4kW 650V Industrial Motor Control Development Kit User Guide

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Table of Contents

Introduction

The STR-MDK-4KW-65SPM31-GEVK is a Motor Development Kit (MDK) for three-phase motor drives. The kit features the NFAM5065L4B Intelligent Power Module in a DIP39 package and rated for 400 VDC input, delivering up to 4 kW of power. The board is fully compatible with the Universal Controller Board (UCB), based on the Xilinx® Zynq®-7000 SoC, which embeds FPGA logic and two ARM® Cortex-A9 processors , and part of the Motor Development Kit (MDK) family. As such, the system is fit for high-end control strategies and enables operation of a variety of motor technologies (AC induction motor, PMSM, BLDC, etc.). As part of the Motor Development Kit (MDK), the Compact IPM Motor Drive is compatible with the powerful Universal Controller Board (UCB), enabling high-end control strategies and AI capabilities for industrial motor control. The Strata graphical user interface ensures an easy startup for evaluation purposes like controlling motor voltage/frequency, choosing between closed loop Field Oriented Control (FOC) and open loop V/F, etc. Through Strata, the developer can do full evaluation and access datasheets, BOMs, schematics, and other collateral they may need.

Features

- Motor Development Kit (MDK)
    - Compatible with the Universal Controller Board (UCB) FPGA/ARM
    - Fully compatible with Xilinx® development tools for Zynq®-7000
- Downloadable V/f and FOC control use cases for the UCB
- 4 kW motor control solution supplied up to 410 VDC
- MDK FPGA-controller based on Xilinx® Zynq®-7000 SoC, including a dual 667 MHz CPU Cortex A9 core with freely configurable digital peripheral, 32 Mbyte Flash, up to 1 GB RAM, USB / UART / JTAG interface, on-board Ethernet phy, bootloader capability via micro SD card, 10 ADC channel, using NCD98011, and 12 complementary PWM channels, capable of delivering advanced networked motor and motion control systems
- Highly integrated power module NFAM5065L4B containing an inverter power stage for a high voltage 3-phase inverter in a DIP39 package delivering
- DC/DC converter producing auxiliary power supply 15 VDC - non-isolated buck converter using NCP1063, DC/DC converter producing auxiliary power supply 5 VDC - non-isolated buck converter using NCV890100MWTXG, and LDO producing auxiliary power supply 3.3 VDC - using NCP718
- Three-phase current measurement using 3 x NCS20166 operational amplifiers
- Three-phase inverter voltage and DC-Link voltage measurement – using resistive voltage divider circuit
- 512 kB EEPROM I2C - using CAT24C512
- Encoder Interface compatible with either 3-HALL sensors 1 Channel Quadrature encoder
- Temperature sensing via build in thermistor
- Over current protection using NCS2250 comparator
- Xilinx® development tools and environments are available for the MDK, such as Vitis and Vivado to program the FPGA

Applications

- White Goods (Washing Machines)
- Industrial Fans
- Industrial Automation
- Industrial Motor Control

User Guide

Scope and Purpose

This user guide provides practical guidelines for using and implementing a three−phase industrial motor driver with the Intelligent Power Module (IPM). The design was tested as described in this document but not qualified regarding safety requirements or manufacturing and operation over the entire operating temperature range or lifetime. The development board has been layout in a spacious manner so that it facilitates measurements and probing for the evaluation of the system and its components. The hardware is intended for functional testing under laboratory conditions and by trained specialists only.

Attention: The STR−MDK−4KW−65SPM31−GEVK is exposed to high voltage. Only trained personnel should manipulate and operate on the system. Ensure that all boards are properly connected before powering, and that power is off before disconnecting any boards. It is mandatory to read the Safety Precautions section before manipulating the board. Failure to comply with the described safety precautions may result in personal injury or death, or equipment damage.

Prerequisites

All downloadable files are available on the board website and in Strata Developer Studio

Hardware

- STR−MDK−4KW−65SPM31−GEVK
- DC power supply (includes earth connection)
- Universal Control Board (UCB)
- USB isolator (5 kV optical isolation, also see Test Procedure)

Software

- Strata Developer Studio
- Downloadable UCB motor control firmware as boot image

DESIGN OVERVIEW

This report aims to provide the user manual for the development board STR−MDK−4KW−65SPM31− GEVK. This development board (from here on MDK_SPM31) is a DC supplied three−phase motor drive inverter intended for industrial motion applications < 4 kW range. In this field, a trade−off between switching frequency and power management is the key to fulfil the requirements while providing a simple and robust solution. The system is compatible with three phase motors (BLDC, Induction, PMSM, Switched Reluctance etc.). The MDK_SPM31 power board is illustrated in Figures 2 and 3 (top and bottom view, respectively). The block diagram of the whole system is depicted in Figure 4.

