ST solutions for efficient motor control

Technical Marketing Team
Systems Lab and Technical Marketing
Industrial and Multi Segment sector

www.emcu.it
• Electric motors classification

• Nomenclature

• Scalar and vector drives

• ST motor control ‘Ecosystem’

• Focus on vector control
  • STM32 Software Development Kit (SDK)
  • Software Tools
  • HW evaluation boards
Electric motors classification

**AC**
- Synchronous
  - Sinusoidal
  - Trapezoidal (BLDC) PM
- Asynchronous (ACIM)
  - Variable reluctance
  - Squirrel cage
  - Wound rotor
- Stepper
  - Switched reluctance

**DC (brushed)**
- Universal

**Internal mounted PM**
- Permanent Magnet (PMSM)

**Surface mounted PM**
- Wound field

**Higher efficiency** and/or reliability
**Lower efficiency** and/or reliability

Can be addressed by ST products
STM8 / STM32 MC FW library available

ST solutions for efficient motor control
Focus on 3Φ motors: Asynchronous motor

- Asynchronous motor or Induction Motor (AC IM)
  - Rotor is powered through electromagnetic induction (Brush-less motor);
  - Stator excitation frequency and rotor electrical speed differ by a quantity called *slip*;
  - Rotor often consists of laminated cylindrical iron cores with slots for receiving some aluminum bars (squirrel cage)

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**Diagram:**

- Torque
- Critical torque
- Loading torque
- Starting torque
- Working torque
- Rotor speed
- Slip
- Break down domain
- Working domain
- Stator frequency

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3-phase motors and nomenclature

- Asynchronous motor or Induction Motor (AC IM)
- Permanent Magnet Synchronous Motor (PMSM)
  - Stator can be the same as AC IM
  - Rotor houses permanent magnets
    - Glued on the surface → Surface Mounted (SM) PMSM
    - Buried within the rotor (different topologies possible) → Internal (I) PMSM
  - Sinusoidal-Bemf
- Permanent Magnet Brushless DC motors (BLDC)
Focus on 3Ф motors: PMSM/BLDC

- **Permanent Magnet Synchronous Motor (PMSM) / Brushless DC (BLDC)**
  - Stator can be the same as AC IM
  - Rotor houses permanent magnets
  - Glued on the surface → Surface Mounted (SM) PMSM
    - Buried within the rotor (different topologies possible) → Internal (I) PMSM
  - Stator excitation frequency matches rotor electrical speed
  - Rotor spinning induced sinusoidal (PMSM) or trapezoidal (BLDC) shaped Back Electro-Motive Force in motor phases
  - Gives best performances (torque steadiness) when driven by sinusoidal phase current
Scalar drives of 3Φ motors for AC IM

- Work often without any feedback devices (open-loop control)

- Low cost and easy-to-implement solution (8-bit MCU)

- On the other side
  - Developed torque is not controlled directly (depends on load)
  - Transient response is not fast due to the predefined switching pattern of the inverter

- Adding a speed sensor (tachometer) and slightly increasing control scheme complexity, transients responses can be made faster and torque estimation possible

Application web pages

ACIM scalar drive motor phase current
Scalar drives of 3Φ motors for PMSM

- Dislike AC IM, always requires speed/position information
  - Hall sensors
  - Drawn from electrical quantities (e.g. phase voltage) feedback (sensor-less)

- Two families of drives available
  - Six-step
    - Sensor-less solution is low cost (8 bit MCU): advanced ADC and timer peripherals are mandatory
    - Torque steadiness is not excellent → noisy compared to other methods
  - Sinusoidal
    - Sensor-ed can be handled by 8 bit MCUs → low cost MCU
    - Sensor-less solution for sinusoidal would require hard computation (not manageable by 8 bit MCUs) → scalar sensor-less wouldn’t be low cost;
    - Torque steadiness is better compared to six step → more quiet
  - In both cases developed torque is not accurately controlled

Application web pages
Field Oriented Control drive

- FOC drive is also called *vector control* drive as the algorithm is based on a vector representation of the stator current, voltage and magnetic flux.

