation.***
- ***Responsive speed control*** to load variations.
- ***Decoupled control*** of both electromagnetic torque and flux.
- Acoustical ***noise reduction*** due to sinusoidal waveforms.
- Active ***electrical brake*** and ***energy reversal.***

PMSM FOC Basics

- <u>Field Oriented Control: stator currents (Field) are controlled in amplitude and phase (Orientation) with respect to rotor flux</u>
  - ➢current sensing is mandatory (3shunt/1shunt/ICS)
  - ➢speed / position sensing is mandatory (encoder/Hall/sensorless algorithm)
  - ➢current controllers needed (PI/D,FF)
    - ❖not easy… high frequency sinusoidal references + stiff amplitude modulation..
    - ❖reference frame transformation (Clarke / Park) allows to simplify the problem:



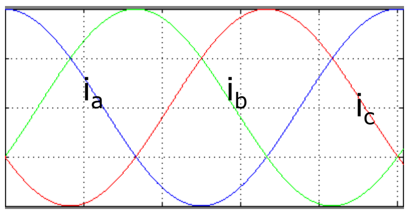


T_e maximized if…

PMSM FOC Basics:

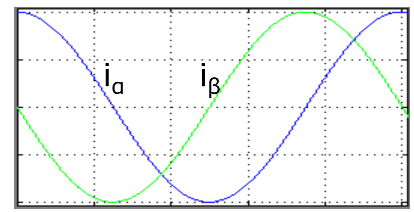
reference frame transformations

- Clarke: transforms i_a,i_b,i_c (120°) to i_α,i_β (90°); (consider that ia+ib+ic=0);

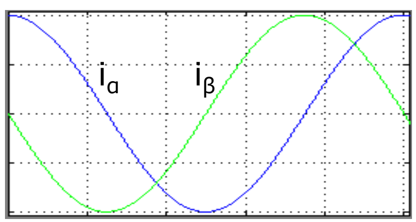


$$i_\alpha = i_{as}$$

$$i_\beta = -\frac{i_{as} + 2i_{bs}}{\sqrt{3}}$$

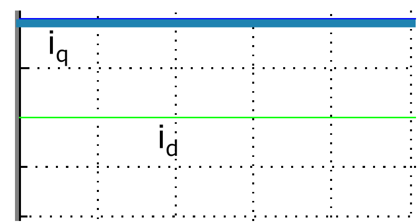


- Park: currents i_α,i_β , transformed on a reference frame rotating with their frequency, become DC currents i_q,i_d (90°)

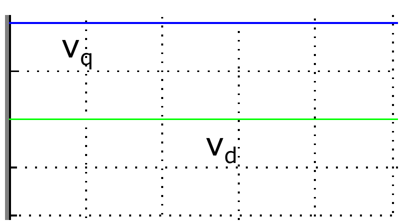


$$i_{qs} = i_\alpha \cos\theta_r - i_\beta \sin\theta_r$$

$$i_{ds} = i_a \sin\theta_r + i_\beta \cos\theta_r$$

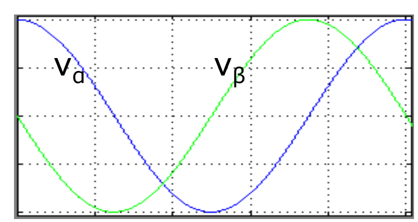


- PI regulators now work efficiently in a ‘DC’ domain; their DC outputs, voltage reference v_q,v_d are handled by the Reverse Park -> v_α,v_β AC domain



$$v_\alpha = v_{qs} \cos\theta_r + v_{ds} \sin\theta_r$$

$$v_\beta = -v_{qs} \sin\theta_r + v_{ds} \cos\theta_r$$



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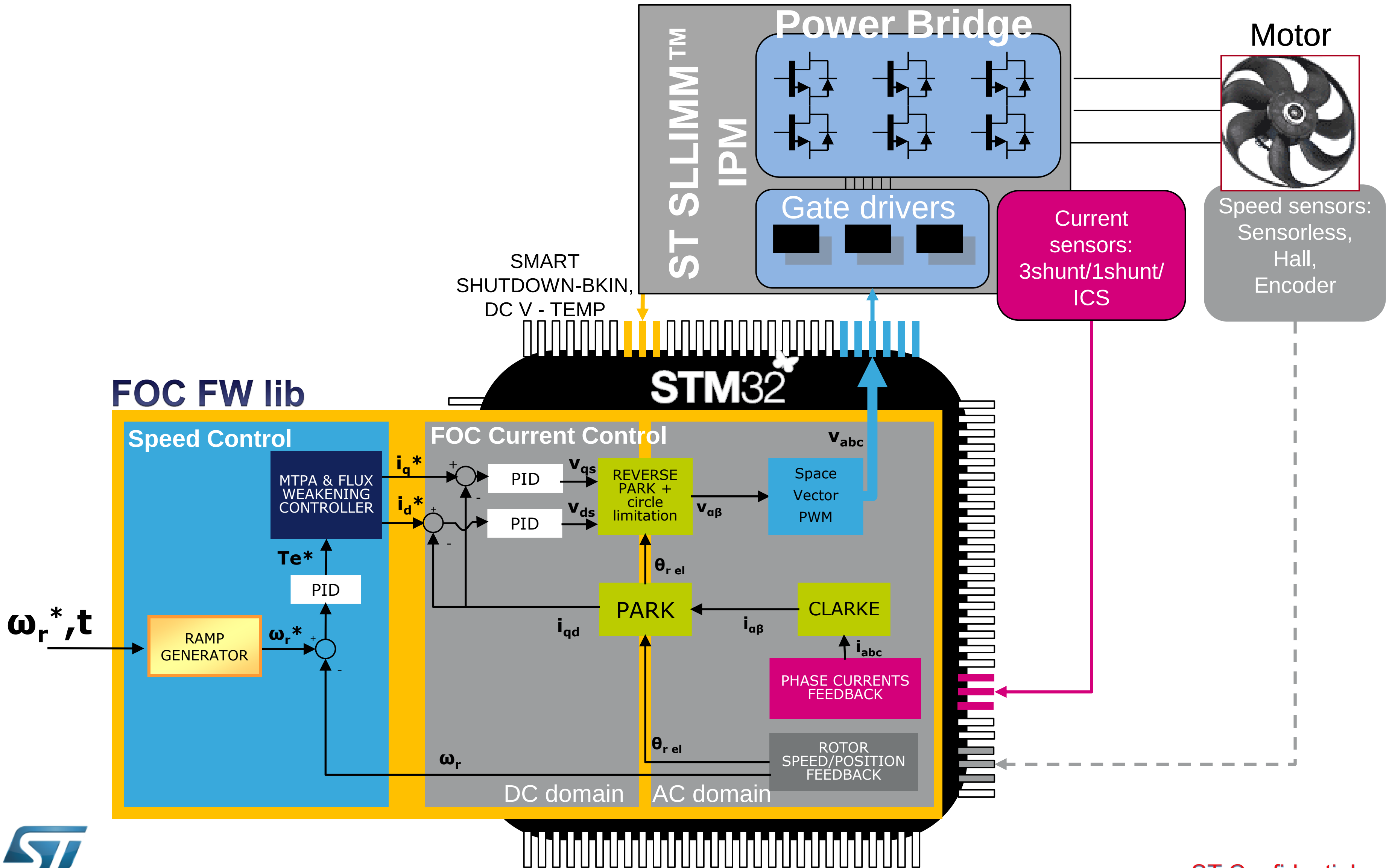
PMSM FOC – Block Diagram