The foremost advantages that this development board brings are:

- System solution for industrial motor control applications
- Low component count with integrated IGBT power module
- Design fit for different motor technologies
- Friendly user experience with Graphical User Interface and selectable open loop/FOC closed loop control
- Rapid evaluation close to application condition

Figure 1. STR−MDK−4KW−65SPM31−GEVK

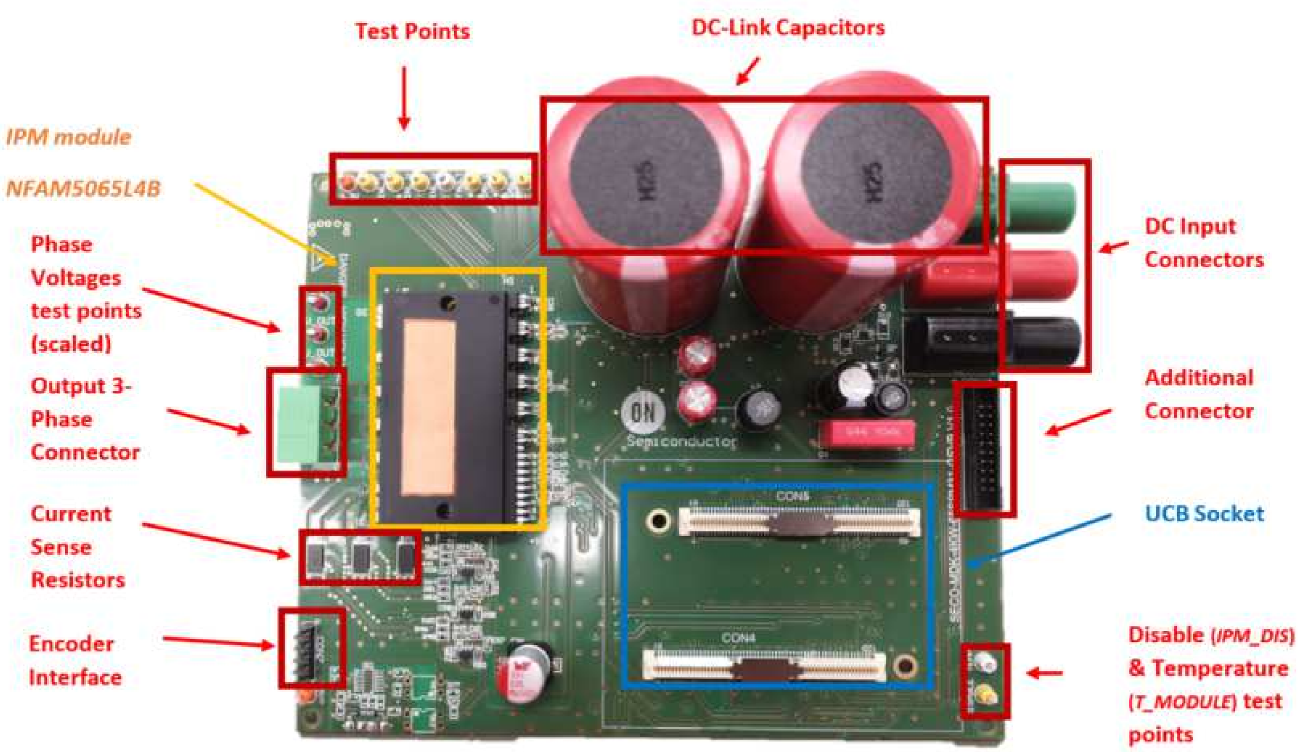


Figure 2. Picture of the evaluation board – top side

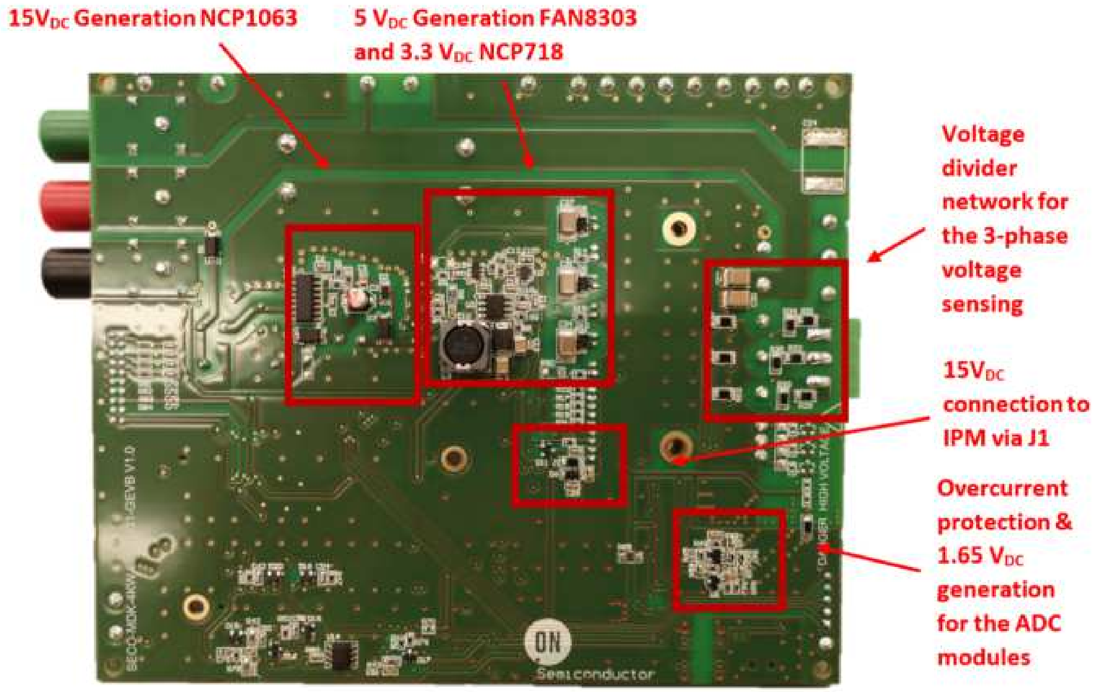


Figure 3. Picture of the Evaluation Board – Bottom Side

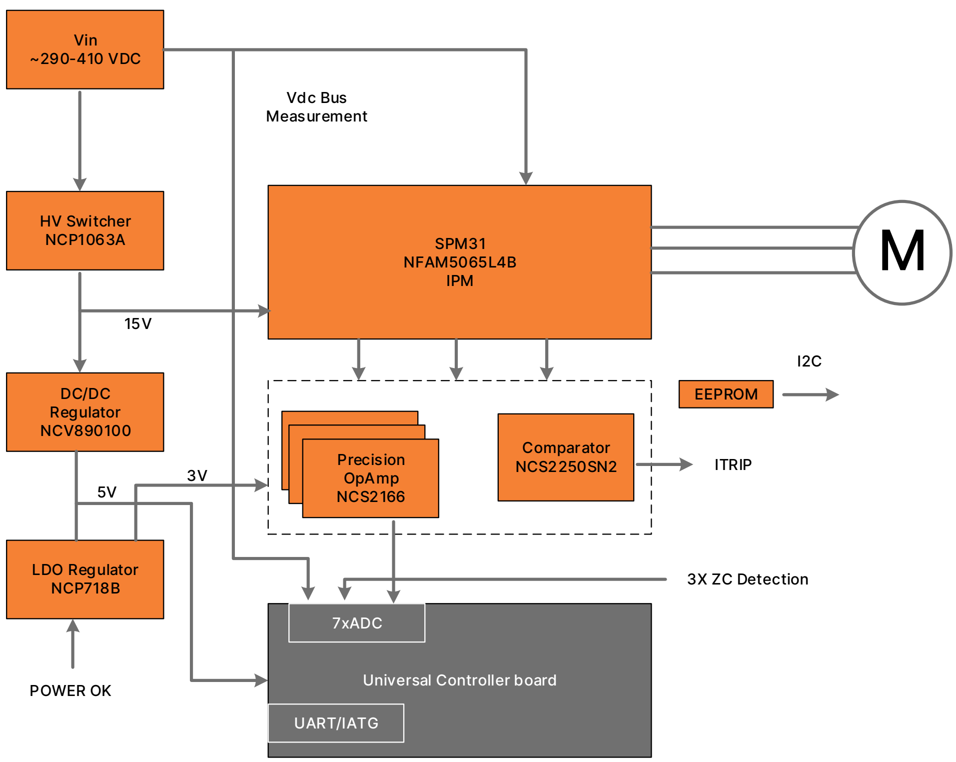


Figure 4. Block Diagram of the MDK_SPM31 Board

The specification and main features are elaborated in Table 1.