- The method always requires rotor speed/position information:
  - Measured through real sensors: Hall sensors, quadrature encoder, tachometer, …
  - Computed indirectly from electrical quantities feedback (sensor-less)

- FOC scheme and rotor position estimation algorithm (where needed) must be executed at a rate comparable with PWM frequency:
  - Higher computational power required compared to scalar drives → higher cost vs scalar
  - At least 16bit MCU

- FOC drive ensures:
  - The torque steadiness typical of a sinusoidal control
  - Excellent performance in terms of accurate static and dynamic speed regulation and rapid response to sudden changes in load torque
  - Provide torque control as an alternative to speed control

Application web pages

Sinusoidal drive - motor phase current
# Scalar drives vs Field Oriented Control drive

- Both of them are Variable Frequency Drives (VFD)

<table>
<thead>
<tr>
<th>Scalar drive</th>
<th>Field Oriented Control drive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only the frequency and the magnitude of the voltage fed to the motor are controlled</td>
<td>The applied voltage is computed each PWM cycle so as to make current follow a precise profile</td>
</tr>
<tr>
<td>Don’t require motor current feedback to the control unit</td>
<td>Requires motor current feedback to control unit</td>
</tr>
<tr>
<td>Do not allow to fully control the torque of the electric motor</td>
<td>Allow to control fully and quickly the torque of the electric motor (e.g reducing the ripple)</td>
</tr>
<tr>
<td>Does not require high computational power</td>
<td>Require computational power (30MIPS for 32bit micro)</td>
</tr>
</tbody>
</table>
ST and efficient motor control: 10 years of 3-phase motor drives

• ST is focusing on 3-phase motor control since 2002
  • 10 years experience in scalar drives of AC IM and Permanent Magnet Synchronous Motors (PMSM)
  • 6 years experience in vector drives of ACIM and PMSM
  • a lot of product and system motor control evaluation boards are available today on www.st.com
STM32’s Motor control ‘Ecosystem’

- The STM32’s MC ‘Ecosystem’ is the right answer to 3-phase FOC PMSM developers to quickly start & complete their design keeping flexibility on their platform strategy (low, mid, hi-end)

- The ‘STM32 MC Ecosystem’ is made of (major items):
  - **MCU**: STM32 large portfolio (Cortex-M based)
  - **SW lib**: 3-phase FOC PMSM SDK (SW lib) + WorkBench to generate code
  - **HW**: Motor Control kit (based on STM32 eval board + MC SW lib & all other ‘power’ component from ST)
  - **Tools**: among others: STM Studio, to monitor any variable selected in the code to optimize application performance

- The STM8’s MC ‘Ecosystem’ complete by the STM32’s one with
  - AC Induction Motors (scalar) and BLDC (6-step) supported in the STM8s MC FW lib
STM32 Family & FOC SDK roadmap

Cortex - M3

- STM32 F1
  - F100 Value line
  - F103 Performance Line
  - F103 High density

- STM32 F2
  - 120Mhz

- STM32 F4
  - 168Mhz

Cortex - M0

- STM32 F0
  - 48Mhz

Cortex - M4

- STM32 F3
  - 72Mhz

STM32 FOC SDK

v3.x (F1xx – F2xx – F4xx – F0xx- F3xx)

www.emcu.it
• **STM32 PMSM FOC SDK v3.x:**
  is a Motor Control Software Development Kit for 3-phase Permanent Magnet Synchronous Motors (PMSM) based on Field Oriented Control (FOC) supporting STM32F103, STM32F100, STM32F2xx, STM32F4xx, STM32F0xx, STM32F3xx.

• **Key features:**
  • Single/Dual simultaneous vector control (FOC)
  • Any combination of current reading topologies and/or speed/position sensors is supported
  • Wide range of STM32 microcontrollers families supported
  • Full customization and real time communication through PC software ST MC Workbench
  • Wide range of motor control algorithms implemented for specific applications
  • Application example based on FreeRTOS
  • Increase code safety through
    • MISRA C rules 2004 compliancy
    • Strict ANSI C compliancy
    • New object oriented FW architecture (better code encapsulation, abstraction and modularity)
FOC SDK distributions and policy

<table>
<thead>
<tr>
<th>Distributions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Web distribution</strong> is available on internet</td>
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<tr>
<td>• Contains compiled ‘MC library’ layer</td>
</tr>
<tr>
<td>• Can be configured using ST MC Workbench enabling all the possible customizations</td>
</tr>
<tr>
<td><strong>Confidential distribution</strong> is not available on internet.</td>
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<tr>
<td>• Source files of motor ‘MC library’ are provided with the only exception of ST protected IPs (not mandatorily to be used) which are furnished as compiled object files.</td>
</tr>
<tr>
<td><strong>Protected IPs source files.</strong></td>
</tr>
<tr>
<td>• Only provided to customers under NDA where there is high confidence and trust.</td>
</tr>
</tbody>
</table>
FOC single motor for budgetary applications

**Target applications:**

- All those applications where:
  - Requirements for dynamic performances are moderate
  - Quietness of sinusoidal current control (vs six steps drive) is valuable
  - Extended speed range is required
- Particularly suitable for **pumps, fans and compressors**

STM32F100x
STM32F05x

- More silent
- Lower torque ripple
- Extended speed range easier to be achieved
FOC single or **dual motor** for higher performance

