Motor Identification and State Diagrams
Motor Identification Overview

- FAST™ Software Encoder
- Rotor Flux Observer
- Motor Parameters ID
- Motor Identification
- PowerWarp™
- Online Recalibration
- EST_run
- ROM
- Motor Phase Currents
- Motor Phase Voltages
- Bus Voltage

- Flux: $\tilde{\psi}$, $\tilde{\theta}$
- Angle: $\tilde{\omega}$
- Speed: $\tilde{\tau}$
- Torque: $\tilde{\tau}$
- Motor Type
- Currents: $I_{\alpha_{in}}$, $I_{\beta_{in}}$
- Voltages: $V_{\alpha_{in}}$, $V_{\beta_{in}}$, $V_{bus}$
- Bus Voltage

Motor Phase

- $\tilde{R}_s$, $\tilde{R}_r$
- $\tilde{L}_{sd}$, $\tilde{L}_{sq}$
- $\tilde{\psi}_{\text{rated}}$
- $\tilde{I}_{\text{rated}}$

- Enable PowerWarp™
- Enable Motor Identification
- Enable $R_s$ Online Recalibration
- Enable Force Angle Startup
- Motor Type
Controller (CTRL) State Machine

Controller Disabled OR
(Controller Enabled AND
Estimator Not Idle AND
Don’t Perform Locked Rotor Test)

Controller Enabled AND
Estimator is Idle AND
(Motor Not Identified OR
(Motor Identified AND
Offset Recalibration Enabled))

Controller Enabled AND
Wait Not Expired

Controller Enabled AND
Wait Expired

Hardware
Offsets
Recalibration

Start → Idle → Offline

Controller Disabled

Start

Controller Enabled AND
(Motor Identified AND
Offset Recalibration Disabled) OR
(Estimator Not Idle AND
Perform Locked Rotor Test)

Controller Enabled AND
Estimator is Idle AND
Motor Identified AND
Offset Recalibration Disabled)

Controller Enabled AND
(EST) State Machine

Motor running in closed
loop or is being identified,
depending on Estimator
(EST) State Machine

Online → Idle → Start

Controller Enabled AND
(Controller Enabled AND
Estimator Not Idle AND
Don’t Perform Locked Rotor Test)
Estimator (EST) State Machine

- **Start**
- **Idle**
  - **Motor Is Not Identified**
- **RoverL**
  - **Wait Expired**
- **Rs**
  - **Wait Expired AND Motor Is Not Identified**
- **Motor Identified**
  - **Controller Disabled**
  - **Controller Enabled**
- **Rated Flux**
  - **Wait Expired**
- **Rated OL**
  - **Wait Expired**
- **Lock Rotor**
  - **Wait Expired**
- **Ramp Up**
  - **Wait Expired**
- **Ramp Down**
  - **Wait Expired**
- **Rated Flux**
  - **Wait Expired**
- **Locked Rotor**
  - **Wait Expired**
- **Rated LO**
  - **Wait Expired**

- **Online**
  - **Motor is Identified AND Rs Recalibration Enabled**
  - **Motor is Identified AND Rs Recalibration Disabled AND Controller Enabled**

- **Waiting Expired**
  - **Motor Is Identified AND Rs Recalibration Enabled**
  - **Motor Is Identified AND Rs Recalibration Disabled AND Controller Enabled**

- **Controller Enabled**
  - **Motor Is Identified AND Rs Recalibration Disabled AND Controller Enabled**
Controller (CTRL) and Estimator (EST) State Machine Dependencies

CTRL State == Online
EST State Machine
Differences between PMSM and ACIM Identification Process

- **Start**
  - Motor is Identified AND Rs Recalibration Disabled AND Controller Enabled
  - Wait Expired AND Motor is Not Identified

- **Idle**
  - Controller Disabled
  - Wait Expired

- **RoverL**
  - Controller Disabled
  - Motor is Identified AND Rs Recalibration Enabled

- **Rs**
  - Controller Enabled
  - Wait Expired AND Motor is Identified

- **Motor Ident**
  - Wait Expired AND Motor Is Not Identified AND Motor is an ACIM

- **Ramp Down**
  - Wait Expired AND Motor Is Not an ACIM
  - Wait Expired AND Motor Is Not Identified

- **Rr**
  - Controller Disabled
  - Wait Expired AND Motor Is Not an ACIM

- **Rated Flux OL**
  - Wait Expired
  - Wait Expired AND Motor Is Not a ACIM

- **Rated Flux**
  - Wait Expired
  - Wait Expired AND Motor Is Not an ACIM

- **Ls**
  - Wait Expired

- **Locked Rotor**
  - Wait Expired
  - Wait Expired AND Motor Is Not a ACIM

- **Rated**
  - Wait Expired

- **Applicable to both PMSM and ACIM Motors**
  - Motor is Identified AND Rs Recalibration Disabled AND Controller Enabled