Table 1. MDK_SPM31 SPECIFICATIONS

Parameters	Values	Conditions/Comments
INPUT		
Voltage DC	200–400 Vdc	Absolute maximum input voltage 410 V
OUTPUT		
Power	1 kW (continues)	Input 200–400 Vdc
	4 kW (short period)	Maximum operation period 15 min @ Ta = 25°C
Current per IPM Leg	±2.5 Arms / 1 kW (140 Vrms Phase voltage and PF 0.98)	Lower output phase voltage will result in higher phase currents for same power
Module Temperature at 25°C Ambient	T_C = 65°C after 25 min @ 400 Vdc / 1 kW	Measured @ F_{PWM} = 16 kHz; lower frequency will result to higher ripple currents which might increase temperature
	T_C = 83°C after 8 min @ 400 Vdc / 4 kW	
CURRENT FEEDBACK		
Current Sensing Resistors	10 mΩ	Three 10 mΩ, one for each phase
Op−Amp Power Supply	3.3 V	Generated by the *NCP718 LDO*
Op−Amp Gain	10	Via resistors
Op−Amp Output Offset	1.65 V	Because of negative current measurement requirement
Current Measurement Resolution	0.016 A / bit	Based on *UCB* integrated 11 bits ADC *NCD98011* [9]
Current Measurement Sampling Frequency	Up to 2 Msamples/sec	Configurable via the *UCB*
Measured Current Range	±16.5 A_{peak}	Configured by the shunt resistors and *NCS20166* output offset and gain
Overcurrent Protection	+21.5 A_{peak} (rise time delay 500 ns)	Configured by the shunt resistors and the – *NCS2250SN2T3G* – comparator threshold
DC−LINK VOLTAGE MEASURING		
DC−Link Voltage Range	0 V – 483.7 V	
DC−Link Voltage Divider Gain	0.0068218	Configured by the voltage divider
DC−Link Voltage Resolution	0.236 V / bit	Based on MDK integrated 11 bits ADC
INVERTER PHASE VOLTAGES MEASURING		
Phase Voltages Range	0 V – 241.7 V	
Phase Voltages Divider Gain	0.0136495	Configured by the voltage divider
Phase Voltages Resolution	0.472 V / bit	Configured by *MDK_SPM31* integrated 11 bits ADC
AUXILIARY POWER SUPPLIES MAXIMUM DEMAND		
15 V	4.4 W	Generated by the *NCP1063*
5 V	2.9 W	Generated by the *FAN8303*
3.3 V	0.05 W	Generated by the *NCP718*
CONTROL (Note 1)		
UCB		Pluggable via two polarized Bergstak® 0.80 mm Pitch connectors
Type of Control (in Flash)		V/f / FOC
Supported Type of Motors		ACIM, PMSM, BLDC
APPLICATION		
White Goods (Washers), Industrial Fans, Industrial Automation		

Out of a variable Vdc input (200–400 Vdc), the board can deliver continuous power in excess of 1 kW or up to 4 kW for a short period to a three−phase motor. The foremost circuitries conforming the system are, the auxiliary power supplies, the current and voltage sensing, the overcurrent protection, and of course the three−phase inverter, build with the NFAM5065L4B IPM. Figure 4 illustrates the overall view of the above circuitries.

Inverter Stage with Intelligent Power Module (IPM) Technology

The inverter power stage is the backbone of this development board and it performs the DC/AC conversion. It utilizes the NFAM5065L4B IPM module, a fully integrated power stage for three−phase motor drives consisting of six IGBTs with reverse diodes, an independent high side gate driver, LVIC, and a temperature sensor (VTS). The IGBT's are configured in a three−phase bridge with separate emitter connections for the lower legs to allow the designer flexibility in choosing the current feedback topology and resolution. This module leverages the Insulated Metal Substrate (IMS) technology from onsemi. Packaged in the DIP39 format, the NFAM5065L4B (from here on IPM) not only provides a highly integrated, compact and rugged solution, but also best−in−class thermal management capabilities. In short, the module enables lower component count designs for industrial motor drives and simplifies the development, reducing the time−to−market of new solutions. Protection function in the system include under−voltage lockout, and external hardware shutdown for over−current protection via a comparator−based trigger event, which is currently configured at +21 A via the current sense and voltage−divider selection. By changing the voltage divider resistors, the designer can change the over−current protection threshold. Finally, external shutdown via software is also possible (via CIN pin), allowing the user to define a multilayer current protection function. In this development board the DC−Link, which is provided by an external power supply, serves as the power input to the inverter module. The module needs to be supplied as well with 15 Vdc, necessary for the IGBT gate drivers, 5 Vdc necessary for the MDK_SPM31, as well as with 3.3 Vdc voltage necessary for the current measurement Op−Amps and over−current protection comparators. The auxiliary power supplies that have been referred earlier (NCP1063, NCV890100MWTXG, and NCP718) in the document provide these voltage rails. IPM_FAULT and T_MODULE (temperature) are the output signals from the IPM module, which are routed to the UCB controller and can be used by the end−user for control and protection purposes. All operational input and output signals and the corresponding voltage references are described in more detail in the UCB Controller section and in Low−power Connectors, High−power Connectors, and in Appendix. The applied design has been influenced by the AND9390/D [10] and the NFAM5065L4B [2] data sheet.

