1kW 600V Industrial Motor Control Development Kit User Guide

Table of Contents

Introduction

The STR-1KW-MDK-GEVK is a complete reference design for three-phase motor drives, featuring the NFAQ1060L36T intelligent power module in a DIPS6 package, and part of the Motor Development Kit (MDK) family. Rated for 230 Vac input and delivering up to 850W. All the necessary system blocks for a motor drive are part of the solution: EMC filtering and rectification stage, interleaved two-channel PFC, auxiliary power supplies, three-phase inverter and measurement and protection. As part of the MDK, the Compact IPM power module 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
- 850W Intelligent Power Module (IPM) three-phase motor driver
- VIN: 230 Vac,rms ± 15% (single-phase)
- IOUT: Irms 10 ARMS per phase
- Compatible with three-phase motors: PMSM, BLDC or ACIM
- DIP/6 IPM NFAQ1060L36T, three-phase/10A with integrated gate drivers
- Cross-conduction, overcurrent and thermal protection embedded in DIPS6 module
- Plug-in connector interface for MCU cards (Arduino DUE footprint)
- Voltage/frequency control strategy implemented
- NCS2250SN2T3G: Push Pull Output Comparator implemented in ITRIP protection system
- Use case pre-loaded and GUI available for a quick-start evaluation
- 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

