Sensorless FOC tuning guide for BPA motor control GUI

Application note

About this document

Scope and purpose

This document describes the control loop tuning procedure for sensorless field-oriented control (FOC) implemented in the EVAL_6EDL7141_FOC_3SH and **EVAL_IMD700A_FOC_3SH** evaluation boards under the battery powered applications (BPA) motor control graphical user interface (GUI) of Infineon Toolbox.

Intended audience

This document provides basic guidance on using the PID tuning tool in the BPA motor control GUI to tune the FOC motor control loop under the VQ motor control scheme and speed motor control scheme. It is targeted at customers, application engineers who are using the BPA motor control GUI s/w to run its motor control application.

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1 Introduction

The sensorless FOC motor control example project consists of shunt field-oriented control algorithm software which targets end applications such as power drills and gardening tools. The example project is downloaded to the evaluation board via the BPA motor control GUI from the Infineon Developer Center.

Furthermore, the sensorless FOC example project also provides a VQ and speed control scheme for different target applications. This document provides general guidelines on tuning the two control schemes with the help of the “PID tuning tool” in the BPA motor control GUI.

Sensorless FOC depends on the three shunt resistors to sense the inverter leg current. So, the choice of the three shunt resistors on the evaluation board also affects the functioning of the sensorless FOC example algorithm.

1.1 Installation of BPA motor control GUI

To follow this motor control tuning guide, the following software must be installed:

- BPA motor control GUI
  - The GUI tool comes from the **Infineon Developer Center Launcher**. Open the Infineon Developer Center Launcher and log in with the “myInfineon” account, find the “BPA Motor Control GUI”, and click “Start” to install the tool.

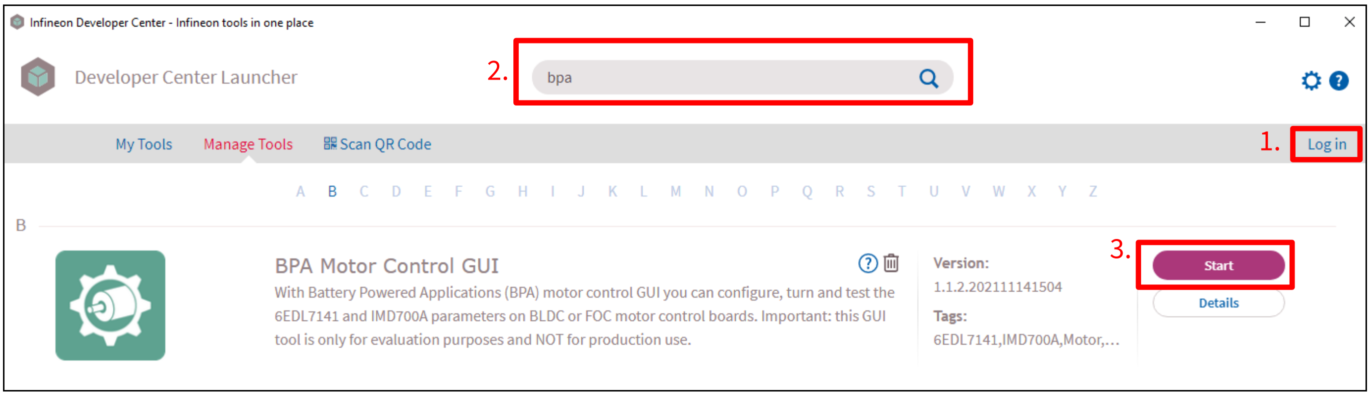

Figure 1 Infineon Toolbox

  - To get started with the BPA motor control GUI, please refer to the “Help” document provided on the start page.

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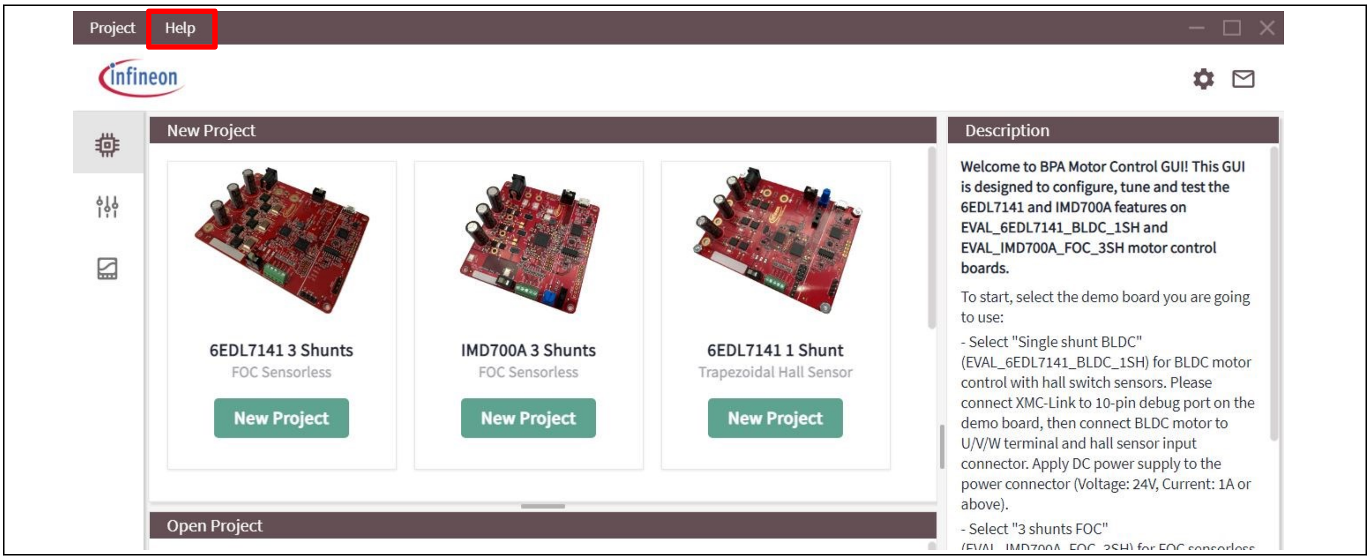

Figure 2 **Start page of the BPA motor control GUI**

- The GUI provides easy configurations to quickly get your motor running. The PID tuning and oscilloscope tools help the user tune the control loop in VQ and speed control mode.
- Use the knob to select VQ or speed control mode when the motor has stopped.