Current Measurement

The development system is round out by the NCS2250 High Speed Comparator, the NCS20166 precision low−offset Op−Amp, and the NCD98011 UCB integrated ADC module. Currently, ADC resolution is 11−bit resulting in an overall resolution of 0.016 A/bit, while the range of phase−current measurement is set to ±16.5 A. The NCS20166 gain selection, the current sense resistor selection, and the NCD98011 ADC module that is integrated in UCB define the overall current resolution. The overall resolution and maximum current range can be found in Table 1. More details around the SAR concept and NCD98011 can be found in [9].

DC−Link and Inverter Phase−voltages Measurement

The DC−Link and inverter phase−voltage are both sensed via resistive voltage divider circuits, where the scaled−down voltage signals are used as inputs for the integrated UCB ADC −NCD98011 − modules. As mentioned above, overall resolution and maximum voltage range can be found in Table 1.

Over−current Protection and Under Voltage Protection Fault

The hardware over−current protection leverages the disable−option on the IPM. This function exploits the disable pin (CIN pin) of IPM, via the ITRIP signal that is provided to the power module by the NCS2250 comparator. The disable−pin (CIN pin) is also controlled by UCB controller, allowing the end−user to configure a multilayer overcurrent protection. Finally, the end−user may also leverage the output fault signal of IPM (VFO), using the UCB controller. Note that VFO output is routed to UCB. As such, when a fault arises the software can use VFO output accordingly to shut down system operation or take other actions. Note that the above protection mechanism is implemented in software level, and as such it might be subjected to delays or spurious tripping if not properly handled.

UCB Controller

The UCB is a powerful universal motor controller that is based on SOC Zynq 7000 series [11]. It includes a dual 667 MHz CPU Cortex A9 core, with freely configurable digital peripheral, bootloader capability via micro SD card, USB/UART/JTAG interface, 32 Mbyte Flash memory, 32−Bit−wide 256 MByte DDR3 SDRAM, on−board Ethernet phy, 10 ADC channel – using onsemi NCD98011), and 12 complementary PWM channels. The UCB is an industrial−grade System on Module (SoM) that can be used for advanced networked motor and motion control systems, capable of delivering advanced control strategies for different types of motors (AC induction motor, PMSM, BLDC). The UCB controller interacts with the power board via specific pins, which are routed to two − 120 pins each – connectors. More details around the connectors can be found in Board Connectors. Auxiliary 5 Vdc and 3.3 Vdc power supplies can be used for powering−up the UCB board. They are located at the main power board. Alternatively, the UCB can be powered−up from the 5 Vdc USB cable, which is connected to the controller. Then, the UCB generates all the voltage rails (3.3 Vdc included) that are required for its proper operation. In addition, it also delivers (independently of the main auxiliary supplies) the necessary 5 Vdc and 3.3 Vdc reference voltages for the Op−Amps and comparators on the power board. Therefore, functionality of the controller, as well as the functionality of the Op−Amps and comparators can be evaluated even when the main power board auxiliary supplies are off. Finally, the UCB provides the control capabilities of the system, and supports the user interface communication. End user can develop its own applications to exploit the UCB features and capabilities. As mentioned earlier the MDK_SPM31 power board provides all the required feedback to the UCB for the generation of PWM driving signals to control the IGBT module gate drivers as well as to enable/disable the module in the event of faults arising. This allows end−user to develop many different control strategies from simple V/F and Field Oriented Control (FOC) up to predictive control algorithms. Moreover, the UCB enables bidirectional serial communication to transfer measurements data for visualization purposes. A Graphical User Interface is provided, along with an appropriate code in flash that can run a simple V/F control or an FOC and allow visualization of key electrical quantities. More details around the software can be found in Software section. The interface header pinout of MDK_SPM31 is described in detail in Board Connectors. A detailed description of the UCB connector can be found in Appendix. Finally, the documentation around UCB can be found in [1].

Auxiliary Power Supplies

There are three auxiliary supplies on the power board to provide the necessary 15 Vdc, 5 Vdc, and 3.3 Vdc rails. The first one is a non−isolated buck converter using NCP1063. This auxiliary supply provides the 15 Vdc, which are necessary for the IPM drivers. The NCP1063 high−voltage switcher serves well this purpose, featuring a built−in 700 V MOSFET with RDS(on) of 11.4 and 100 kHz switching frequency. NCP1063 is fed directly from the high−voltage DC−Link. A minimum 90 V DC−Link voltage is required for operation. Next, the NCV890100MWTXG non−isolated buck is used to convert the 15 Vdc to the 5 Vdc that is necessary for the UCB controller circuitry. Last but not least, the LDO NCP718 converts the 5 Vdc to 3.3 Vdc, necessary for the current measuring and protection circuitry, and for the integrated UCB NCD98011 ADC modules. The non−isolated power supplies provides a simple and effective solution for industrial and commercial motor control applications. More details about the auxiliary power supplies can be found in the corresponding ICs data sheets, [3], [4], and [5], respectively. Last but not least, the power rating of the auxiliary power supplies can be found in Table 1.