Overview

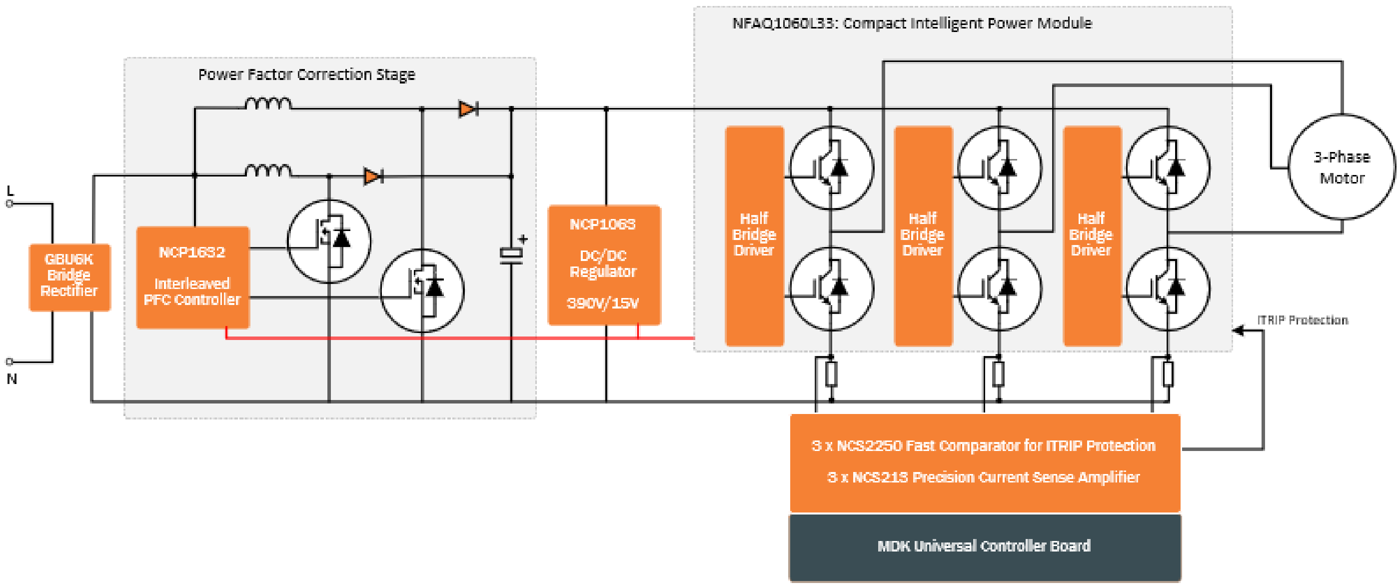

Figure 1. Block Diagram of the 1kW MDK

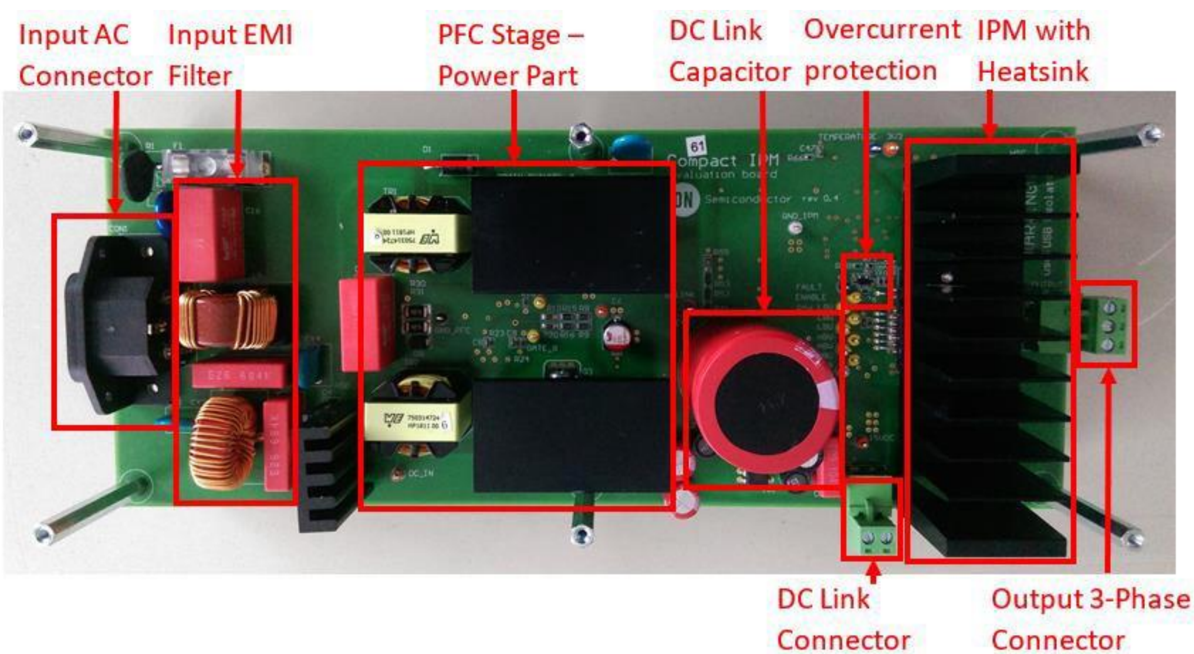

Figure 2. Picture of the evaluation board – top side

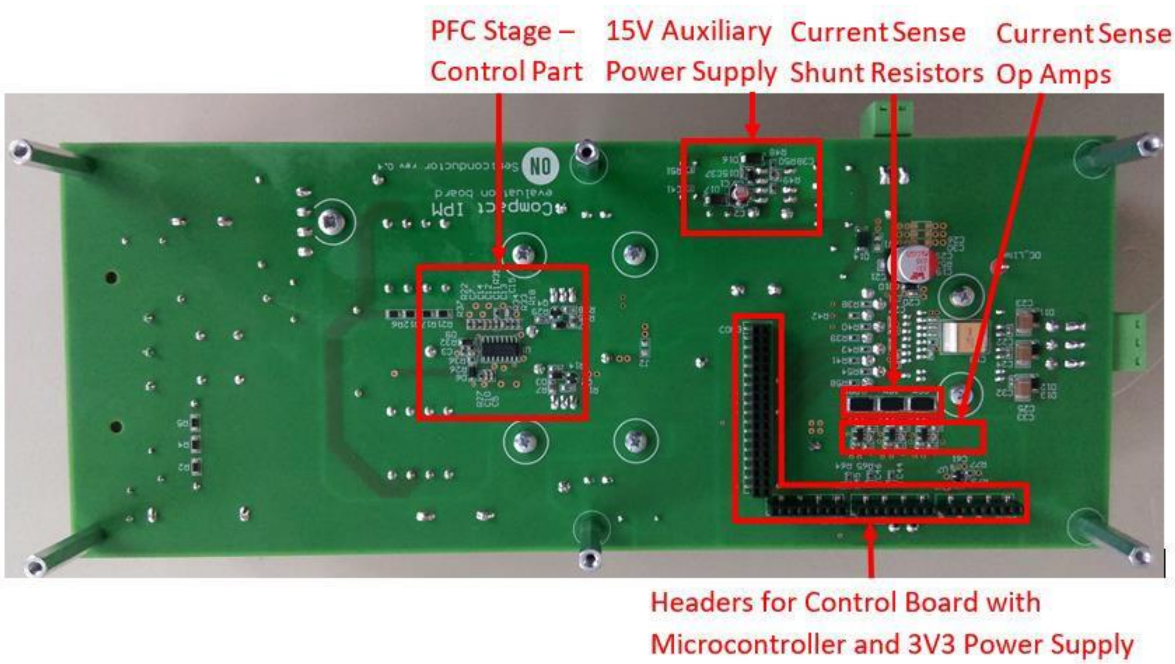

Figure 3. Picture of the Evaluation Board – Bottom Side

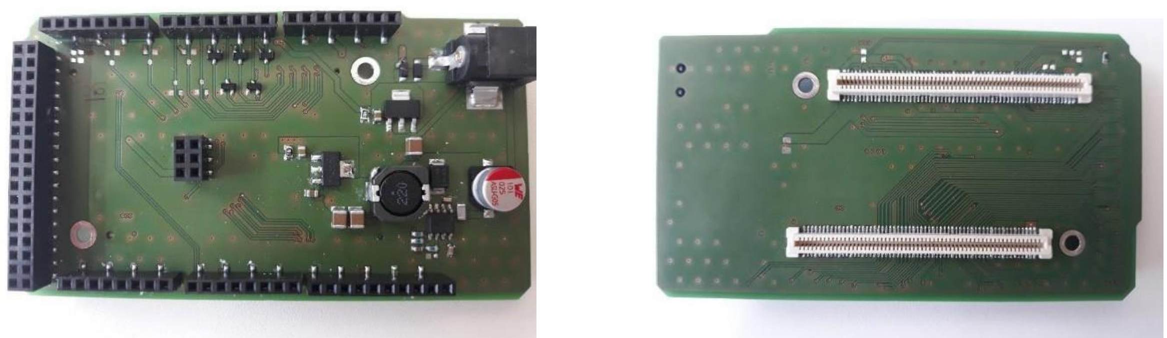

Figure 4. Picture of the UCB Adapter

Hardware

- STR−1KW−MDK-GEVK (includes power board, adapter for UCB)
- AC power cord one−phase
- Universal Controller Board (UCB) or pin−compatible controller board
- USB isolator (5 kV optical isolation)
- HF ferrite clamp i.e. WE 7427154

Software

- Strata Developer Studio
- Binary file

Table 1. EVALUATION BOARD SPECIFICATIONS

Parameters	Values	Conditions/comments
INPUT		
Voltage	230 V_{rms} ± 15%	
OUTPUT		
Power	850 W	Input 230 V_{AC}, f_{PWM} = 16 kHz, T_A = 25°C
Current per IPM leg	±5 A_{rms}	T_C = 100°C
DC BUS Voltage	390 V	Higher voltage value is created by interleaved PFC withNCP1632 working as a booster
CURRENT FEEDBACK		
Current sensing resistors	39 mΩ	
Op Amp power supply	3.3 V	
Set Op Amp gain	5	
Set output offset	1.65 V	Because of negative current measurement
Overcurrent protection	9 A_{peak}	Configured by shunt resistors and comparator threshold(voltage divider)
AUXILIARY POWER SUPPLY		
15 V	4.6 W	Used NCP1063
CONTROL		
Board with Microcontroller and 3V3 power supply		Arduino DUE headers
Type of control		V/f, Field Oriented Control (Sensor−less)
Supported type of motors		ACIM, PMSM, BLDC
APPLICATION		
White goods (washers), Industrial fans, Industrial automation		

SAFETY PRECAUTIONS

Table 2.

STR−1KW−MDK−GEVK	
	The ground potential of the system is biased to a negative DC bus voltage potential. When measuring voltage waveform by oscilloscope, the scope's ground needs to be isolated. Failure to do so may result in personal injury or death
	The ground potential of the system is NOT biased to an earth (PE) potential. When connecting the MCU board via USB to the computer, the appropriate galvanically isolated USB isolator have to be used. The recommended isolation voltage of USB isolator is 5 kV
	STR-1KW-MDK-GEVK system contains DC bus capacitors which take time to discharge after removal of the main supply. Before working on the drive system, wait ten minutes for capacitors to discharge to safe volt- age levels. Failure to do so may result in personal injury or death.
	Only personnel familiar with the drive and associated machinery should plan or implement the installation, start−up and subsequent maintenance of the system. Failure to comply may result in personal injury and/or equipment damage.
	The surfaces of the drive may become hot, which may cause injury.
	STR−1KW−MDK−GEVK system contains parts and assemblies sensitive to Electrostatic Discharge (ESD). Electrostatic control precautions are required when installing, testing, servicing or repairing this assembly. Component damage may result if ESD control procedures are not followed. If you are not familiar with electrostatic control procedures, refer to applicable ESD protection handbooks and guidelines.
	A drive, incorrectly applied or installed, can result in component damage or reduction in product lifetime. Wiring or application errors such as under sizing the motor, supplying an incorrect or inadequate AC supply or excessive ambient temperatures may result in system malfunction.

	Remove and lock out power from the drive before you disconnect or reconnect wires or perform service. Waitten minutes after removing power to discharge the bus capacitors. Do not attempt to service the drive until the bus capacitors have discharged to zero. Failure to do so may result in personal injury or death.
	STR−1KW−MDK−GEVK system is shipped with packing materials that need to be removed prior to installation. Failure to remove all packing materials which are unnecessary for system installation may result in overheating or abnormal operating condition.

SCHEMATICS AND LAYOUT

To meet customer requirements and make the evaluation board a basis for development, all necessary technical data like schematics, layout and components are included in this chapter. Also simple measurements were done to show the functionality of individual stages.

Input EMI Filter

Figure 5 depicts schematic from AC input to rectifier input. This circuitry includes a passive EMI filter consisting of elements C16, L5, CY1, CY3, CY4, C51, L4 and C17.

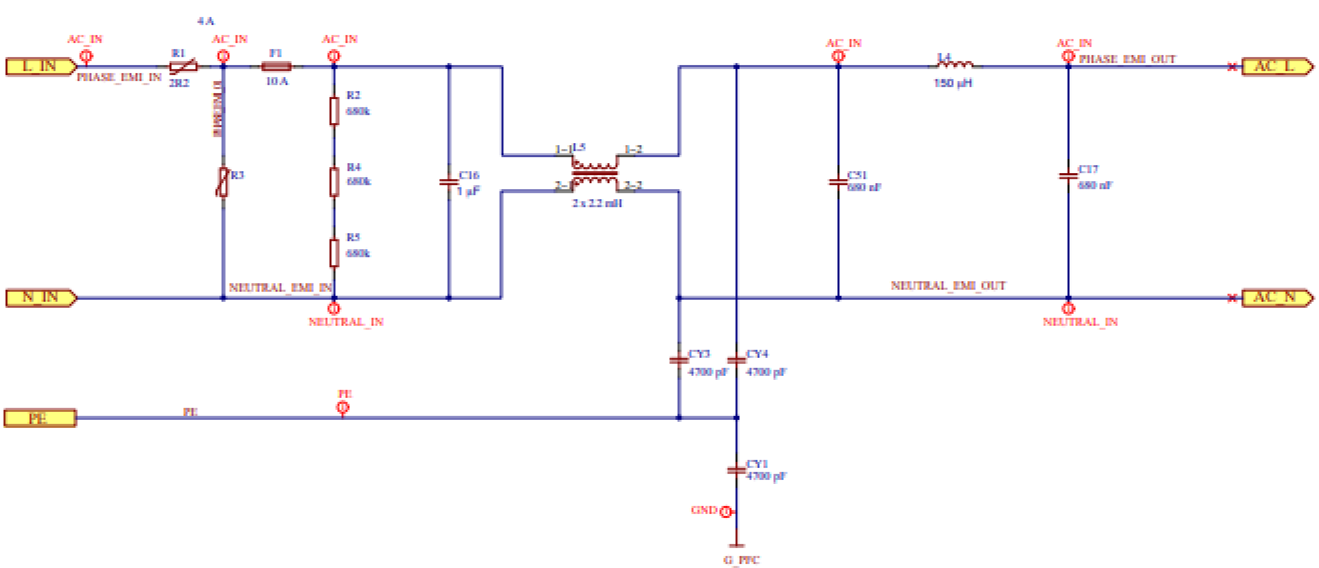

Figure 5. Schematic of EMI filter

Interleaved PFC Stage

In higher power applications to utilize full capacity power of mains and reduce harmonics is PFC−regulators generallyrequired. This high-power application uses interleaved PFC stages, where may reduce inductor size, input and output capacitors ripple current. In overall, power components are smaller include capacitors. The NCP1632 as voltage mode IC for interleaved PFC applications used in conduction critical mode. It drives two MOSFETs 180° phase shifted. The most important at design should be focused significant inductance value of selected PFC coils. It significantly specifies working range.