- **Only Applicable to PMSM Motors**
  - Wait Expired AND Motor is Not Identified AND Motor is an ACIM

- **Controller**
  - Wait Expired

- **Controller Enabled**
  - Wait Expired

- **Controller Disabled**
  - Wait Expired

- **Ls**
  - Wait Expired

- **Rated Flux**
  - Wait Expired

- **Only Applicable to ACIM Motors**
  - Wait Expired

- **Wait Expired**
  - Wait Expired

- **Wait Expired AND Motor Is Not Identified**
  - Wait Expired

- **Wait Expired AND Motor Is Identified**
  - Wait Expired

- **Wait Expired AND Motor Is Not an ACIM**
  - Wait Expired

- **Wait Expired AND Motor Is an ACIM**
  - Wait Expired

- **Motor Is Identified AND Rs Recalibration Enabled AND Controller Enabled**
  - Wait Expired

- **Motor Is Identified AND Rs Recalibration Disabled AND Controller Enabled**
  - Wait Expired

- **Motor Is Identified**
  - Wait Expired
  - Wait Expired AND Motor Is Not Identified

- **Motor is Identified AND Rs Recalibration Enabled**
  - Wait Expired

- **Motor is Identified AND Rs Recalibration Disabled**
  - Wait Expired

- **Motor is Identified AND Controller Enabled**
  - Wait Expired

- **Motor is Identified**
  - Wait Expired

- **Motor is Identified AND Rs Recalibration Enabled AND Controller Enabled**
  - Wait Expired

- **Motor is Identified AND Rs Recalibration Disabled AND Controller Enabled**
  - Wait Expired

- **Controller Enabled**
  - Wait Expired
Motor Identification Prerequisites

• Mechanical Prerequisites
  – Motor Connection
  – Order of the Phases
  – Minimum Mechanical Load

• Managing Motor Signals
  – Hardware Prerequisites
  – Software Prerequisites

• Software Configuration for PMSM Motor Identification

• Software Configuration for ACIM Motor Identification
Software Configuration for PMSM Motor Identification

- Motor Type
- Number of Pole Pairs
- Frequency for Rhf and Lhf
- Current for Rs
- Current for Ls
- Frequency for Ls and Flux

User.h:

```c
#define USER_MOTOR_TYPE MOTOR_Type_Pm
#define USER_MOTOR_NUM_POLE_PAIRS (4)
#define USER_R_OVER_L_EST_FREQ_Hz (100)
#define USER_MOTOR_RES_EST_CURRENT (0.5)
#define USER_MOTOR_IND_EST_CURRENT (-0.5)
#define USER_MOTOR_FLUX_EST_FREQ_Hz (20.0)
```
Software Configuration for ACIM Motor Identification

• Motor Type
• Number of Pole Pairs
• Frequency for Rhf and Lhf
• Rated Flux
• Current for Rs
• Frequency for IdRated, Ls and Rr

User.h:

#define USER_MOTOR_TYPE MOTOR_Type_Induction
#define USER_MOTOR_NUM_POLE_PAIRS (4)
#define USER_R_OVER_L_EST_FREQ_Hz (100)
#define USER_MOTOR_RATED_FLUX (0.8165*220.0/60.0)
#define USER_MOTOR_RES_EST_CURRENT (-0.5)
#define USER_MOTOR_FLUX_EST_FREQ_Hz (5.0)
Full Identification of PMSM Motors

CTRL State Machine

Idle
CTRL_State_Idle

CTRL_setFlag_enableCtrl(ctrlHandle,TRUE);