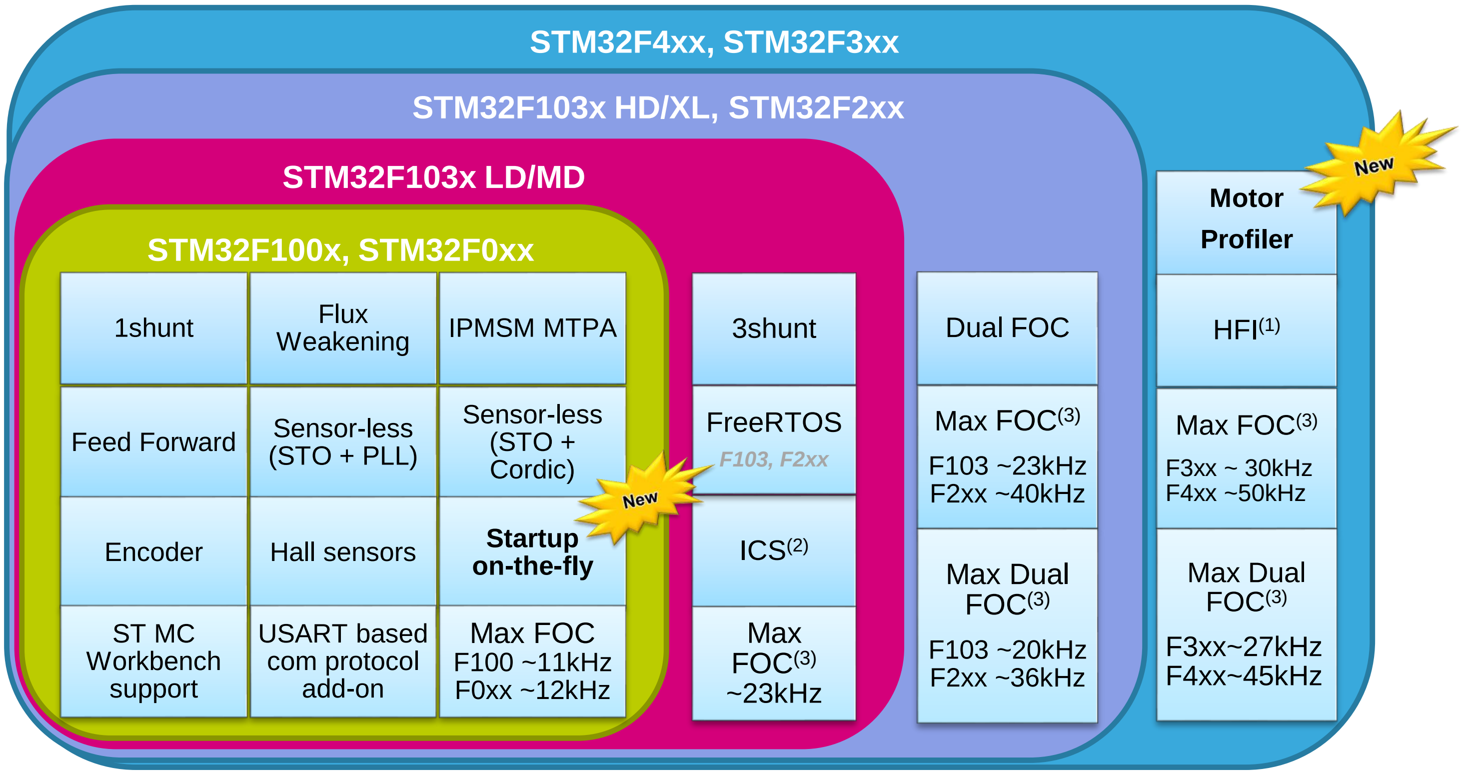
STM32 PMSM FOC SDK v4.1

- ***STSW-STM32100*** - **includes the PMSM FOC FW library and ST MC Workbench (GUI),** allowing the user to evaluate ST products in applications driving single or dual Field Oriented Control of 3-phase Permanent Magnet motors **(PMSM)**, featuring STM32F3xx, STM32F4xx, STM32F0xx, STM32F1xx, STM32F2xx

New

STM32 FOC SDK
Key Features

MC FW LIB v4.1



Plug-in: Digital PFC

(1) High Frequency Injection
(2) Supported only for STM32F103, STM3F2, STM3F4
(3) Max FOC estimated in sensorless mode

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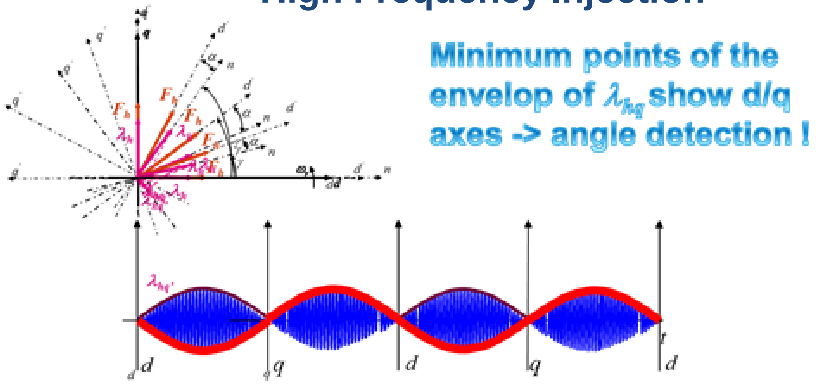
ST PMSM FOC library

Features

- Speed/position sensors supported:
  - Quadrature Encoder
    - Expensive sensor, usually only in robotics applications
  - Hall Sensors
    - Cheaper sensors, usually for application requiring full torque at zero speed
  - Sensor-less
    - High frequency injection (ST patent pending):
      - for anisotropic motors (IPMSM, Ld<Lq)
      - allows precise rotor angle detection; it enables advantages of FOC in torque/speed/position control mode at very low and zero speed
      - STM32F3 and STM32F4 only
    - State observer + PLL
      - Use electrical quantities (mainly current feedback) to estimate rotor position
      - Used for many applications not requiring full torque at zero speed or very low speed operations (< 3-5% of nominal speed)
    - State Observer + CORDIC