Figure 6 depicts schematic from rectifier input to DC link output. Activation of stage (connection to 15 V DC power supply) is via J2 (soldered pads).

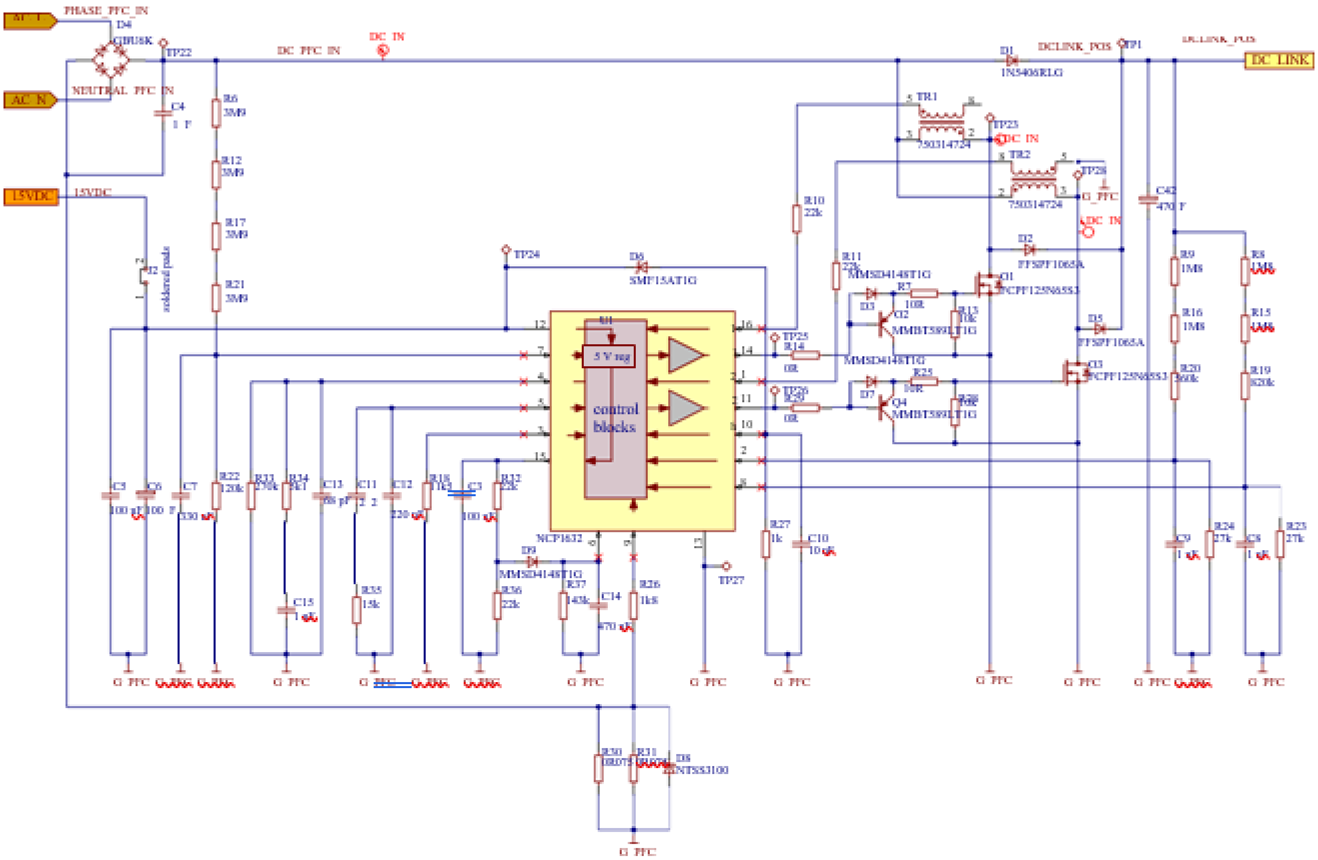

Figure 6. Schematic of interleaved PFC stage

Basic tests and measurements were done. The results of efficiency, power factor, power losses, load transients and startup can be seen in the Figures 7–12. The used load was Halogen light bulb.