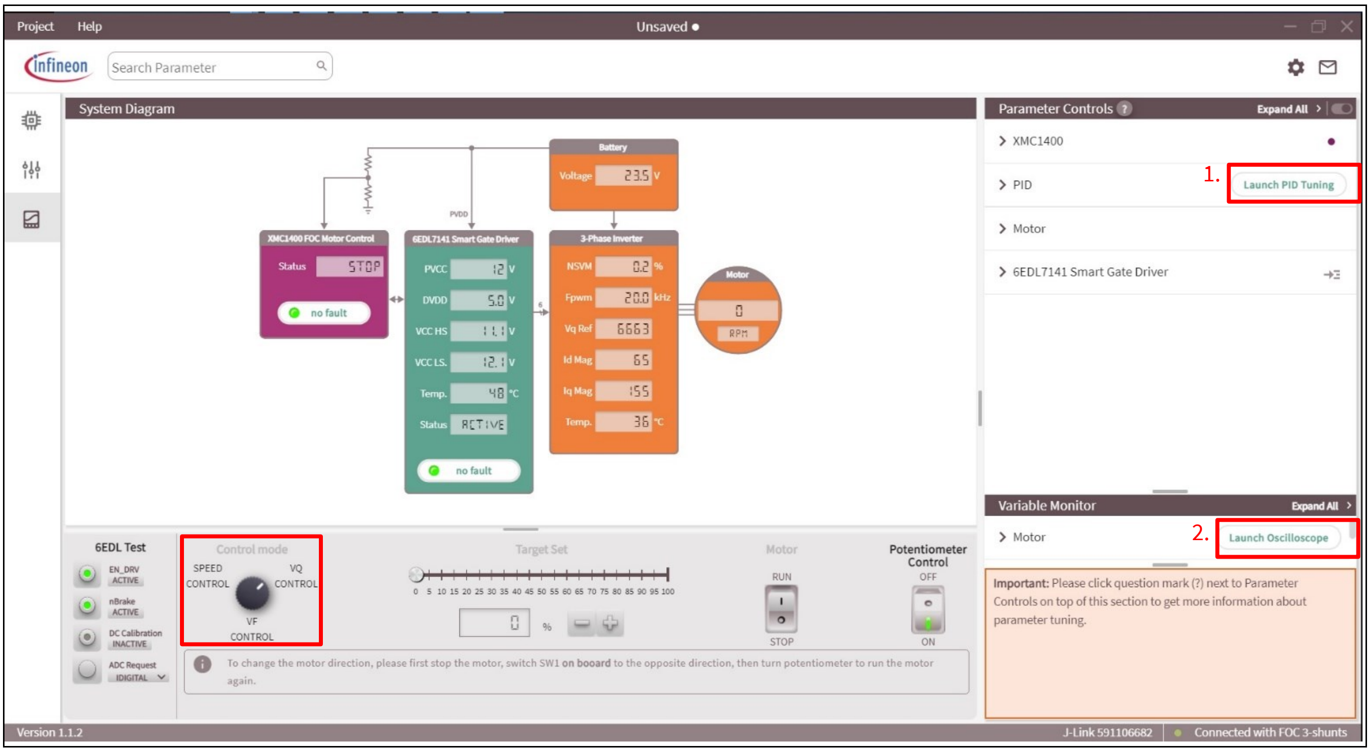

Figure 3 **BPA motor control GUI**

1.2 Selecting current sensing resistor

A high current sense resistance value increases the power loss in the sensing resistors. But a too-low sense resistance value will cause the sensorless FOC algorithm to malfunction, as the sense current will be masked by the noise floor voltage. So, the selected current sense resistor R_{sense} should produce a clean voltage at the analog-to-digital converter (ADC) from the phase current when operating the motor. Furthermore, the

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maximum overcurrent protection (OCP) threshold of the **MOTIX™ 6EDL7141** is 300 mV. So, if the maximum instantaneous phase current is 100 A (peak-peak) and the CS_OCP_PTHR register field of the MOTIX™ 6EDL7141 is set to 300 mV, then the maximum shunt resistance should be 0.3 V/50 A = 6 mΩ.

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2 Control schemes

2.1 V/f open loop mode

In an open loop voltage control, a reference voltage (V_{ref}) is used to cause the power inverter to generate a given voltage at the motor. The mechanical load influences the speed and the current of the PMSM motor.

In the BPA motor control GUI, this mode is used for debugging purposes. It is used to test the current sensing circuitry on the board, and the motor should run under no-load condition so it can spin smoothly. If the current sensing is working fine, the oscilloscope tool should display a somewhat sinusoidal waveform for IU, IV and IW signals (**Figure 5**). By comparing the phase U current captured using a current probe in **Figure 6**, we can see that the current sensing circuit on the evaluation board is working fine, as both **Figure 5** and **Figure 6** are similar. Under the condition that the motor is heavy and it is not spinning when operating in V/f open loop mode, we can increase the VF_OFFSET value to overcome the inertia of the motor.

The V_{ref} is also restricted to a low voltage in the example project to prevent a large current being drawn when running the motor under V/f open loop mode. So the user might be able to change the potentiometer on the BPA motor control GUI, but the speed of the motor will not increase further.