Offline
CTRL_State_Offline

Online
CTRL_State_OnLine

EST State Machine

Idle
EST_State_Idle

RoverL
EST_State_RoverL

Rs
EST_State_Rs

RampUp
EST_State_RampUp

RatedFlux_DL
EST_State_RatedFlux_DL

RatedFlux
EST_State_RatedFlux

Ls
EST_State_Ls

RampDown
EST_State_RampDown

MotorIdentified
EST_State_MotorIdentified

Idle
EST_State_Idle

CTRL_setFlag_enableCtrl(ctrlHandle,TRUE);
CTRL_State_OffLine and EST_State_Idle

Offset Recalibration for 5 seconds
At 50% Duty Cycle

CTRL_State_Idle
EST_State_Idle

CTRL_State_OnLine
EST_State_RoverL

CTRL_State_OffLine
EST_State_Idle

```
<table>
<thead>
<tr>
<th>drv_adcBias</th>
<th>struct_DRV_AdcDat...</th>
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<tr>
<td>value</td>
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</tr>
<tr>
<td>(0)= [0]</td>
<td>long [3]</td>
</tr>
<tr>
<td>(0)= [1]</td>
<td>long [3]</td>
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<tr>
<td>(0)= [2]</td>
<td>long [3]</td>
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<table>
<thead>
<tr>
<th>I</th>
<th>struct_MATH_vec3...</th>
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<td>(0)= [0]</td>
<td>long</td>
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<tr>
<td>(0)= [1]</td>
<td>long</td>
</tr>
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<td>(0)= [2]</td>
<td>long</td>
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<table>
<thead>
<tr>
<th>V</th>
<th>struct_MATH_vec3...</th>
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<tr>
<td>value</td>
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<tr>
<td>(0)= [0]</td>
<td>long</td>
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<td>(0)= [1]</td>
<td>long</td>
</tr>
<tr>
<td>(0)= [2]</td>
<td>long</td>
</tr>
</tbody>
</table>
```
CTRL_State_OnLine and EST_State_RoverL

EST States
- Start
- Idle
- RoverL

CTRL_State_OffLine
EST_State_Idle
CTRL_State_OnLine
EST_State_RoverL
CTRL_State_OnLine
EST_State_Idle
CTRL_State_OffLine
EST_State_Idle
CTRL_State_OnLine
EST_State_Rs

// Code example to get high frequency R (Rhf) and high frequency inductance (Lhf) to variables
float32_t Rhf = CTRL_getRhf(ctrlHandle);
float32_t Lhf = CTRL_getLhf(ctrlHandle);
float32_t RoverL = Rhf / Lhf;
CTRL_State_OnLine and EST_State_Rs

// get the stator resistance
gMotorVars.Rs_Ohm = EST_getRs_Ohm(obj->estHandle);
CTRL_State_OnLine and EST_State_RampUp

EST States

<table>
<thead>
<tr>
<th>State</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Idle</td>
<td></td>
</tr>
<tr>
<td>RoverL</td>
<td>Motor is not identified</td>
</tr>
<tr>
<td>Rs</td>
<td>Wait expired</td>
</tr>
</tbody>
</table>

CTRL_State_OnLine
EST_State_RampUp
CTRL_State_OffLine
EST_State_Idle
CTRL_State_OnLine
EST_State_Rs
CTRL_State_OnLine
EST_State_RatedFlux

Acquisition
- High Res
- 10.0kSa/s

Channels
- DC 10.0:1
- DC 10.0:1
- DC 1.00:1
- DC 1.00:1

Cursors
- $\Delta X$: +20.0000000000000s
- $1/\Delta X$: +50.000MHz
- $\Delta Y(1)$: -1.00000A

Channel 1 Menu
- Coupling
  - DC
- Imped
  - 1M Ohm
- BW Limit
- Fine
- Invert
- Probe

Texas Instruments
CTRL_State_OnLine and EST_State_RatedFlux

Current Slope = 0.66 A / 2 s = 0.33 A/s

Agilent

Acquisition
High Res
25.0kSa/s

Channels

| DC   | 10.0:1 |
| DC   | 10.0:1 |
| DC   | 1.00:1 |
| DC   | 1.00:1 |

Cursors

\[ \Delta X: +7.000000000000000 \text{ s} \]

\[ \frac{1}{\Delta X}: +142.86 \text{ Hz} \]

\[ \Delta Y(1): -652.50 \text{ mA} \]
Full Identification of PMSM Motors - Summary

- Idle
- RoverL
  - Wait Expired
- Rs
  - Wait Expired
- Motor Identified
  - Wait Expired
  - Motor Is Not Identified
- Ramp Down
  - Wait Expired
  - Motor Is Not Identified
- Rated Flux OL
  - Wait Expired
  - Motor Is Not an ACIM
- Rated Flux
  - Wait Expired
  - Motor Is Not an ACIM
- Ls

CTRL State OffLine
EST State RoverL
EST State Rs
EST State RampUp
EST State RatedFlux
EST State Ls
~83 s
Full Identification of ACIM Motors - Summary

Start → Idle → RoverL → Rs
- Wait Expired
- Motor is Not Identified

Motor Ident → Ramp Up → Id Rated → Ls
- Wait Expired
- Motor is Not Identified

Ramp Down → Lock Rotor → Rated Flux → Ls
- Wait Expired
- Controller Disabled
- Wait Expired
- Motor is an ACIM

Controller Enabled

Wait Expired AND Motor Is Identified
Wait Expired AND Motor Is an ACIM
Wait Expired AND Motor Is Not Identified
Wait Expired AND Motor Is Not Identified AND Motor is an ACIM
Wait Expired AND Motor Is Not Identified AND Motor is an ACIM AND Motor Is Identified
Wait Expired AND Motor Is Not Identified AND Motor is an ACIM AND Motor Is Identified AND Controller Disabled