EEPROM

The main power board is equipped with the CAT24C512 EEPROM unit. The CAT24C512 is an EERPOM Serial 512−Kb I2C, which is internally organized as 65,536 words of 8−bits each. It features a 128−byte page write buffer and supports the Standard (100 kHz), Fast (400 kHz) and Fast−Plus (1 MHz) I2C protocol. External address pins make it possible to address up to eight CAT24C512 devices on the same bus. The device Serial Click and Serial Data pins of the CAT24C512 (pins DIO_1_1, DIO_1_2) are routed to the UCB controller B35 buss (B35_L16_N and B35_L16_P, respectively), via CON4 (pin 13 and pin 14). The data sheet of CAT24C512 EEPROM device can be found in [8].

UCB with Pre−flashed Firmware

(UCB acquired as part of STR−1KW−MCTRL−GEVK) If you acquired the UCB as part of the onsemi kit, the controller is already flashed with V/F control and FOC control. The user does not have to perform any further actions for booting. It is noted however, that booting from the flash, the SD−socket at UCB should be empty. With the flashed controller, the user can control the motor via the graphical user interface (GUI). Download and install Strata Developer Studio to access the GUI. Once this step is done, UCB can be connected and powered up, Strata Developer Studio will detect the board automatically and display the board as connected. To open the GUI, click Hardware controls next to the connected board. With the GUI, the user can select between the V/F and FOC strategy. The GUI also assists the end−user to configure and tune the foremost V/F and FOC parameters, while it also provides visual representation of key electrical variables, such as the DC−Link voltage and temperature of IPM, the RMS value of the inverter output current and voltage, and the motor speed.

User Interface

The UI within the Strata app allows the user to control and monitor the MDK without needing other lab equipment or training. The steps below cover what's in the UI.

If you acquired the UCB as part of the kit, the controller is already flashed with V/F control and FOC control. The user does not have to perform any further actions for booting. It is noted however, that booting from the flash, the SD−socket at UCB should be empty. With the flashed controller, the user can control the motor via the graphical user interface (GUI).

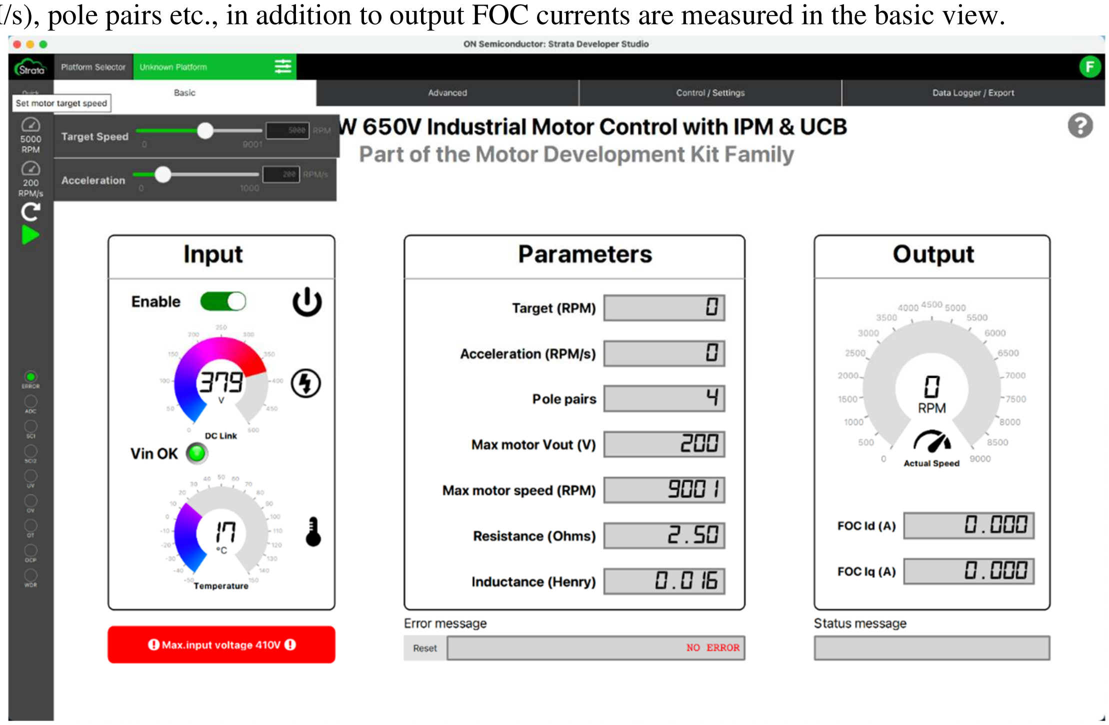
1. First, download and install the most recent version of Strata. It can be found here: https://www.onsemi.com/support/strata-developer-studio
2. Open the Strata app. Login, then the home screen will appear.
3. Plugin the USB cable from the UCB board to the PC running Strata software.
4. The app will automatically detect the kit and will bring up the UI for the board that is plugged in.
   a. Depending on user settings, the UI may not automatically come up, but the connected board will be the first choice