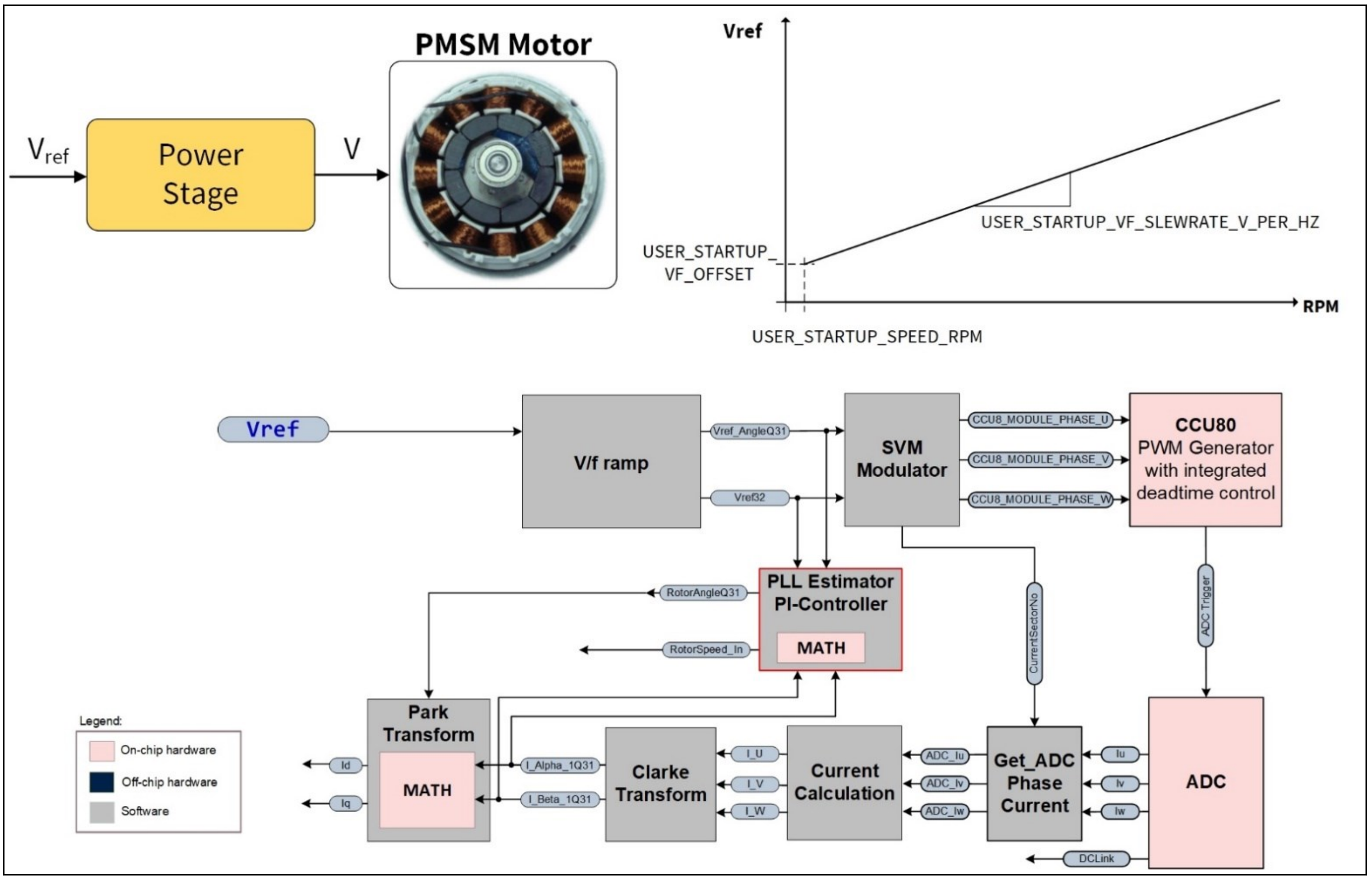

Figure 4 **Open loop V/f voltage control**

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Ch En	Symbol	Type	Max / Min	Average	RMS
1	IU	CPU_INT08U	3872 / -4048	-127.74	2458.61
2	IV	CPU_INT08U	3888 / -4032	15.46	2498.63
3	IW	CPU_INT08U	3904 / -4112	140.01	2566.86
4	IU	CPU_INT08U	1073741824 / -1073741824	1823320.43	77620912.2

Figure 5 V/f open loop IU, IV, IW current waveform captured by the GUI's oscilloscope