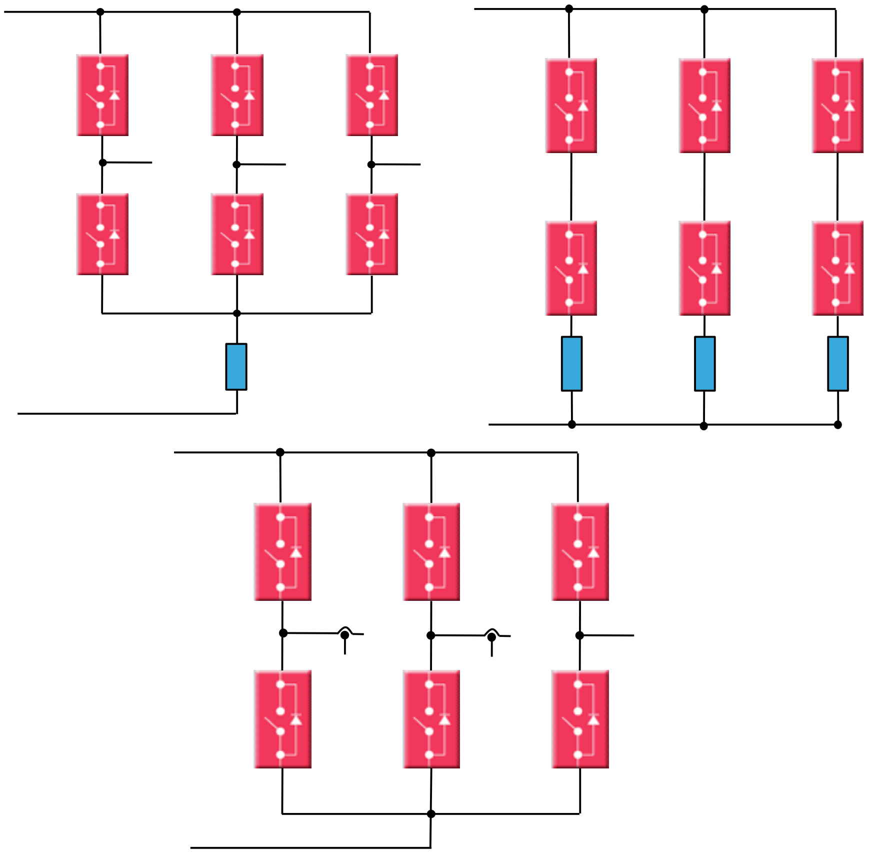
High Frequency Injection



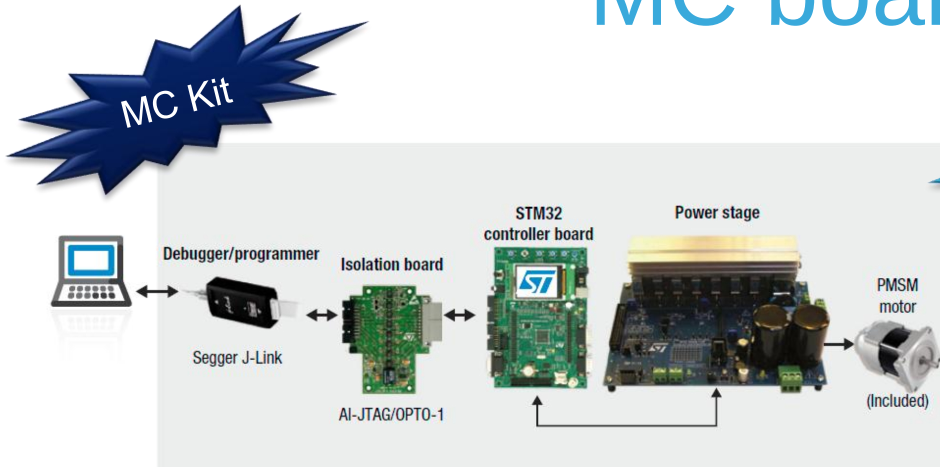
ST PMSM FOC library

Features

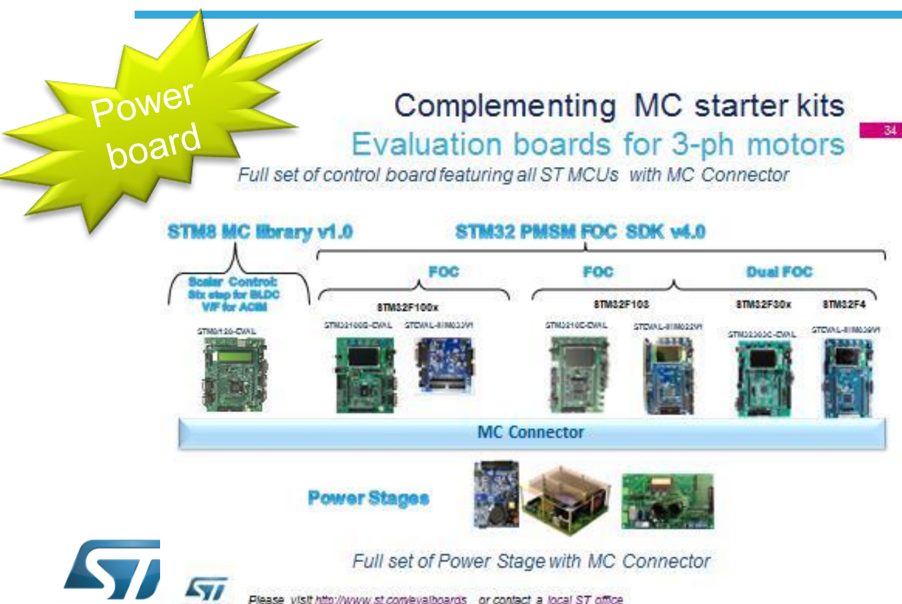
- Current sensing topologies:
  - 1 shunt resistor placed on the DC link
    - ST patented algorithm
    - Only one op-amp /shunt resistor is needed → lowest cost
    - Current reading algorithm may result in not accurate torque regulation
  - 3 shunt resistors placed in the three legs
    - Current reading accuracy: high
    - Best compromise cost / performances
  - 2 Isolated Current Sensors (ICS)
    - Not dissipative current sensing topology → mandatory when current exceed some tens Ampere
    - Expensive
  - Any possible configuration (2 motors x 3 current sensing x 3 speed sensors type) is supported by FW library