Telemetry, Controls, and Functionality

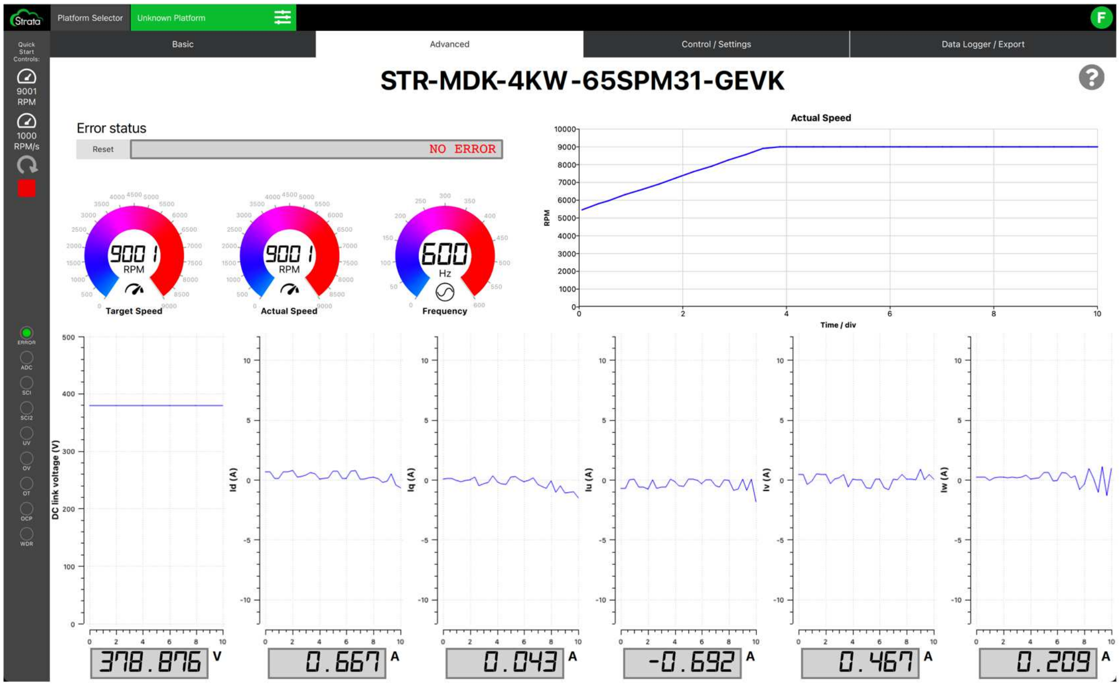
This section will go over the different UI views within Strata.

Input values, such as target speed and acceleration can be entered and modified from the user-friendly Quick Start Controls side bar from any UI view tab.

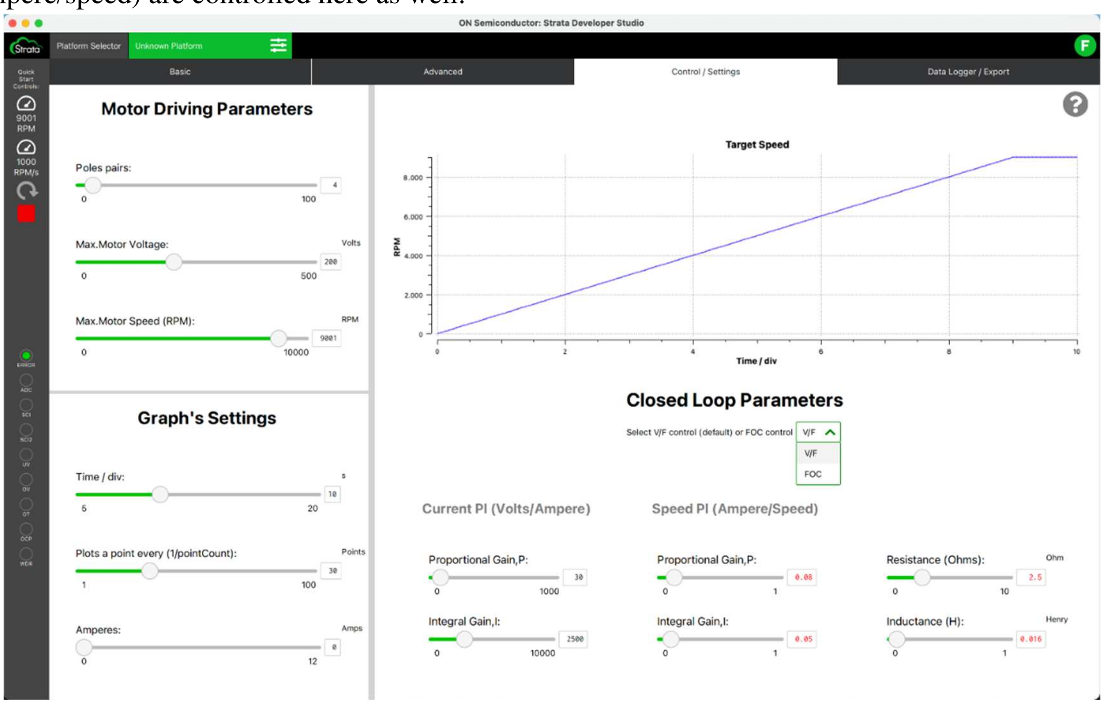
1. Basic view
   Enable switch, DC link input voltage, temperature reading, parameters like target (RPM), acceleration (RPM/s), pole pairs etc., in addition to output FOC currents are measured in the basic view.