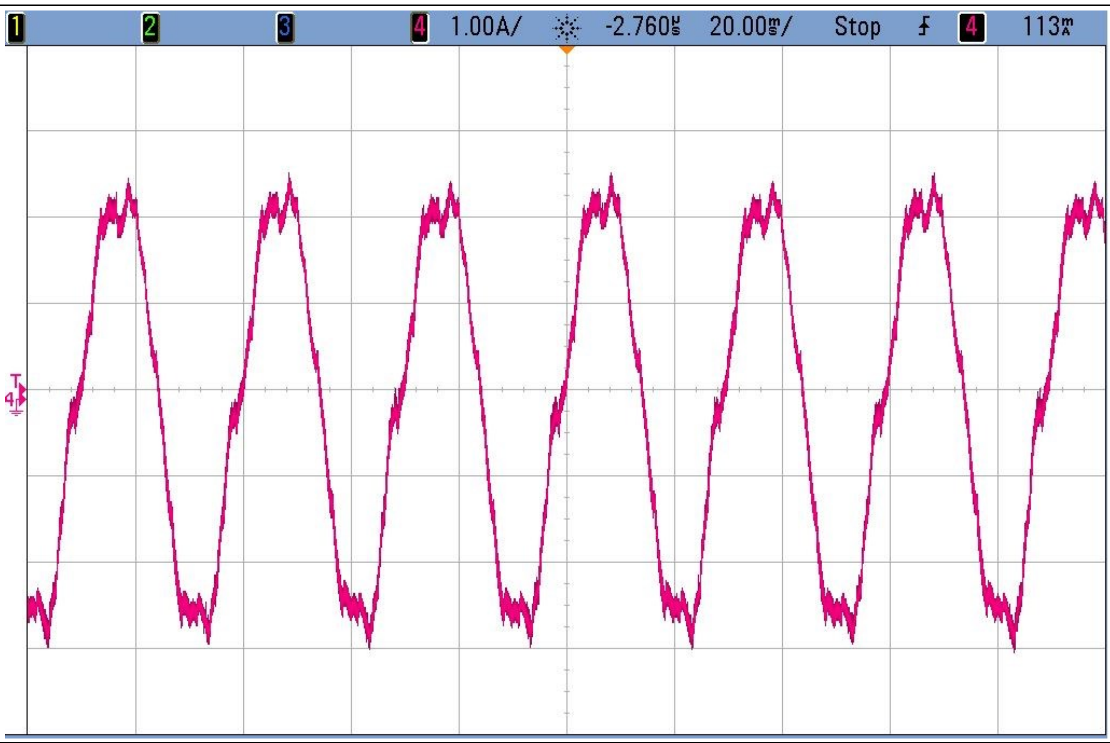

Figure 6 V/f open loop IU current waveform captured by the current probe

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2.2 VQ control direct start-up

The VQ control is used when a fast response is required and varying speed is not a concern.

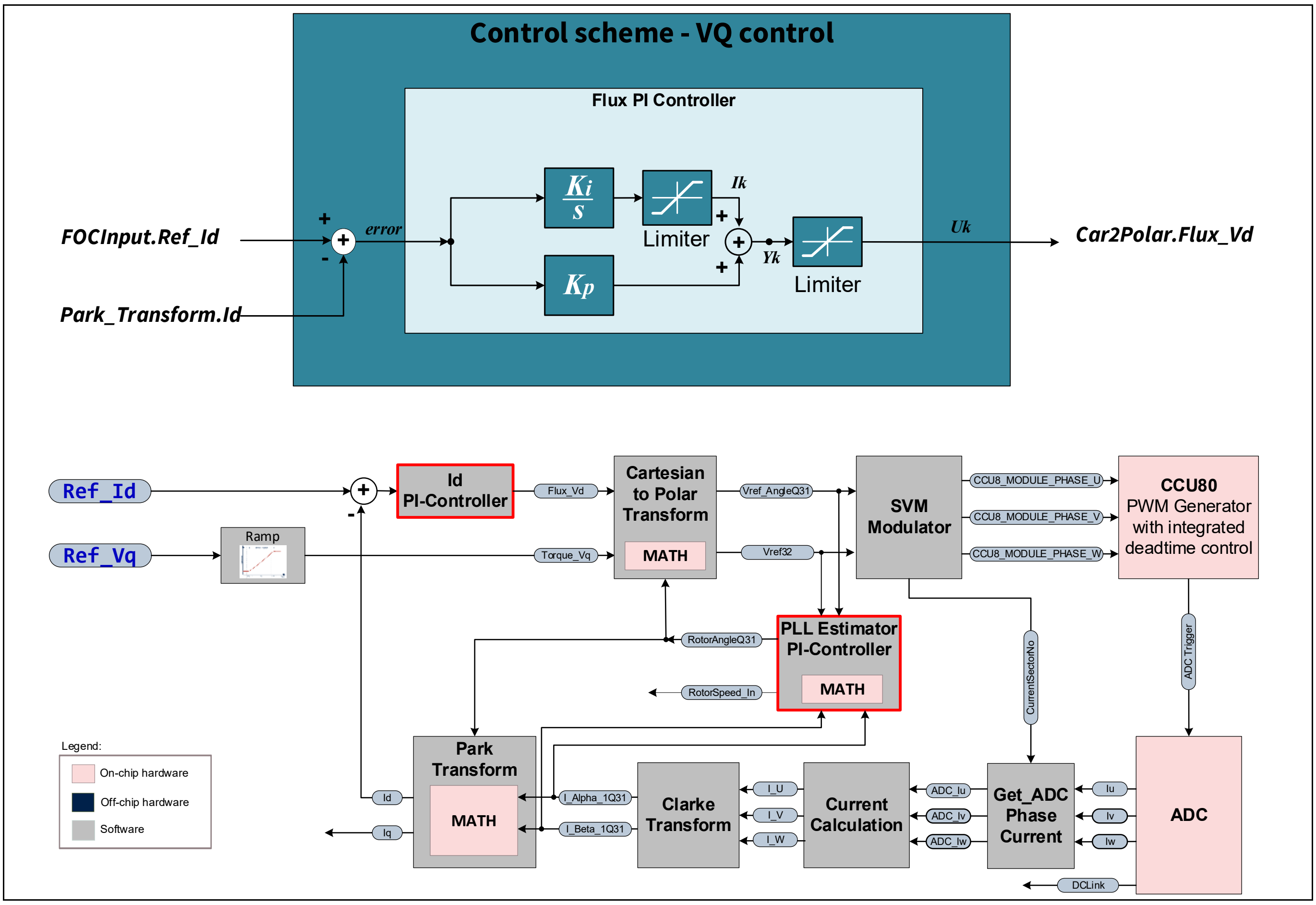

Figure 7 Control scheme - VQ control scheme

2.2.1 VQ control loop tuning

In **Figure 7** we can see that only Id or Flux PI control and PLL PI control (for the IP restricted PLL estimator) need to be tuned for VQ control. The purpose of tuning the control loop is to enable smooth running of the motor with a sinusoidal phase current waveform even when the motor encounters load changes.

In **Figure 8** we see that for each control loop, there is Kp, Ki and scale for the user to input. Adjusting those values will affect output response to the error detected at the input of the control loop. Their relationships are as follows:

$K_{proportional\ gain} = Kp/2^{Scale}$ and $K_{integral\ gain} = Ki/2^{Scale}$ where Kp, Ki and scale are integer values represented in the source code for proportional gain, integral gain and scale calculation, respectively.