MC boards offer on ST.com



Kit: from isolated debug probe to motor



MC Kit

Motor control kits

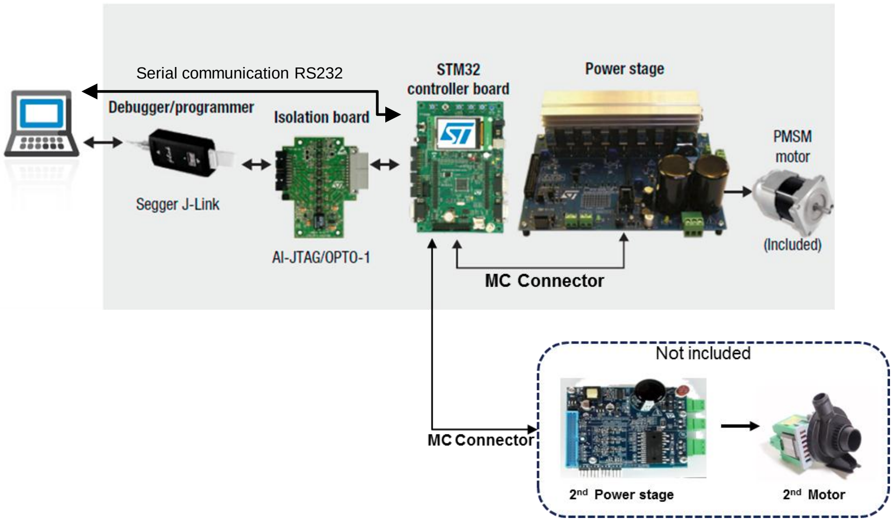
Part Number	Description	ST Link onboard	Type
STM32100B-MCKIT	Motor control starter kit for STM32F100 (128KB Flash) Value Line MCUs	Yes	Single drive
STM3210B-MCKIT	Motor control starter kit for STM32 (128KB flash) Performance and Access Line microcontrollers	No	Single drive

The motor control kit connections represented below can also be applied when combining STM32 control boards and evaluation power boards.

Motor control kits

STM32100B-MCKIT

STM3210B-MCKIT



Inverters

ST complete inverters

Part Number	Description	ST Link onboard	Type
STEVAL-IHM034V2	Dual motor control and PFC demonstration board featuring the STM32F103 and STGIPS20C60	No	Single/Dual drive
STEVAL-IHM036V1	Low power motor control board featuring the SLLIMM™ STGIPN3H60 and MCU STM32F100C6T6B	No	Single drive
STEVAL-IHM038V1	BLDC ceiling fan controller based on STM32 and SLLIMM-nano	No	Single drive
STEVAL-IHM040V1	BLDC/PMSM driver demonstration board based on STM32 and the SLLIMM nano™	No	Single drive
STEVAL-IHM042V1	Compact, low-voltage dual motor control board based on the STM32F303 and L6230	Yes	Single/Dual drive
STEVAL-IHM043V1	6-Step BLDC sensorless driver board based on the STM32F051 and L6234	No	Single drive
STEVAL-IFN003V1	DC PMSM FOC motor drive	No	Single drive

STEVAL-IHM034V2

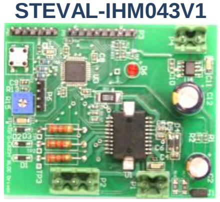
STEVAL-IHM036V1

STEVAL-IHM038V1

STEVAL-IHM040V1

STEVAL-IHM042V1

STEVAL-IHM043V1



STEVAL-IFN003V1

Control board

STM32 evaluation boards with MC connector

Part Number	Description	ST Link onboard(1)	Type
STM3210E-EVAL	Evaluation board for STM32 F1 series - with STM32F103 MCU	No	Single drive
STM3220G-EVAL	Evaluation board for STM32 F2 series - with STM32F207IG MCU	Yes	Single drive
STM32303C-EVAL	Evaluation board for STM32F303xx microcontrollers	Yes	Single/Dual drive
STM3240G-EVAL	Evaluation board for STM32F407 line - with STM32F407IG MCU	Yes	Single drive
STEVAL-IHM022V1	High density dual motor control demonstration board based on the STM32F103ZE microcontroller	No	Single/Dual drive
STEVAL-IHM039V1	Dual motor drive control stage based on the STM32F415ZG microcontroller	No	Single/Dual drive

STM3220G-EVAL

STM3240G-EVAL

STM3210E-EVAL

STEVAL-IHM022V1

STM32303C-EVAL

STEVAL-IHM039V1

(1) Only necessary for high-voltage applications or if not included with the evaluation board:

In-circuit debugger/programmer..

- ST-LINK/V2
- ST-LINK/V2-ISOL (2500 VRMS high isolation voltage)

Power board

ST evaluation power boards with MC connector

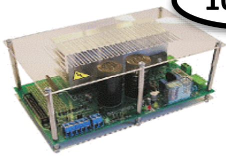
Part Number	Description
STEVAL-IHM021V2	100 W, 3-phase inverter based on L6390 and UltraFASTmesh™ MOSFET for speed FOC of 3-phase PMSM motor drive
STEVAL-IHM023V3	1 kW 3-phase motor control evaluation board featuring L6390 drivers and new IGBT STGP10H60DF
STEVAL-IHM025V1	1 kW 3-phase motor control demonstration board featuring the IGBT SLLIMM™ STGIPL14K60
STEVAL-IHM028V2	2 kW 3-phase motor control demonstration board featuring the IGBT intelligent power module STGIPS20C60
STEVAL-IHM032V1	150 W inverter featuring the L639x and STGD3HF60HD for 1-shunt based sinusoidal vector control and trapezoidal scalar control
STEVAL-IHM035V2	3-phase high voltage inverter power board for FOC and scalar motor control based on the STGIPN3H60 (SLLIMM™-nano)
STEVAL-IHM045V1	3-phase high voltage inverter power board for FOC based on the STGIPN3H60A (SLLIMM™-nano)