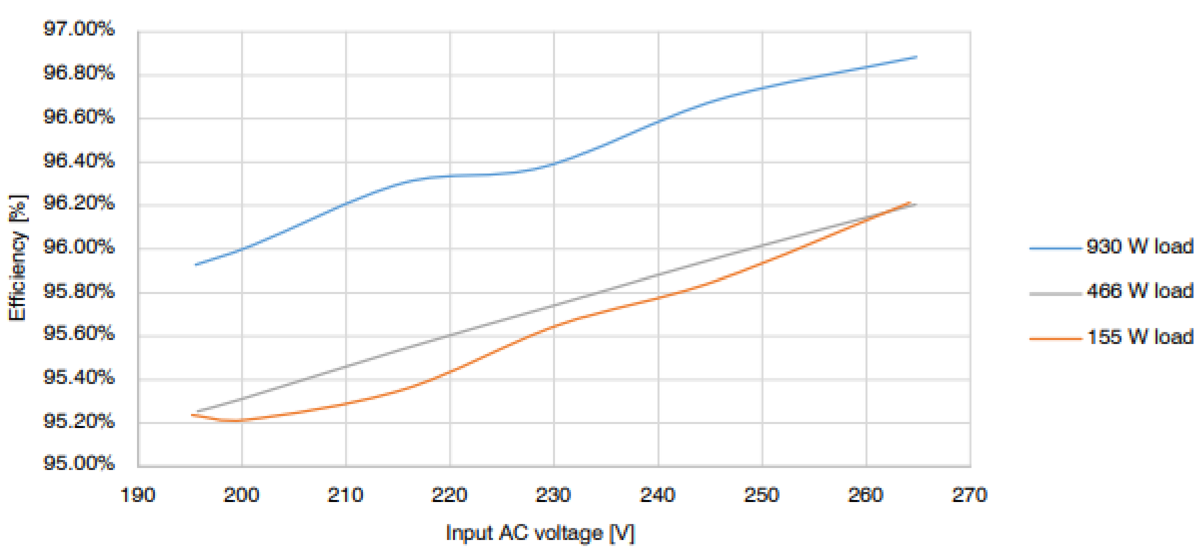

Figure 7. Efficiency of PFC Stage for Various Value of Input AC Voltage and Load

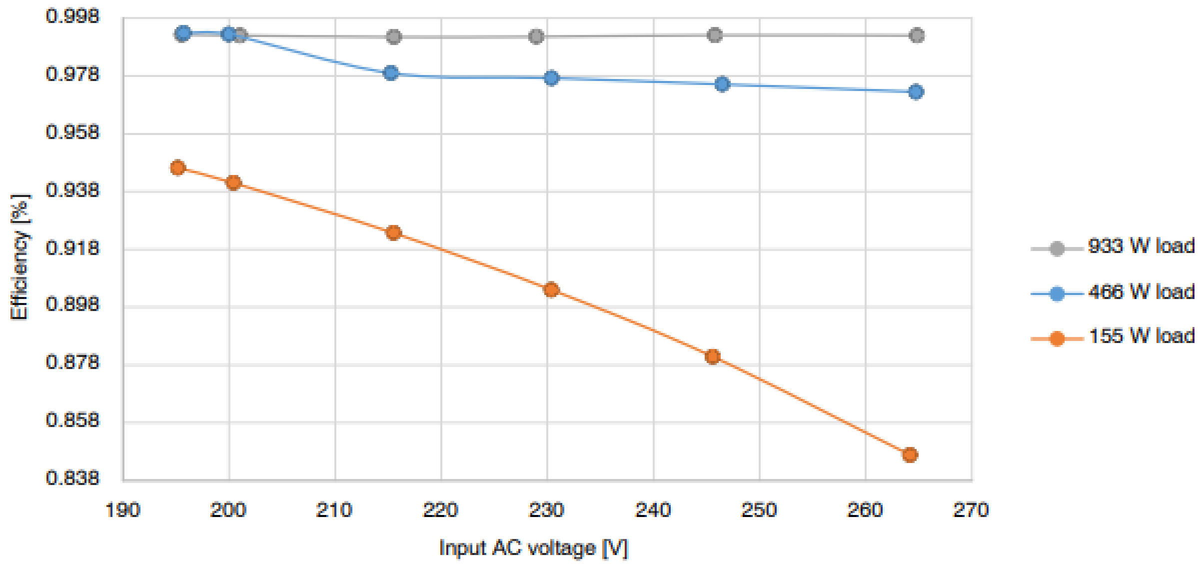

Figure 8. Power Factor of PFC Stage for Various Value of Input AC Voltage and Load