As FOCInput.Ref_Id in **Figure 7** is zero, we are minimizing the error of the flux PI control by minimizing the peak-peak fluctuation of Park_Transform.Id. Furthermore, the output (uk) of the controller should not be saturated. Hence, we are monitoring the feedback (Park_Transform.Flux_Id) and output (uk) of the flux PI control loop in **Figure 8**. We are also monitoring the input error (error) and output (uk) of the PLL PI control loop. For VQ control, we want to minimize the error of the flux PI control and PLL PI control by adjusting their Kp, Ki and scale value under the motor operation condition.

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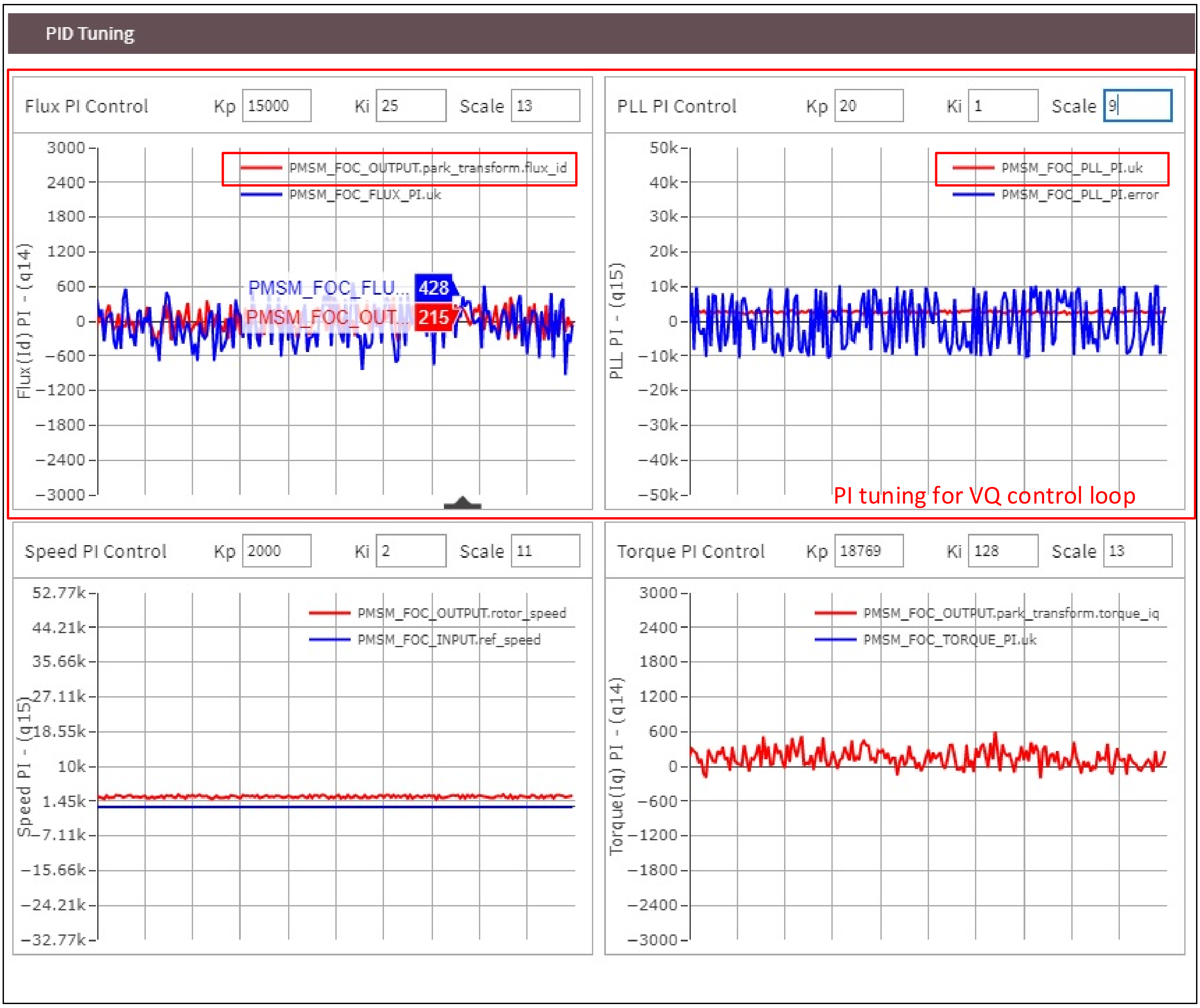

Figure 8 PID tuning page in the BPA motor control GUI

2.2.1.1 PI control loop tuning

To increase both the value of $K_{proportional\ gain}$ and $K_{integral\ gain}$ by one time, reduce the scale value by one. If you want to reduce both $K_{proportional\ gain}$ and $K_{integral\ gain}$ values to half, increase the scale value by one. Generally, try to increase or decrease the value of the scale and check whether the current waveforms of IU, IV and IW become more sinusoidal. The current waveforms of IU, IV and IW can be monitored by using the BPA motor control GUI's oscilloscope function, illustrated in **Figure 10**.

After that, you could further fine-tune the current waveform by individually adjusting the value of Kp and Ki for the control loop.

The effects of increasing the proportional gain Kp or integral gain Ki of the PI controller independently are illustrated in **Table 1**, with reference to **Figure 9**:

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Table 1 Effects of increasing the proportional gain Kp or integral gain Ki of the PI controller

Gain change	Effect on step-response characteristics			
	Rise time	**Overshoot**	**Settling time**	**Steady-state error**
Kp increase, Ki unchanged	Decrease	Increase	Minor change	Decrease
Ki increase, Kp unchanged	Decrease	Increase	Increase	Eliminate