STEVAL-IHM021V2

STEVAL-IHM023V3

1KW

STEVAL-IHM025V1



1000W

STEVAL-IHM032V1

150W

STEVAL-IHM035V2

100W

STEVAL-IHM045V1

100W

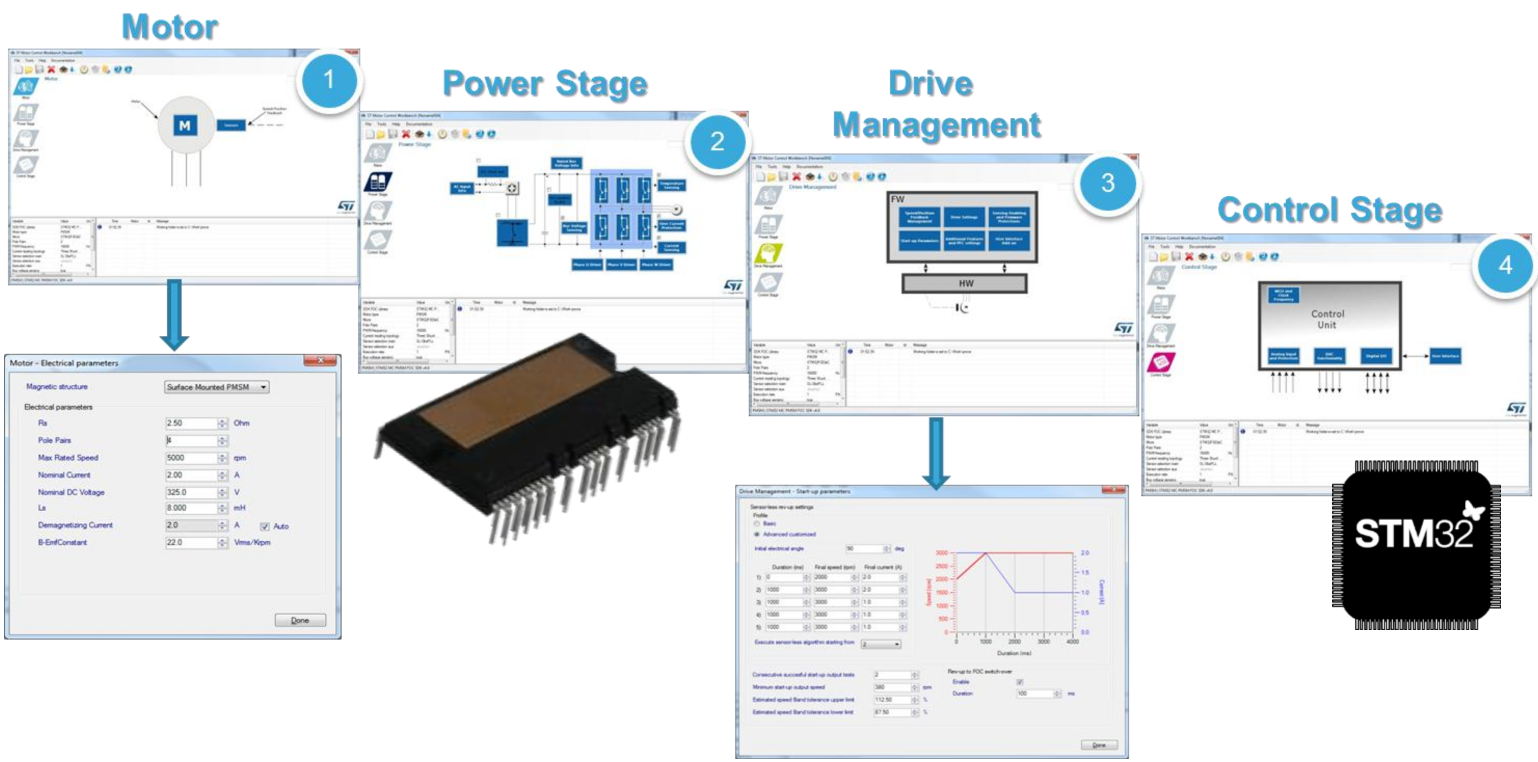
STEVAL-IHM028V2

2000W

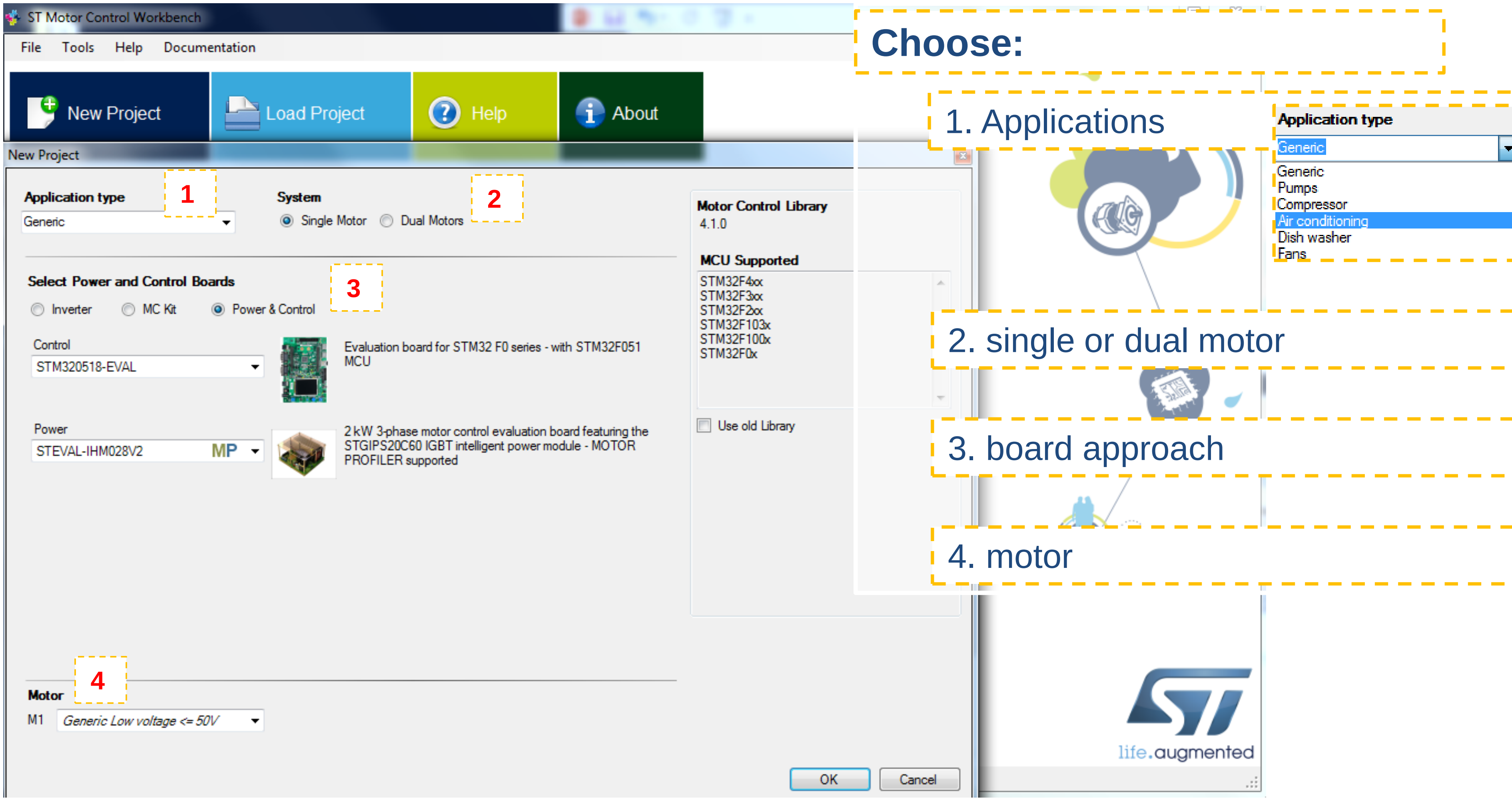
ST PMSM FOC library

Features

- Wide range of ST products supported (STM32, SLLIMM IPM, L639x, IGBT/Power Mosfet) using PC tool configurator: ST MC Workbench