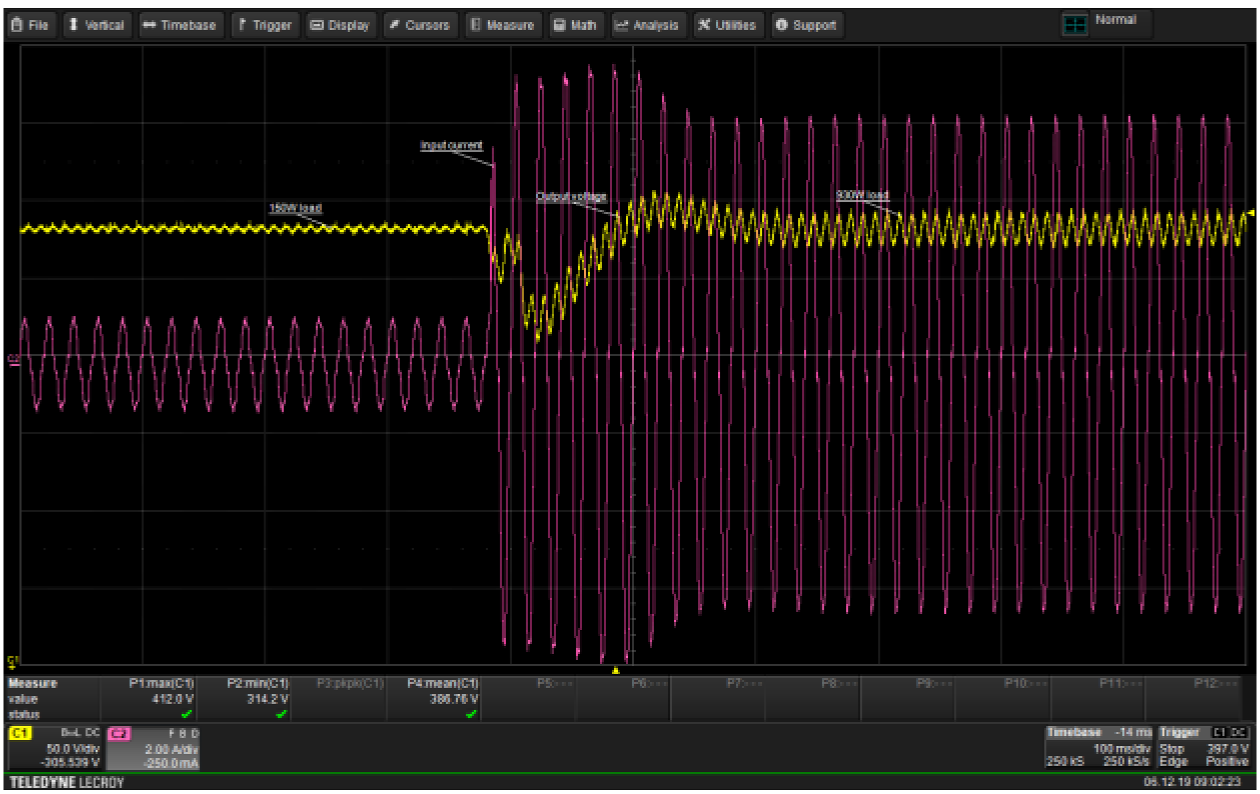

Figure 9. Load Transient 155 W to 930 W at 230 V AC Input

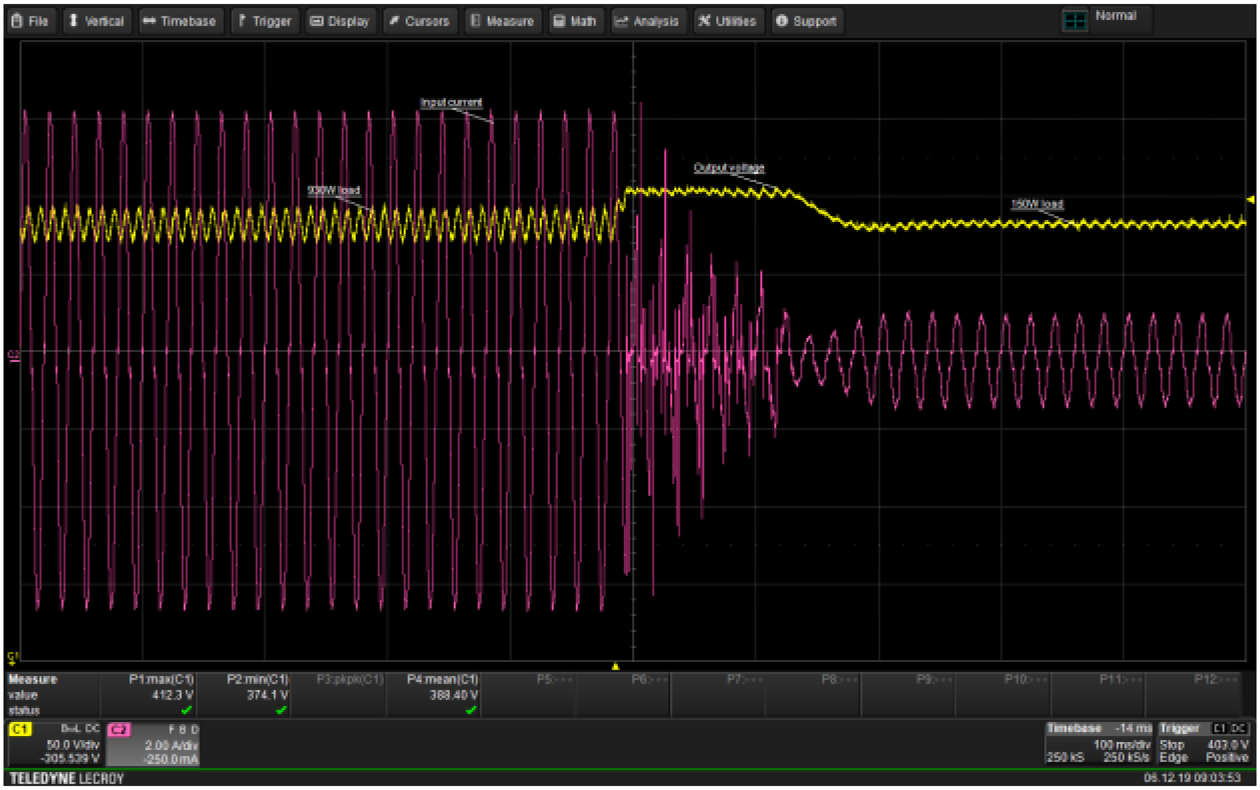

Figure 10. Load Transient 930 W to 155 W at 230 V AC Input

Figure 11. Start up to Open Circuit, 155 W and 930 W at 230 V AC Input

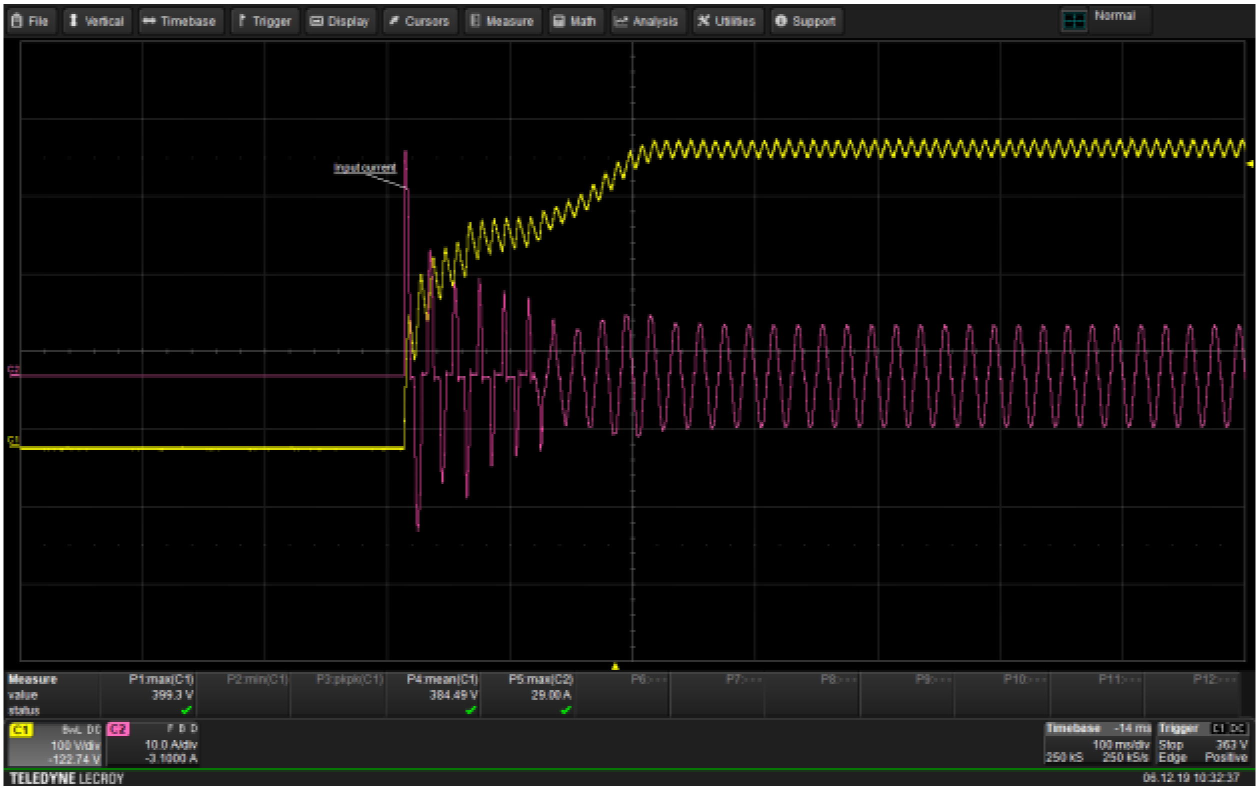

Figure 12. Start to 930 W at 230 V AC Input, Inrush Current

Auxiliary 15 V Power Supply

The NCP1063 is used as converter 390 V to 15 V output to supply PFC, IPM and Control board (Arduino Due). The maximal power delivered is up to 4.6 W. Figure 14 depicts schematic of 15 V auxiliary power supply. Figure 14 shows startup of the converter.