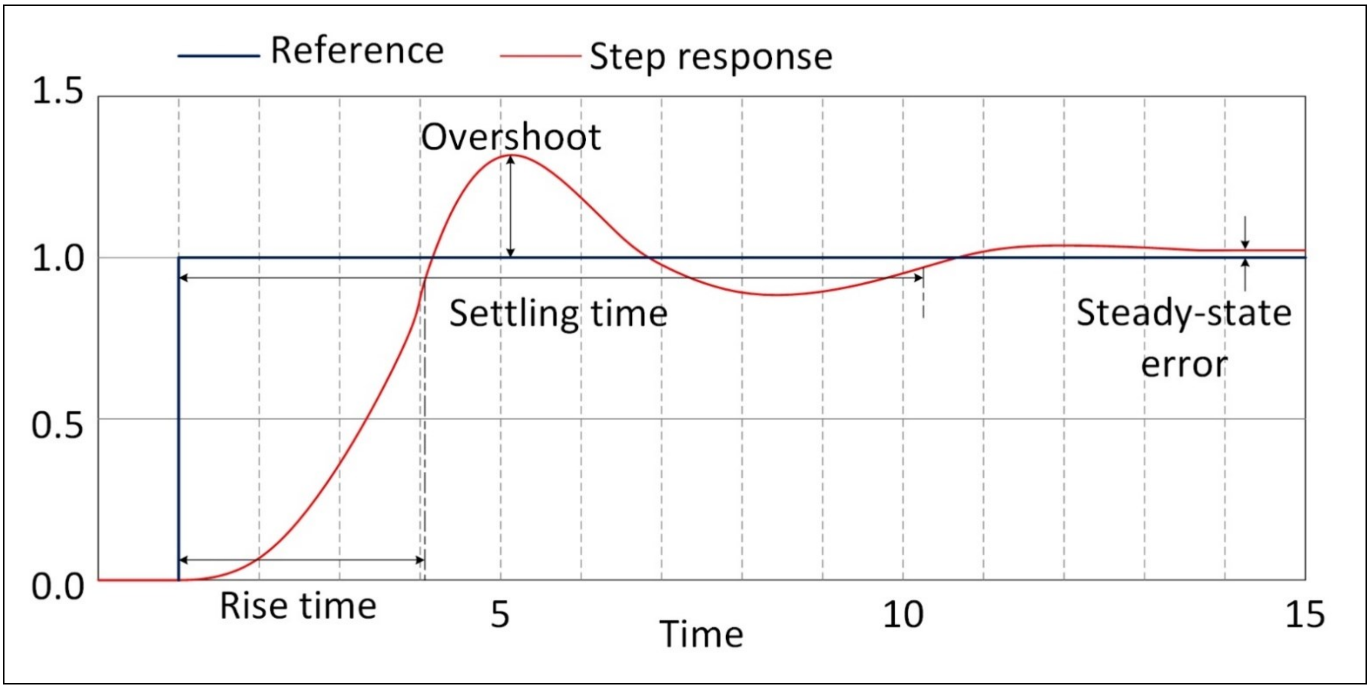

Figure 9 Step response of a control system

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Figure 10 Oscilloscope monitoring IU, IV, IW in BPA Motor Control GUI

If the motor is unable to run when starting up, increase the scale value of the PLL PI control loop first and then decrease the PLL control loop Kp and Ki value. If you are still unable to get the motor running, try it the opposite way by reducing the scale value of the PLL PI control loop and increasing the PLL control Kp and Ki value instead. When tuning the PLL PI control loop, make sure that the PMSM_FOC_PLL_PI.uk (red line of the PLL PI control) in **Figure 8** is not saturated to a constant value.

When tuning the flux PI control loop PI setting, the main objective is to minimize the fluctuation of the PMSM_FOC_OUTPUT.park_transform.flux_id (red line of the flux PI control) around the zero level. Generally, you can use the calculated PI setting of the flux PI control provided as a good starting point for PI tuning.

2.3 Speed control

A speed control scheme is a closed loop control. For the speed control scheme, a cascaded speed and current control structure is used. This is because the change response requirement for speed control loop is much slower than the one for current loop.

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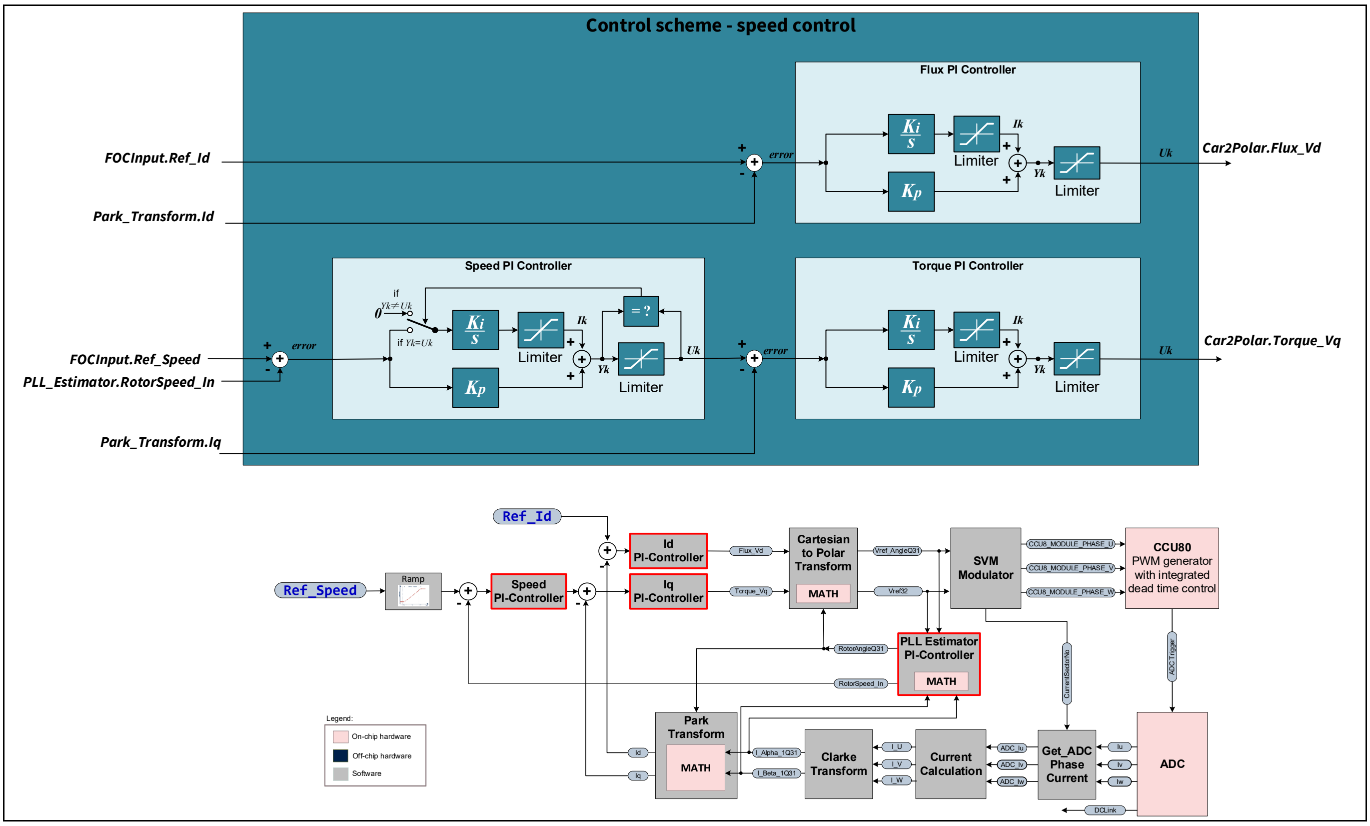