**Target applications:**
- Wide range from home appliances to robotics, where:
  - Accurate and quick regulation of motor speed and/or torque is required (e.g. in torque load transient or target speed abrupt variations)
  - CPU load granted to motor control must be low due to other duties
FOC block diagram and possible configurations

- Speed position feedback is mandatory
- Three speed/position sensors are 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
    - 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)
- Current feedback is mandatory
FOC block diagram and possible configurations

- **Three current sensing HW 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 (worsening with ratio V/L)
  - **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**
Features set, MCU support

STM32F103x HD/XL, STM32F2xx, STM32F4xx, STM32F3yy

STM32F103x LD/MD

STM32F100x, STM32F0xx

- 1shunt
- Flux Weakening
- IPMSM MTPA
- Feed Forward
- Sensor-less (STO + PLL)
- Sensor-less (STO + Cordic)
- Encoder
- Hall sensors
- Debug & Tuning
- ST MC Workbench support
- USART based com protocol add-on
- Max FOC F100 ~11kHz
- F0xx ~12kHz

3shunt

- FreeRTOS
- F103, F2xx

Dual FOC

- Max FOC
- F103 ~25kHz
- F2xx ~40kHz
- F2xx ~50kHz
- F3xx T.B.D.

- Max FOC dual
- F103 ~20kHz
- F2xx ~36kHz
- F4xx~45kHz
- F3xx T.B.D.

Max FOC ~25kHz

ICS

Max FOC

15/01/2013

ST solutions for efficient motor control
<table>
<thead>
<tr>
<th>Drives / MCU FW availability matrix</th>
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<tbody>
<tr>
<td><strong>Notes</strong></td>
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<tr>
<td><strong>AC IM Scalar</strong></td>
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<tr>
<td>Available now</td>
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<tr>
<td>Not planned yet</td>
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<td>Not planned yet</td>
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<tr>
<td>Not planned yet</td>
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<tr>
<td>Open &amp; closed speed loop</td>
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<tr>
<td><strong>AC IM FOC drive</strong></td>
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<tr>
<td>Not feasible</td>
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<tr>
<td>Expected Q2/2013</td>
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<td>Expected Q1/2013</td>
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<tr>
<td>Available now</td>
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<td>Not planned yet</td>
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<td>Not planned yet</td>
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<tr>
<td>Not planned yet</td>
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<tr>
<td>Senored, Sensor-less to be planned</td>
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<tr>
<td><strong>BLDC/PMSM Scalar 6-steps</strong></td>
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<tr>
<td>Available now</td>
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<td>planned</td>
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<td>Not planned yet</td>
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<td>FW example available</td>
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<td>Not planned yet</td>
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<td>Only sensored</td>
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<td><strong>BLDC/PMSM scalar sinus</strong></td>
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<tr>
<td>Q2/2013</td>
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<tr>
<td>Sensored &amp; Sensor-less</td>
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<tr>
<td><strong>BLDC/PMSM 2x FOC drive</strong></td>
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<td>Sensored &amp; Sensor-less</td>
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MC Workbench

Quick setup of the library according customer needs

- ST Motor Control Workbench
  - PC software that reduces the design effort and time in the STM32 PMSM FOC firmware library configuration. The user through a graphical user interface (GUI) generate all parameter header files which configures the library according the application needs.

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Serial communication

• Real time communication
  • Using the ST MC workbench is possible to instantiate a “real time communication” to send start/stop commands or to set a speed ramp.
  • Debug or fine tuning motor control variables (like speed PI parameters) can be assessed using the advanced tab.
  • Plotting significant motor control variables (virtual oscilloscope) like target or measured motor speed.

• RS232 (Available)
• SPI (T.B.I.)
• I2C (T.B.I.)
Making life easier with ST tools

Start with the right STM32 and get the optimum pinout configuration

- **MicroXplorer tools**
  - MCU product selector
    - Identify the best STM32 to fit your application needs (performance, memory, peripherals, I/Os, etc.)
  - MCU configuration tool
    - Configure the STM32 pinout to fit your application needs

Optimize application performance

- **STM Studio tool**
  - Monitor any variable selected in your code to optimize application performance (motor control, touch sense, etc.)
    - Several display modes
    - On-the-fly acquisition modes
    - Log to/replay from file
    - Variables read/write capability
For further info about STM32 PMSM FOC SDK v3.2, please visit:

http://www.st.com/stm32

Downloads:

**STM32 PMSM FOC SDK v3.2:**

http://www.st.com/internet/com/SOFTWARE_RESOURCES/SW_COMPONENT/FIRMWARE/stm32_pmsm_foc_motorcontrol_fwlib.zip

**ST MC Workbenchv2.0.0:**

http://www.st.com/internet/com/SOFTWARE_RESOURCES/TOOL/CONFIGURATION_UTILITY/motorcontrol_workbench.zip