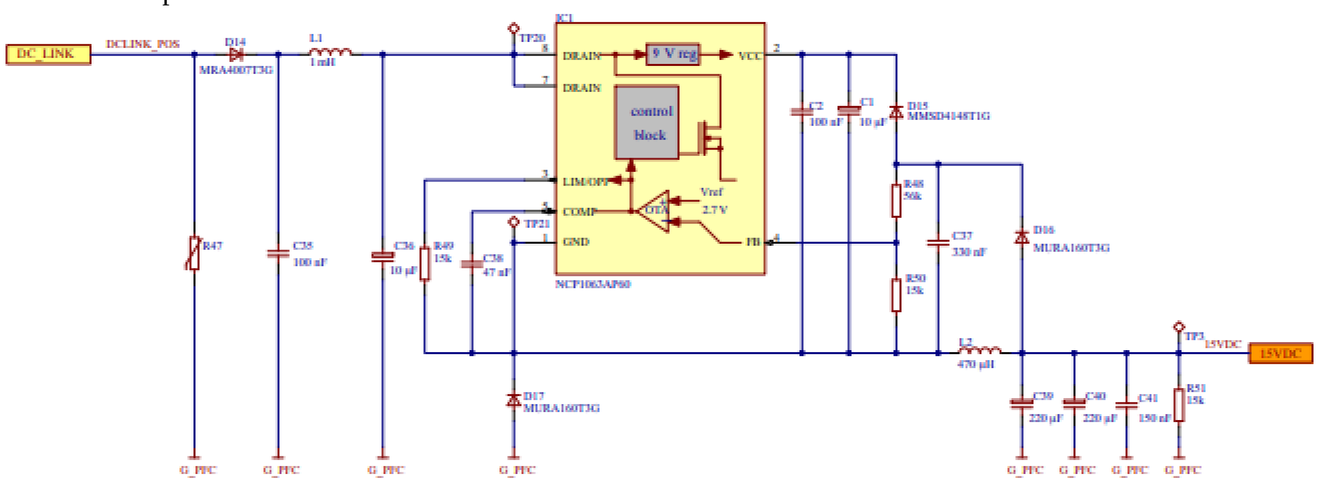

Figure 13. Schematic of Auxiliary 15V Power Supply

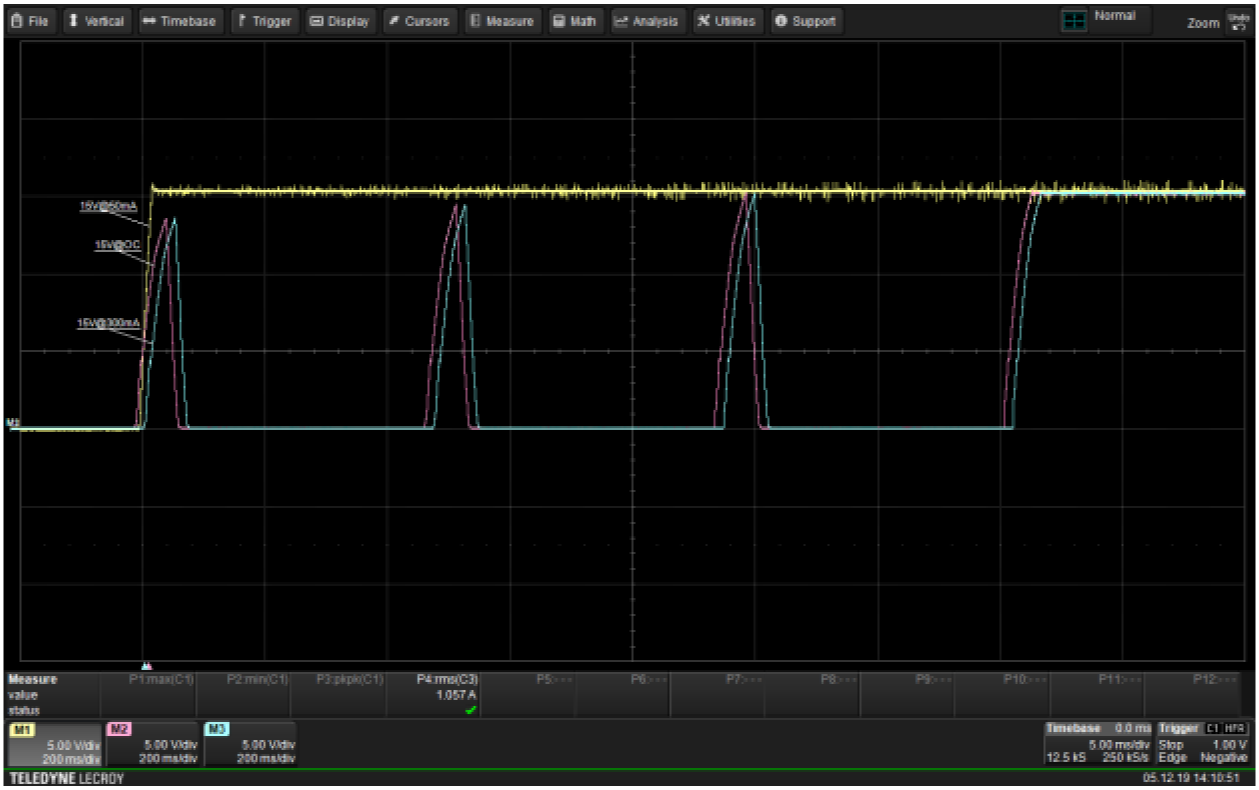

Figure 14. Start Up to Open Circuit, to 50 mA and to 300 mA at 390 V DC Input

IPM Stage

This stage uses NFAQ1060L36T IPM for 3−phase motor drives containing three−phase inverter, gate drivers for the inverter and a thermistor. It uses onsemi's Insulated Metal Substrate (IMS) Technology. Very important function is over−current protection which is deeply described in chapter – Current Measurement and Over−Current Protection. Module also contains fault pin which is keeping high level during normal state. Activation of IPM stage (connection to 15 V DC power supply) is via J1 (soldered pads). In the figure 15 is shown schematics of IPM stage also with DC link voltage measurement (voltage divider containing R46, R52, R53 and R55). Signals from 39 m shunt resistors are going to current measurement and over−current protection circuits.

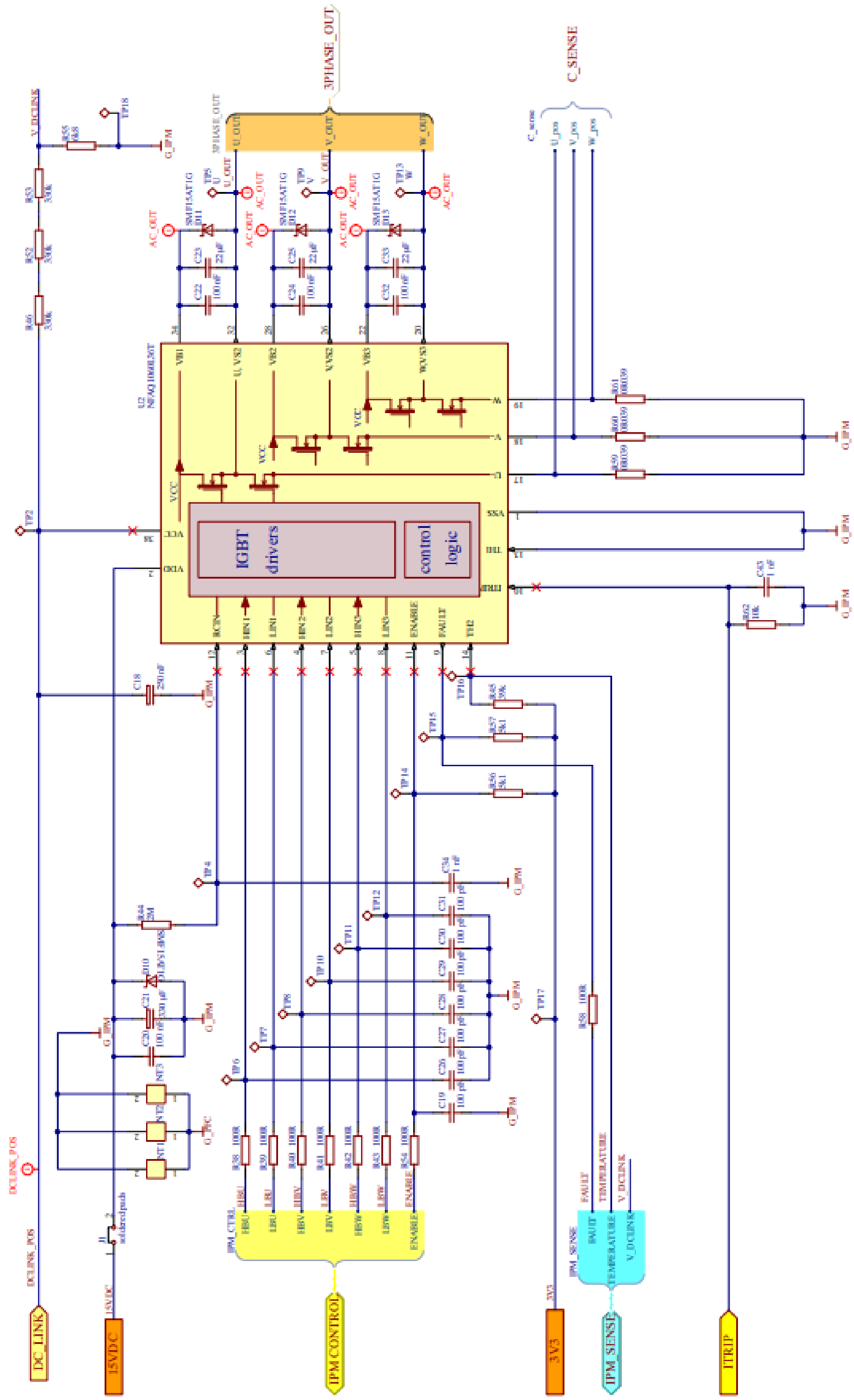

Figure 15. Schematic of IPM Stage

Current Measurement and Over−Current Protection

Schematic of current measurement and over−current protection can be seen in the Figure 16. Information about currents is provided via 39 m shunt resistors. Voltage drop from shunt resistor is going to input of operational amplifier (op−amp) NCS2003 which gain is set to 4.99 with 1k resistor and 4k99 resistor connected as negative feedback. U7 (TLV431) is creating 1.65 V reference which is connected to non−inverting input of op−amps. This connection provides voltage offset at the output of op−amps, which is needed for negative current measurement. Overcurrent protection is offered by NCS2250 comparator. Comparator threshold is set by voltage divider which consists of R68, R71 and C48. Signals from shunt resistors are going via R78, R81 and R84 connected to non−inverting input. These resistors together with C58 are also acting as low pass filter for high frequency signals interference. On the one hand, with insufficient filtering the over− current protection can react for lower values of current even if there is 350 ns blanking time on ITRIP pin of IPM to improve noise immunity (see datasheet of IPM). On the other hand, when we are designing this filter it is needed to be careful about the maximal time constant value according short circuit safe operating area (see datasheet of IPM, NFAQ1060L36T− for VCE = 400 V is 4 s). Output from comparator is connected to ITRIP pin of IMP module. As was mentioned in previous chapter, IPM has fault pin and its voltage level is high during normal state. An over−current condition is detected if the voltage on the ITRIP pin is larger than the reference voltage (typically 0.5 V). After a shutdown propagation delay of typically 1.1 s, the FAULT output is switched on. The FAULT output is held on for a time determined by the resistor and capacitor connected to the RCIN pin (IPM pin 12). If R44 = 2 MΩ and C34 = 1 nF, the FAULT output is switched on for 1.65 ms (typical). The over−current protection threshold should be set to be equal or lower to 2 times the module rated current. The reaction of the protection can be seen in the Figure 17 and 18. System is also using ENABLE pin of the IPM. After the over−current fault, fault signal is generated and sent to microcontroller which disable the IPM via ENABLE pin (programmed by user). New operation is possible after microcontroller reset.