Figure 11 Control scheme - speed control

Direct FOC start-up and V/f start-up are supported in speed control. The speed PI controller supports integral anti-windup. The integral output is held stable when either PI output or integral output reaches its limit. The output of the speed PI is used as the reference for the torque PI controller.

2.3.1 Speed control loop tuning

In **Figure 11**, we can see that there are four control loops, namely PLL PI control, flux or Id PI control, torque or Iq PI control and speed PI control. Usually we should do the VQ voltage control PI tuning first, then use the PI values of PLL PI control and flux PI control for the speed control PI tuning. The torque PI control setting should follow the flux PI control setting. With the PLL, flux and torque PI setting defined, we can start to tune the speed PI control to get sinusoidal phase current waveforms under different load conditions and at steady speed.

Similarly, as shown in **Figure 12**, the PID tuning and oscilloscope tools are available to help with PI control loop tuning.

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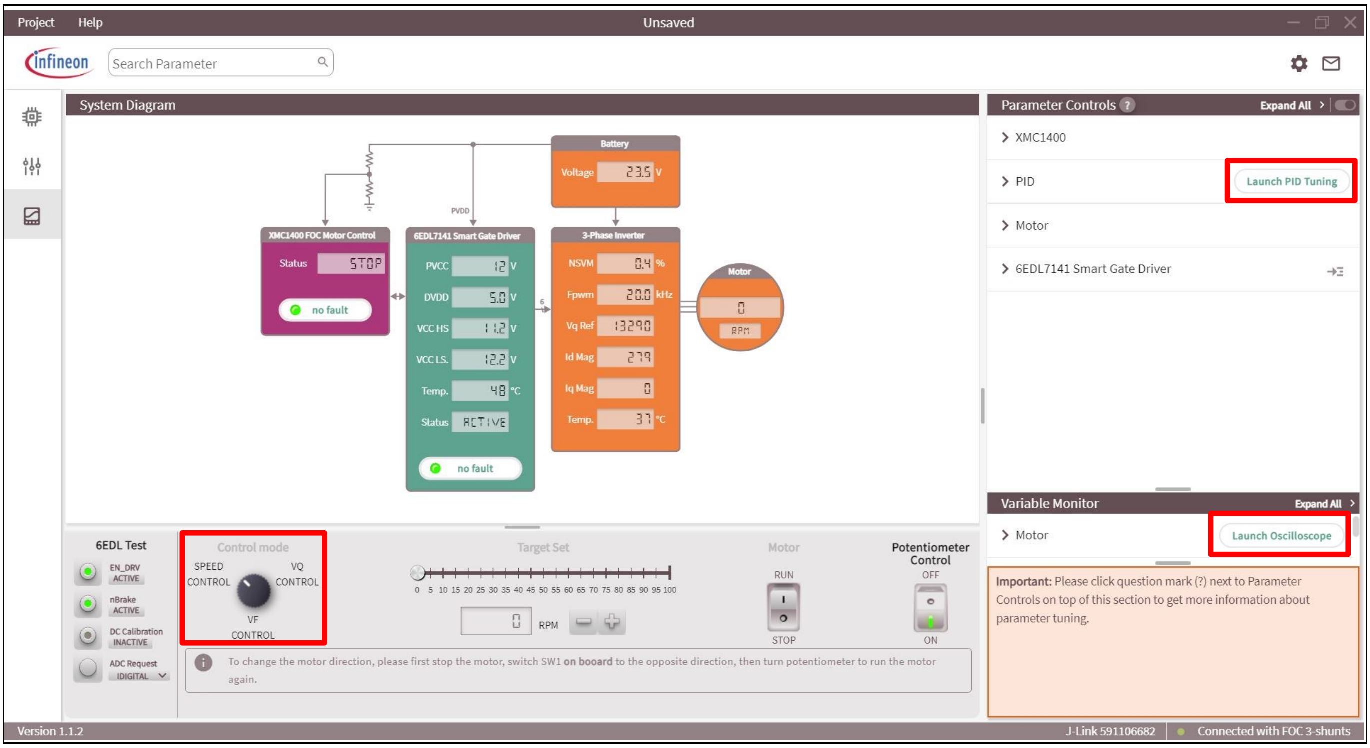

Figure 12 BPA motor control GUI test bench view

The Kp, Ki of the flux, torque and speed PI control chart of **Figure 13** correspond to the PI controller block diagram of **Figure 11**. The PLL PI control block diagram is not shown in **Figure 11** as the PLL estimator is IP restricted. To understand the relationship between Kp, Ki and scale of the control loop and the effect of adjusting those values, please refer to chapter **2.2.1** and chapter **2.2.1.1**.