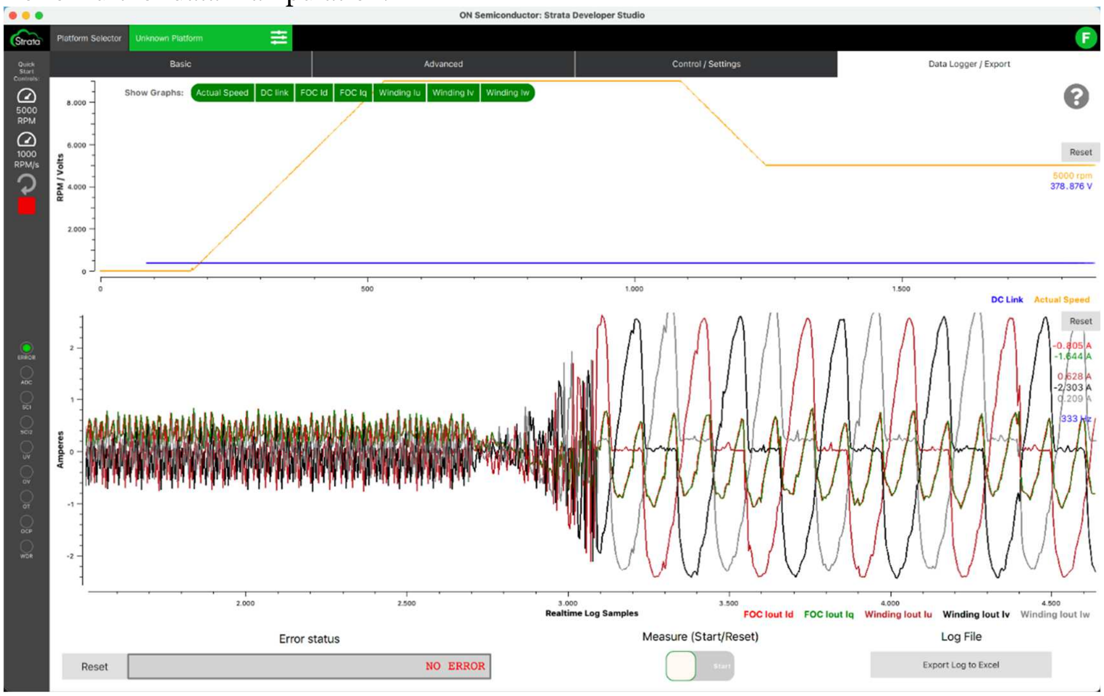
2. Advanced view
   Essential system variables values, such as input and output voltages/currents, speed, acceleration, and temperatures are displayed and plotted on dynamic charts in real time.



3. Control/Settings
   Motor driving parameters such as number of poles, max motor voltage, and max motor speed can be specified here, in addition to fixable graph's setting. The user has the option here to select between closed loop Field Oriented Control (FOC) or open loop V/F, current PI (volts/ampere) and speed PI (ampere/speed) are controlled here as well.



4. Data Logger / Export
   Speed/DC link graphs (actual speed and DC link), current graphs (FOC Id, FOC Iq, and winding Iu, Iv, Iw) graphs are plotted here for any desired timeline, the user has the option to export all data to Excel as a log file for further data manipulation.



REFERENCES

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[2] NFAM5065L4B data sheet. Intelligent Power Module (IPM) 6500 V, 50 A.
[3] NCP1063 data sheet.
[4] NCV890100MWTXG data sheet.
[5] NCP718 data sheet.
[6] NCS20166 data sheet.
[7] NCS2250 data sheet.
[8] CAT24C512 data sheet.
[9] NCD98011 data sheet.
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[16] Boot from flash
[17] Strata Developer Studio

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