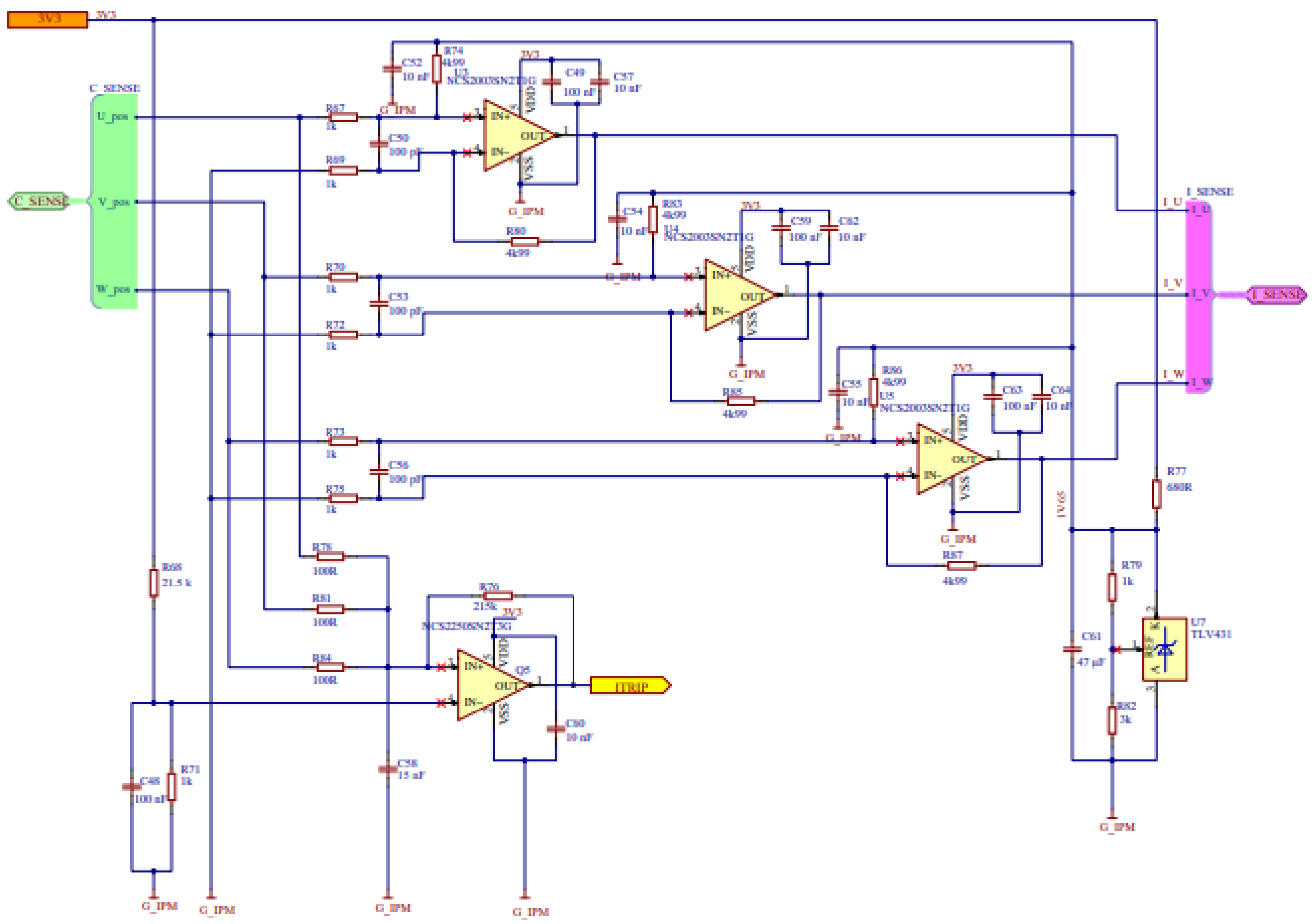

Figure 16. Schematic of Current Measurement and Overcurrent Protection

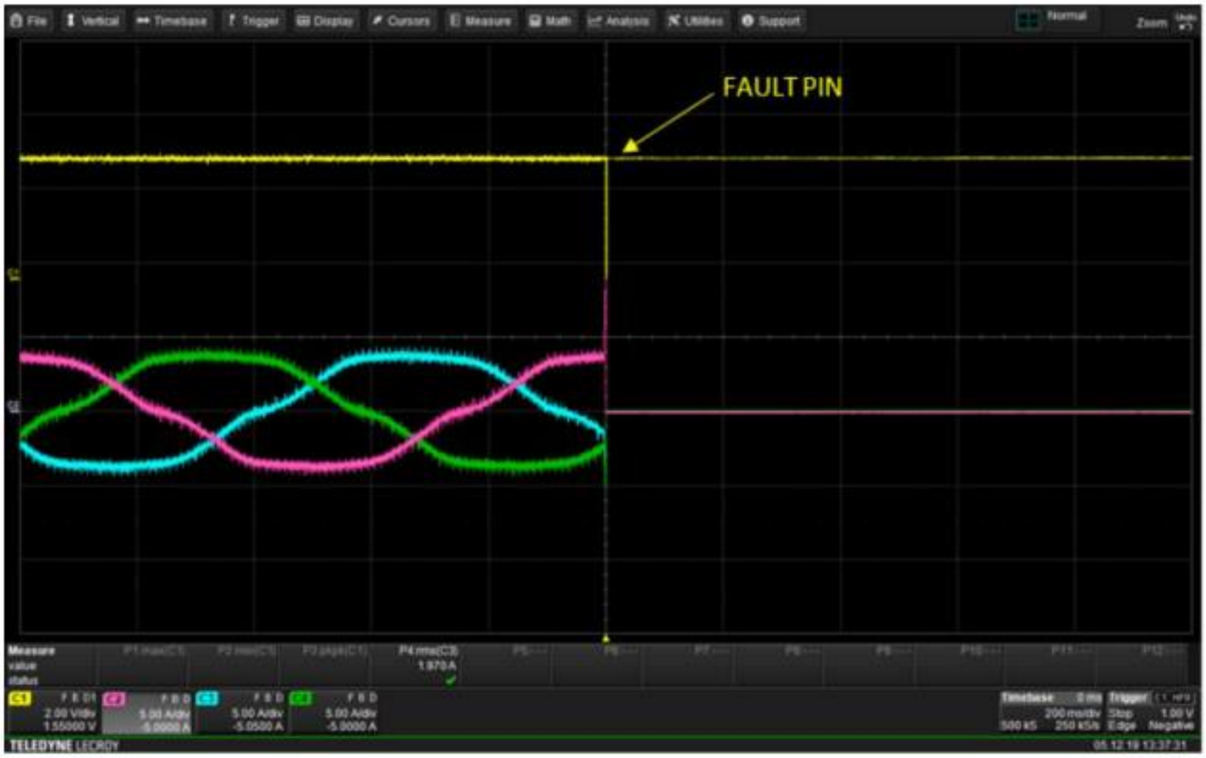

Figure 17. Reaction of Over−current Protection

Figure 18. Reaction of Over−current Protection − Detail

Control Board Headers

Schematic of control board headers can be seen in the Figure 19. The headers have Arduino Due footprint. The applied control board has to contain 3V3 power supply as it is also used for supplying current measurement op amps and comparator for over−current protection. Low pass filters for current and voltage measurement signals are placed closed to the headers (see CON4). When connecting the control board to the PC, do not forget to use isolator.