If the phase current waveform is not sinusoidal by adjusting the scale value of the speed PI control, we might need to adjust the scale value of the flux and torque PI control to check their effect on the phase current. One thing to note is that the Kp, Ki and scale values for both flux and torque PI control should be the same when tuning the speed control of the motor.

If the motor is unable to run when starting up, increase the scale value of the PLL PI control loop first and decrease the PLL control loop Kp and Ki value. If you are still unable to get the motor running, do it the opposite way by decreasing the scale value of the PLL control loop and increasing the PLL control Kp and Ki value instead.

When tuning the flux PI control loop PI setting, the main objective is to minimize the fluctuation of PMSM_FOC_OUTPUT.park_transform.flux_id (red line of the flux PI control) at zero value.

If the rotor_speed(red line) cannot reach the ref_speed(blue line) in the speed PI control chart, scale of torque PI control needs to decrease while its Kp and Ki values need to increase to get a higher output (uk) at the torque PI control loop. A higher output at the torque PI control loop should help to increase the rotor_speed at the speed PI control loop, as shown in **Figure 13**.

By adjusting the Kp, Ki and scale value of the four control loops in speed control, the motor should be able to run at target speed under its operating condition and achieve a sinusoidal phase current waveform for IU, IV and IW as shown in **Figure 14**.

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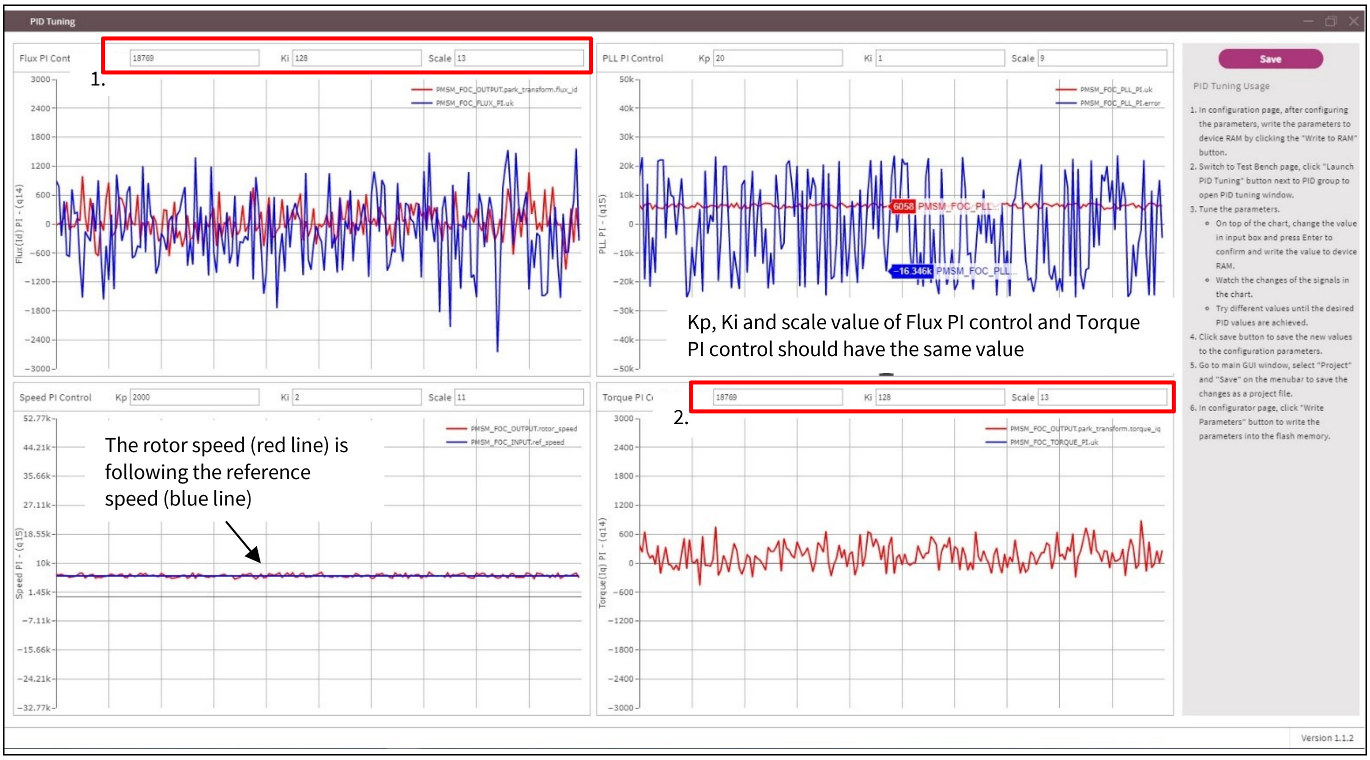

Figure 13 PID tuning page in speed control

Figure 14 Oscilloscope view for speed control, showing IU (green), IV (pink) and IW (blue) waveforms

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3 Summary

The main purpose of PI tuning is to adjust the responsiveness of a controller input by following the input reference of the controller. In VQ control, there are two controllers, namely the PLL PI control and flux/Id PI control. In the speed controller, there are four controllers, namely PLL PI control, flux/Id PI control, torque/Iq PI control and speed PI control. By making use of the PID tuning page in the BPA motor control GUI, we are able to do course adjustments to Kp, Ki of the controller using the scale setting. Then, we use the Kp and Ki setting to fine-tune the adjustment of Kp, Ki of the controller.

Furthermore, if we are using the scale setting to make course adjustments to the Kp and Ki values, we should stop the motor first. Large changes of the Kp and Ki value while the motor is running will cause a sharp spike of the motor phase current and might damage the MOSFETs.

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4 References

[1] Infineon Technologies AG: PMSM FOC motor control software using XMC™, application note (V 1.5); 2018-12-31. **Available online**.

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Revision history

Document version	Date of release	Description of changes
V 1.0	2022-05-04	First release

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