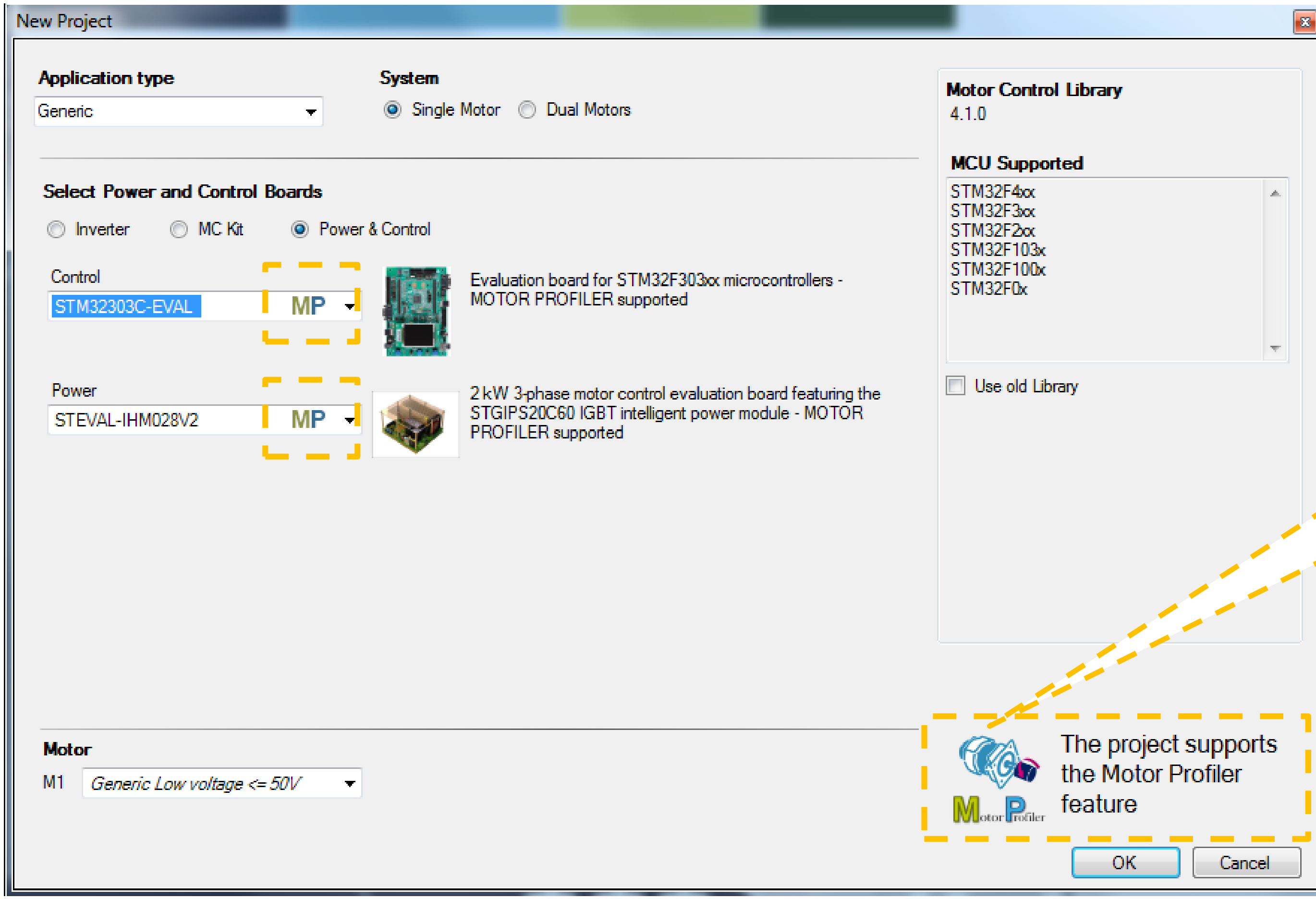
New project creation (1/2)
Starting from the Hardware



Choose:

1. Applications
2. single or dual motor
3. board approach
4. motor

New project creation (2/2)
Hardware for Motor Profiler



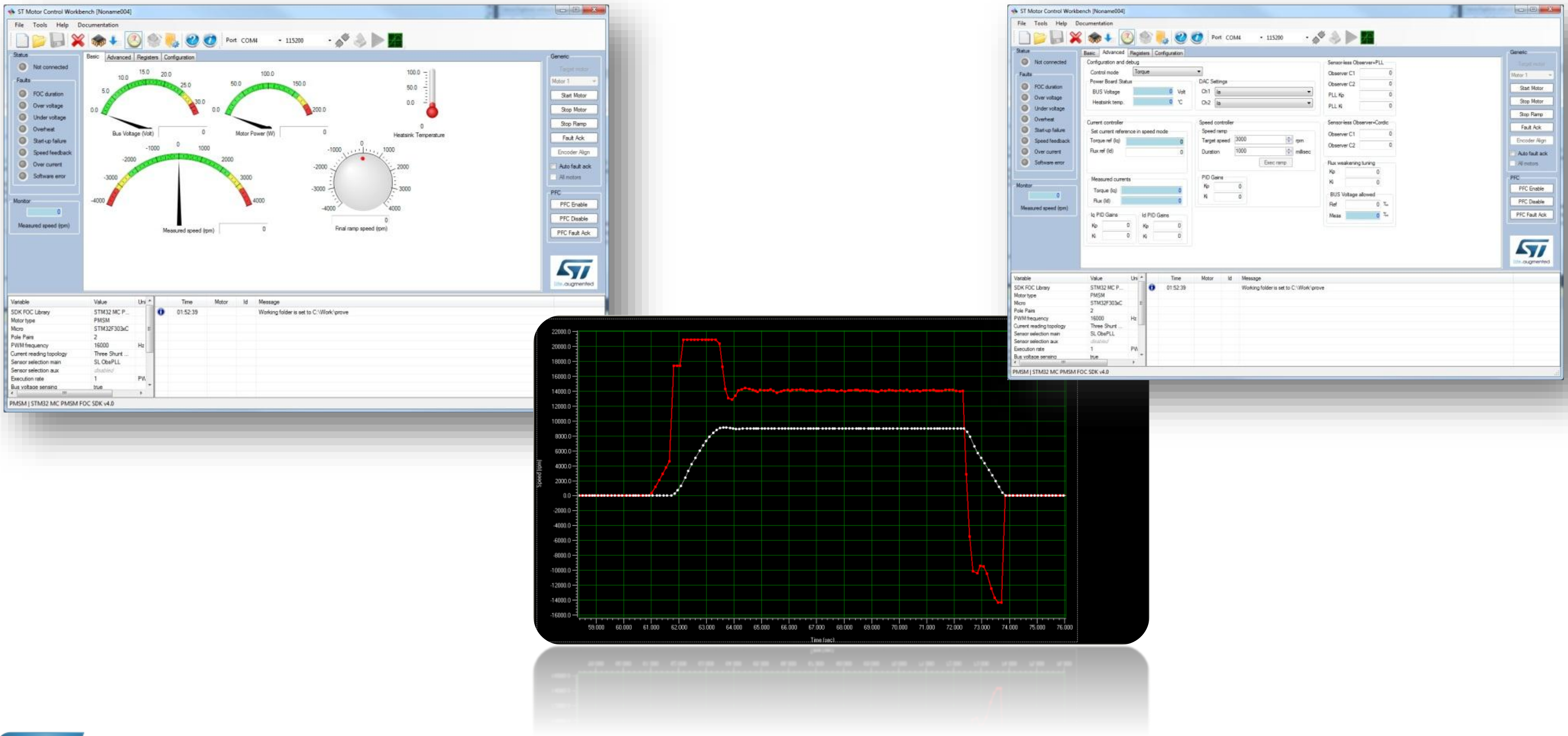
Example

HW supporting Motor Profiler

ST PMSM FOC library

Features

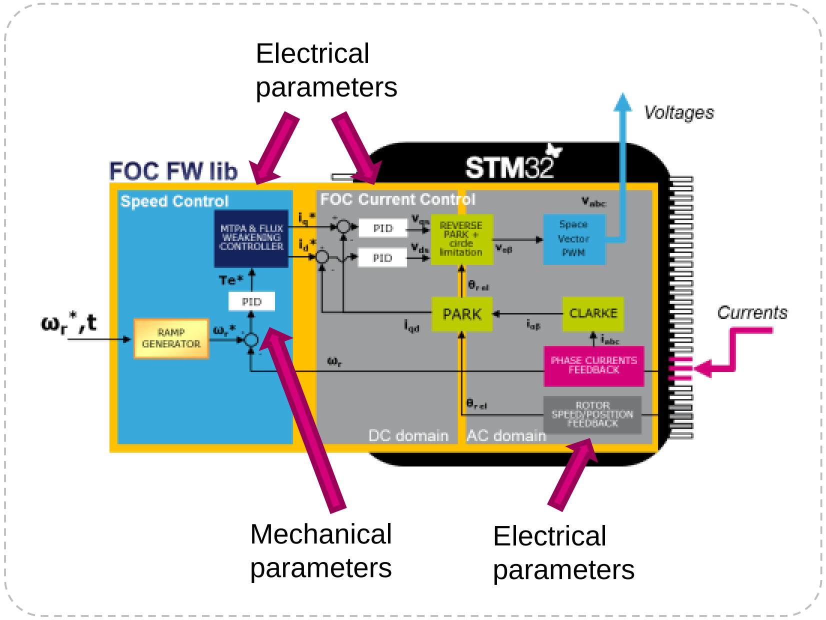
- Real time tuning capabilities



“Motor Profiler” why?

Why motor electrical parameters are required by FOC?

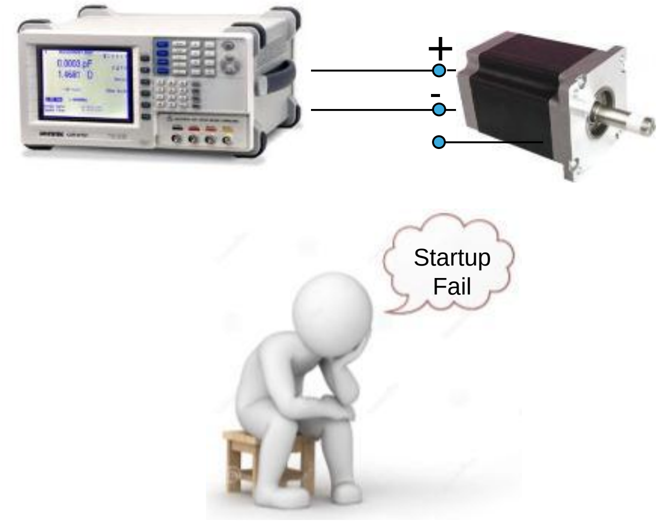
- Electrical and mechanical parameters are required by the algorithms to define the model of the motor
- It is required to tune the current regulators
- It is required for Sensorless state observer algorithm
- It is required for additional features
- It is required to tune the speed regulators



“Motor Profiler” why?

Sometimes to start the evaluation of motor control solution can be hard

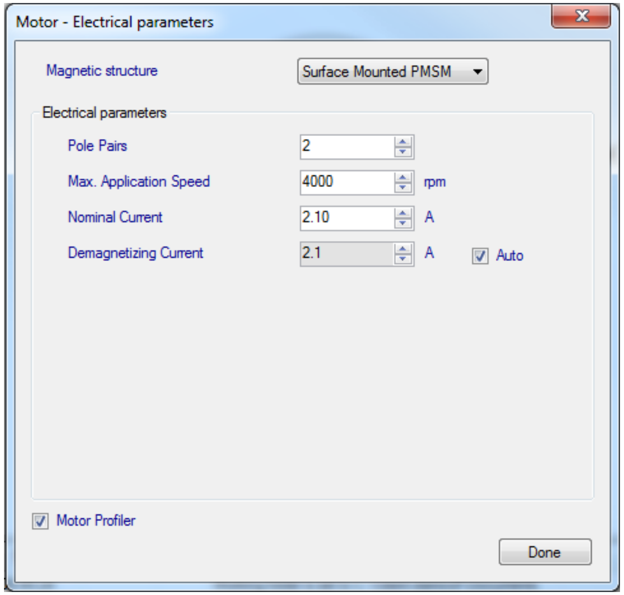
- To measure the motor parameters can requires specific skills and equipment
- Tuning of the regulators can be empirical
- Find the proper acceleration for the startup can’t be easy
- Many trials and errors before to run the motor



What can't be measured

These parameters shall be insert by the user

- Motor poles pairs
- Maximum Application speed
    - Nominal speed of the motor will be computed and used to validate the maximum application speed insert by the user
- Nominal current
- Motor anisotropy Lq/Ld ratio



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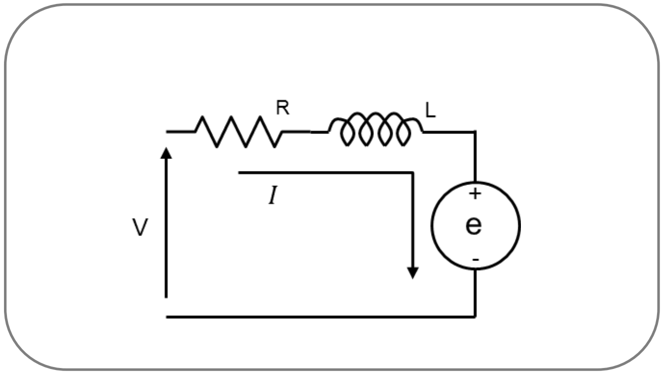
Measure electrical parameters

Electrical motor parameters measurement

- No additional HW and equipment required
- To perform the measurements is required to apply a voltage and measure the current
- Usual PWM generation is used to supply the voltage
- To compute the real voltage applied it is also measured the DC bus voltage
- Usual motor phase current sensing is used to measure the current

Electrical motor parameters

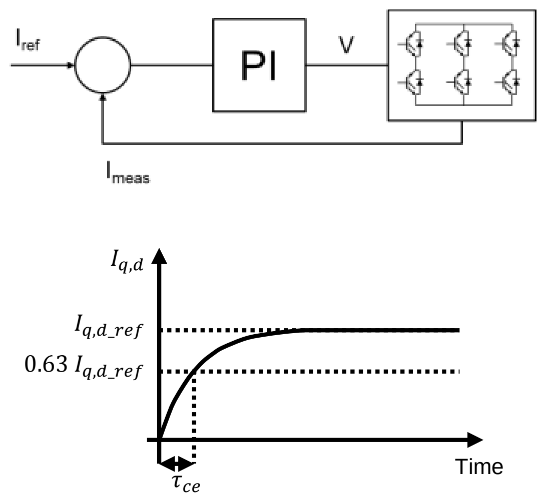


Current regulators tuning

Automatic tuning of current regulators

- Once the Rs and Ld are known, is possible to tune-up the closed loop current regulators
- Kp and Ki of Iq and Id current regulator, and related dividers, are computed according a single common parameter ω_{ce} (current regulation closed loop bandwidth)
- ω_{ce} defines the closed loop electrical constant time τ_{ce}