Agilent
- Acquisition: High Res, 2.50kHz/s
- Channels: DC 10.01, DC 10.01, DC 100.1, DC 100.1
- Cursors: ∆X: +100.00000000000s, T/∆X: +10.000mHz, ∆Y(1): +8.000000A

Texas Instruments
Recalibration of PMSM and ACIM Motor Identification

CTRL State Machine

- **Idle**: CTRL_State_Idle
- **Offline**: CTRL_State_OffLine
- **Online**: CTRL_State_OnLine

CTRL_setFlag_enableCtrl(ctrlHandle, TRUE);

EST State Machine

- **Idle**: EST_State_Idle
- **Rs**: EST_State_Rs
- **Online**: EST_State_OnLine

EST_setFlag_enableCtrl(ctrlHandle, FALSE);

Controller Enabled

Recalibration

Motor Running Closed-loop

 Idle

Enabled

Recalibration

Motor Running

Closed-loop

Idle
Recalibration of PMSM and ACIM Motor Identification

Motor is Identified &
Rs Recal Disabled &
Controller Enabled
Wait Expired &
Motor Is Identified
Controller Enabled

Controller Disabled

Motor is Identified &
Rs Recal Enabled &
Controller Enabled

Wait Expired &
Motor Is Identified
Controller Enabled

Controller Enabled

Start

Idle

Rs

CTRL State OffLine
EST State Idle

Fixed 50% Duty Cycle
Variable Duty Cycle

Offsets Recalibration

Rs Recalibration

Closed Loop

CTRL State OnLine
EST State Rs

Agilent

Acquisition:
High Res
250 kS/s

Channels:
DC 10.01
DC 10.01
DC 10.01
DC 10.01

 Cursors:
ΔX: +10.4000000000 s
ΔY: +9.5802 mHz
ΔY(1): +40.0000 A

Texas Instruments
#define USER_MOTOR_Rs         (0.4009805)
#define USER_MOTOR_Ls_d       (0.0006364161)
#define USER_MOTOR_Ls_q       (0.0006364161)
#define USER_MOTOR_RATED_FLUX (0.0341805)
# Updating User.h from Motor Datasheet

<table>
<thead>
<tr>
<th>Model</th>
<th>2310</th>
<th>P/C/Y</th>
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<tbody>
<tr>
<td><strong>INDIVIDUAL SPECIFICATIONS</strong></td>
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<tr>
<td>Electrical Interface Option</td>
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</tr>
<tr>
<td>Resistance, phase to phase, [$\Omega$]</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td>Inductance, phase to phase, [mH]</td>
<td>0.40</td>
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<tr>
<td>Electrical Time Constant, [mS]</td>
<td>0.56</td>
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<tr>
<td>Back EMF (Ke), [Vpeak/kRPM]</td>
<td>4.64</td>
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</tr>
<tr>
<td>Continuous Torque [oz-in]$^{1.2}$</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>Motor Poles</td>
<td>8 (4 Pairs)</td>
<td></td>
</tr>
</tbody>
</table>

### Parameters

- $R_{user.h} = R_{phase-phase} \cdot \frac{1}{2} = 0.72 \Omega \cdot \frac{1}{2}$
- $R_{user.h} = 0.36 \Omega$
- $L_{s_d} = L_{s_q} = L_s \cdot \frac{1}{2} = 0.4 \text{mH} \cdot \frac{1}{2}$
- $L_{user.h} = L_{s_d} = 0.0002 \text{H}$
- $\psi_{user.h} = K_{e} \frac{V_{peak}}{\text{Vpeak}} \cdot \frac{60 \text{sec}}{1 \text{min}} \cdot \frac{1 \text{REV}}{1000 \text{REV}} \cdot \frac{1 \text{REV}}{\text{PolePairs}} \cdot \frac{1 \text{V}_{\text{line-neutral}}}{\sqrt{3} \text{V}_{\text{line-line}}}$
- $\psi_{user.h} = 4.64 \cdot 60 \cdot \frac{1}{1000} \cdot \frac{1}{4} \cdot \frac{1}{\sqrt{3}}$
- $\psi_{user.h} = 0.0402 \frac{V}{Hz}$

```c
#define USER_MOTOR_NUM_POLE_PAIRS (4)
#define USER_MOTOR_Rs (0.36)
#define USER_MOTOR_Ls_d (0.0002)
#define USER_MOTOR_Ls_q (0.0002)
#define USER_MOTOR_RATED_FLUX (0.0402)
```