**UM1052:** STM32F103xx/ STM32F100xx/STM32F2xx/STM32F4xx PMSM single/dual FOC SDK v3.2

**UM1053:** Advanced developers guide for STM32F100x/103x/2x/40x/41x MCUs PMSM single/dual FOC library
Hardware tools
STM32Fxx MC kit

Main Features
- Driving Strategy: Vector Control
- PMSM motor sensored and sensorless
- Two (34-pin) dedicated motor control connectors
- Encoder sensor input
- Hall sensor input
- Tachometer sensor input
- Current sensing mode:
  - 3 shunt resistors
  - Single shunt

Key Component
- L6390D (Gate Drivers)
- VIPer16LD (Power Supply down converter)
- L7815ABV, L78M05CDT, LD1117S33TR (Voltage regulators)
- STGP10NC60KD (IGBT)
- TS391ILT, (Comparator)
- M74HC14TTR (Logic)
Complementing MC starter kits
STM8/32 Evaluation boards

STM8 MC library v1.0
- Scalar Control
  - STM8/128-EVAL

STM32 PMSM FOC SDK v3.0
- FOC
  - STM32F100x
    - STM32100B-EVAL
    - STEVAL-IHM033V1
  - FOC
    - STM32F103
      - STM3210E-EVAL
      - STEVAL-IHM022V1

MC connector

Power Stages

Please visit http://www.st.com/evalboards or contact a local ST office

Thanks configurable tools it is possible to have diverse motor drive solutions
Complementing MC starter kits
STM8/32 Evaluation boards

**STEVAL-IHM025V1**
- 1 x IGBT SLLIMM™ STGIPL14K60
- 1 converter based on Viper16
- 1 x IGBT STGP10NC60KD

**STEVAL-IHM027V1**
- 1 x IGBT SLLIMM™ STGIPS10K60A
- 1 converter based on Viper16
- 1 x IGBT STGP10NC60KD

**STEVAL-IHM028V1**
- 1 x IGBT SLLIMM™ STGIPS20K60
- 1 x PWM SMPS VIPer26LD
- 1 x IGBT STGW35NB60SD

**STEVAL-IHM035V1**
- 1 x IGBT SLLIMM™ STGIPLN3H60
- 1 x PWM SMPS VIPer16L

**STEVAL-IHM023V2**
- 3 x PWM smart driver L6390
- 1 converter based on Viper16
- 7 x IGBT power switch STGP10NC60KD

**STEVAL-IHM021V2**
- 3 x PWM smart driver L6390
- 1 converter based on Viper12
- 6 x MOSFET power switch STD5N52U

**STEVAL-IHM032V1**
- 3 x PWM smart driver: 2xL6392D and 1x L6391D
- 1 converter based on Viper12
- 6 x IGBT power switch: STGD3HF60HD

**SLLIMM™ (ST IPMs) based**

**Gate drivers & Power Transistors based**

Please visit: System evaluation boards or contact a local ST office

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Complementing MC starter kits
Low Voltage Power Stages

**STEVAL-IHM031V1**
Power stage up to 12/24V
- 3 x dual PowerMOSFETs STS8dnh3l
- 2 x PWM smart driver L6387E
- 1x step down converter L4976D

**STEVAL-IEM003V1**
Power stage up to 48V
- 3 x PWM smart driver L6388
- 6x LV Power MOSFET STV250N55F3
- 1x step down converter L4978D

Please visit [System evaluation board](#) or contact a [local ST office](#)

ST solutions for efficient motor control  15/01/2013
Complete 3ph motor drive solutions

Low voltage drives

STEVAl-IFN003V1
PMSM FOC Motor Drive
- 1 x 32bit Micro STM32F103C
- 1 x Motor Drive IC L6230PD

STEVAl-IFN004V1
BLDC Six-Steps Motor Drive
- 1 x 8bit-Micro STM8S
- 1 x Motor Drive IC L6230Q

STEVAl-IHM036V1
PMSM FOC Motor Drive
- 1 x 32bit Micro STM32F100C6
- 1 x IGBT SLLIMM™ STGIPN3H60
- 1 converter based on Viper16

STEVAl-IHM034V1
Dual motor drive + digital PFC
- 1 x 32bit Micro STM32F103C8T6
- 1 x IGBT SLLIMM™ STGIPS20K60
- 1 converter based on Viper16L

STEVAl-IHM038V1
FAN Drive + PFC + IrDA
- 1 x 32bit Micro STM32100
- 1 x IGBT SLLIMM™ STGIPN3H60
- 1 PFC controller L6562A

High voltage drives

Please visit System evaluation board or contact a local ST office

ST solutions for efficient motor control 15/01/2013
Thanks for your attention