Current regulators tuning

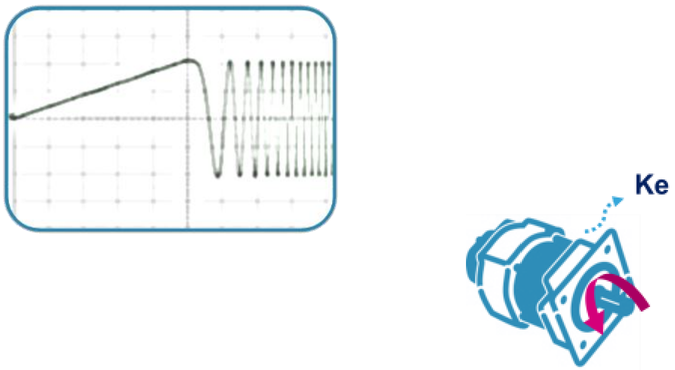


Measure electrical parameters

Startup and Ke measurement

- To measure the Ke (motor BEMF voltage constant) is necessary that the motor is running
- With tuned current controllers it is possible to apply an open loop acceleration (Startup)
- On the fly measurement of Ke is performed using the motor model

Startup and Ke measurement

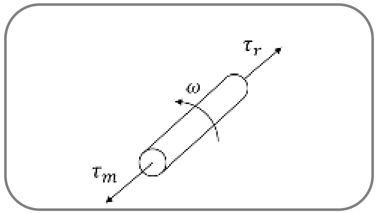


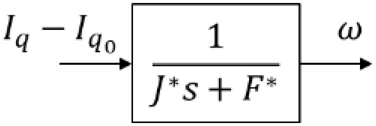
Mechanical motor parameters

Mechanical motor parameters measurement

- First order (inertial plus frictional) mechanical system model is used to perform the measurement

Mechanical motor parameters

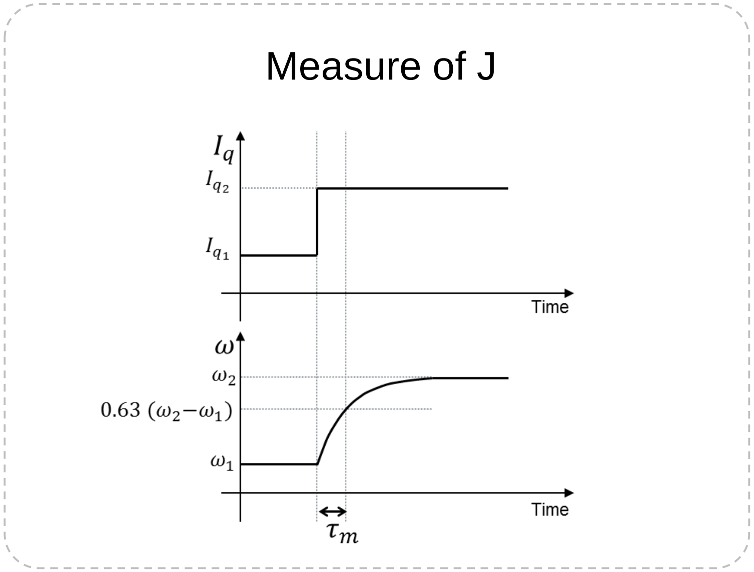




Mechanical motor parameters

Measurement of J (moment of inertia)

- The measurement of the moment of inertia is done through the measurement of the mechanical constant time τ_m

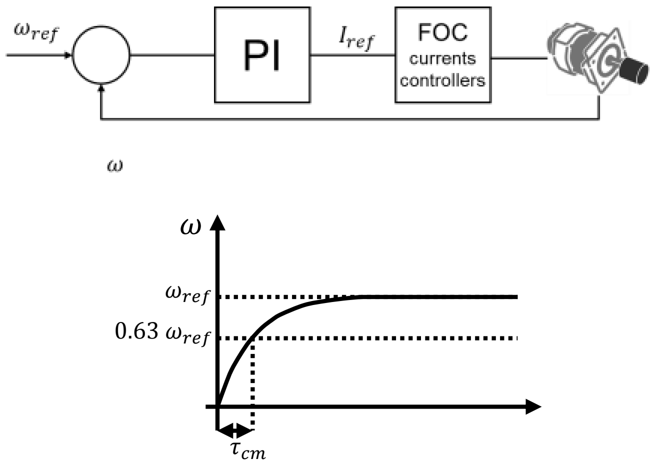


Speed regulators tuning

Automatic tuning of speed regulators

- Once the J and F are measured is possible to tune-up the closed loop speed regulators
- Kp and Ki of speed regulator, and related dividers, are computed according a single common parameter ω_{cm} (speed regulation closed loop bandwidth)
- ω_{cm} defines the closed loop mechanical constant time τ_{cm}

Speed regulators tuning

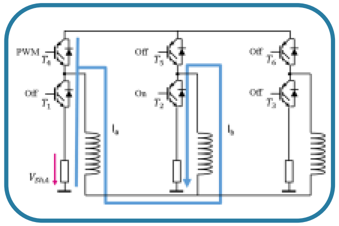


Motor Profiler + One Touch Tuning

Plug and Spin your Motor in less than 60 seconds

Motor stopped

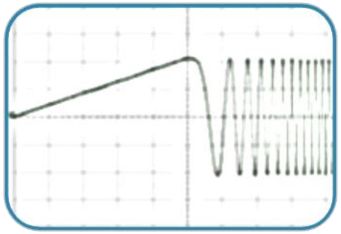
- Rs measurement
- Ls measurement
- Current regulators set-up



10 sec

Open loop

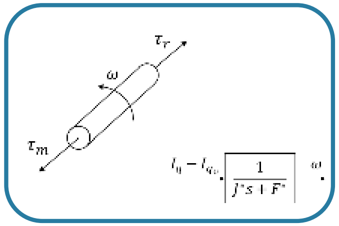
- Ke measurement
- Sensorless state observer set-up
- Switch over



5 sec

Closed loop

- Friction coefficient measurement
- Moment of inertia measurement
- Speed regulator set-up



45 sec

For further info about ***STM32 PMSM FOC SDK***, please visit:

http://www.st.com/stm32

Part number: *STSW-STM32100*

Downloads:

STM32 PMSM FOC SDK:

http://www.st.com/web/catalog/tools/FM147/CL1794/SC961/SS1743/PF257936

***UM1052*:**

STM32F PMSM single/dual FOC SDK

***UM1053*:**

Advanced developer guide for STM32F PMSM single/dual FOC library

UM1080:

Quick start guide for STM32F PMSM single/dual FOC SDK V4.0

Motor Control FORUM

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