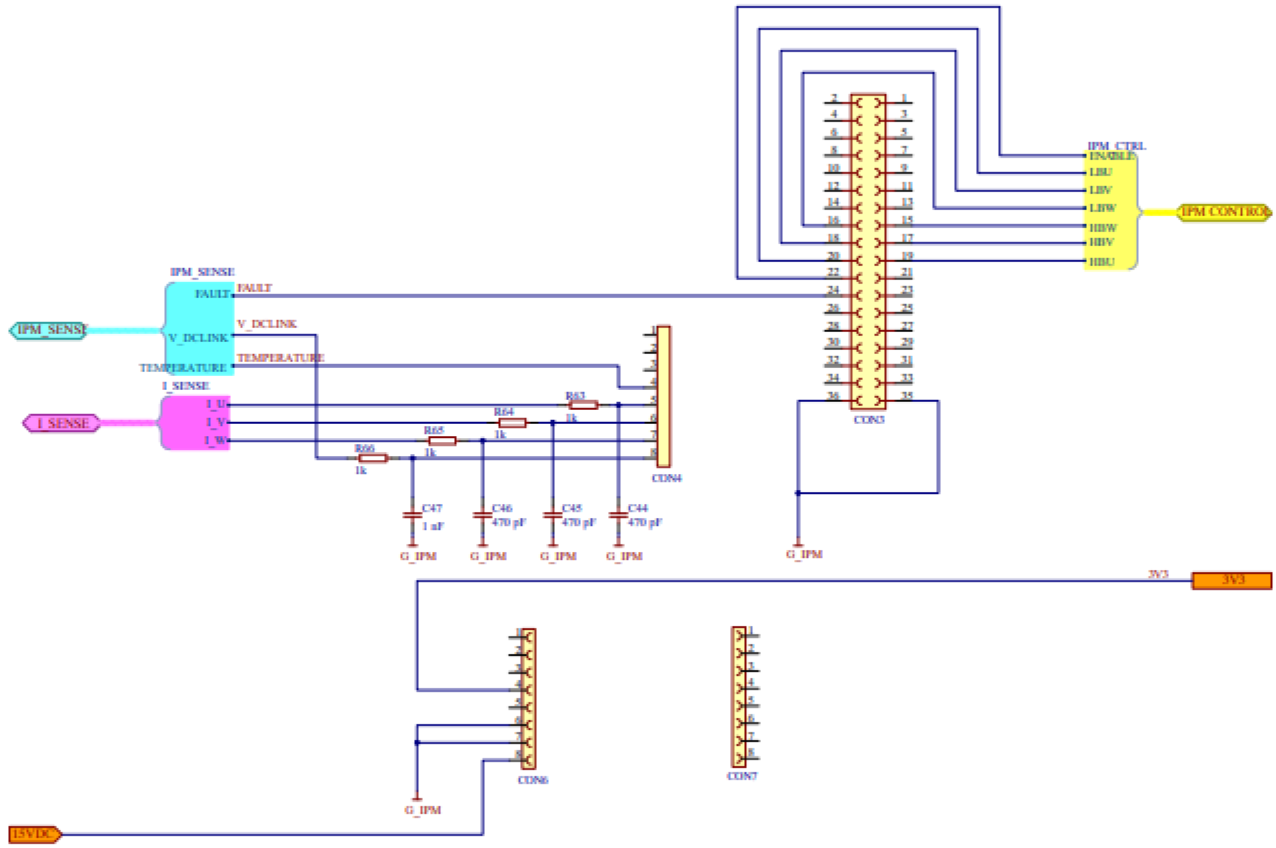

Figure 19. Schematic of Control Board Headers

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.

Electromagnetic Compatibility

Due to the inherent high frequency common mode noise generated by the power switches, it is strongly recommended to install a ferrite clamp on the motor wires. This will prevent disturbing other electronic devices in the vicinity, including the UCB. The recommended CM filter setup is depicted in the picture below.

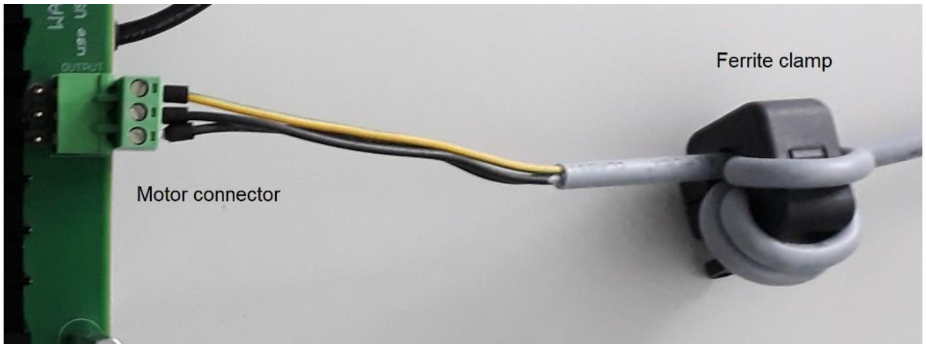

Figure 20. Recommended EMC Filter

USB Isolator

During the communication with control board and PC, using USB isolator is very important because of safety. In the Figure below, it shows the evaluation board with USB isolator (5 kV optical isolation).

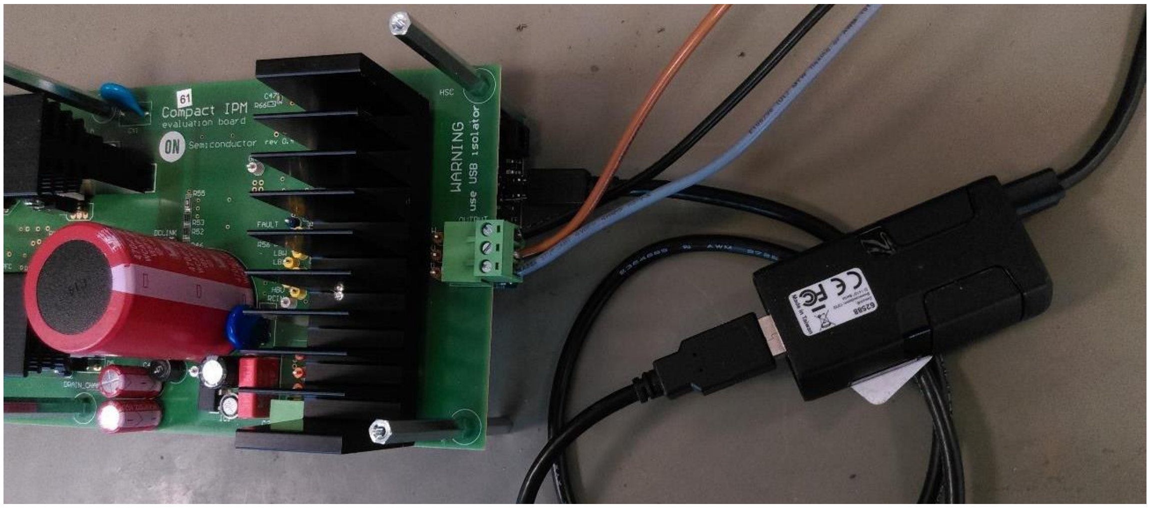

Figure 21. Evaluation Board with Control Board and USB Isolator

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.

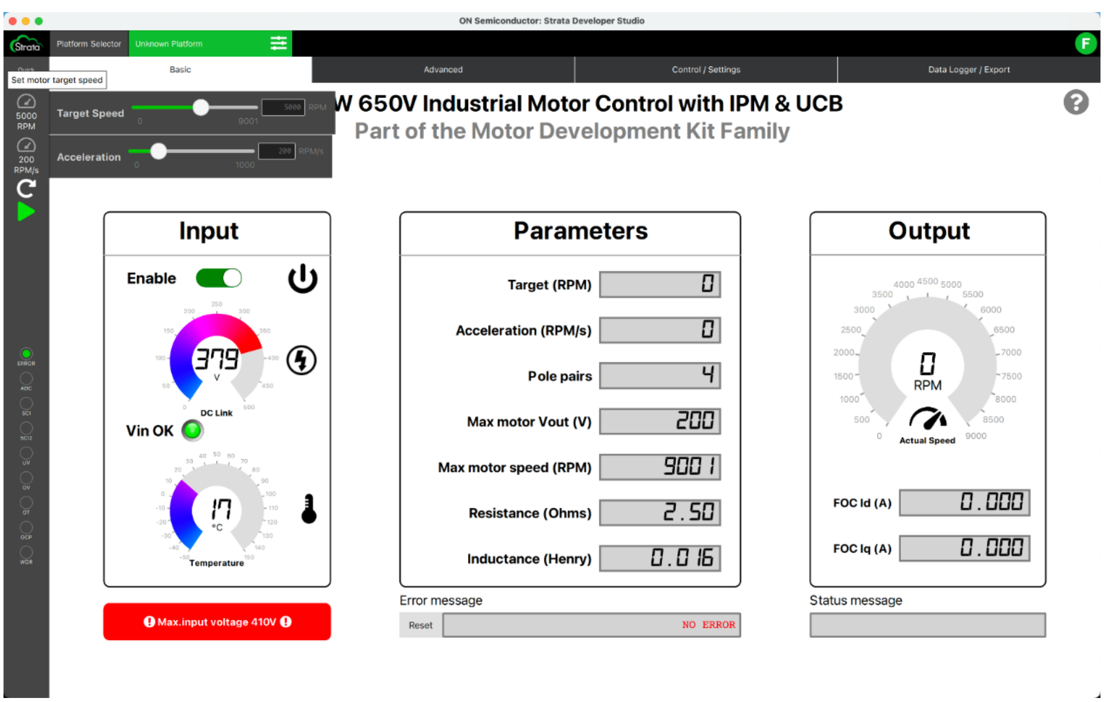

Figure 22. Strata app (User Interface) – Basic View

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.

Figure 23. Strata app (User Interface) – Advanced View

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.

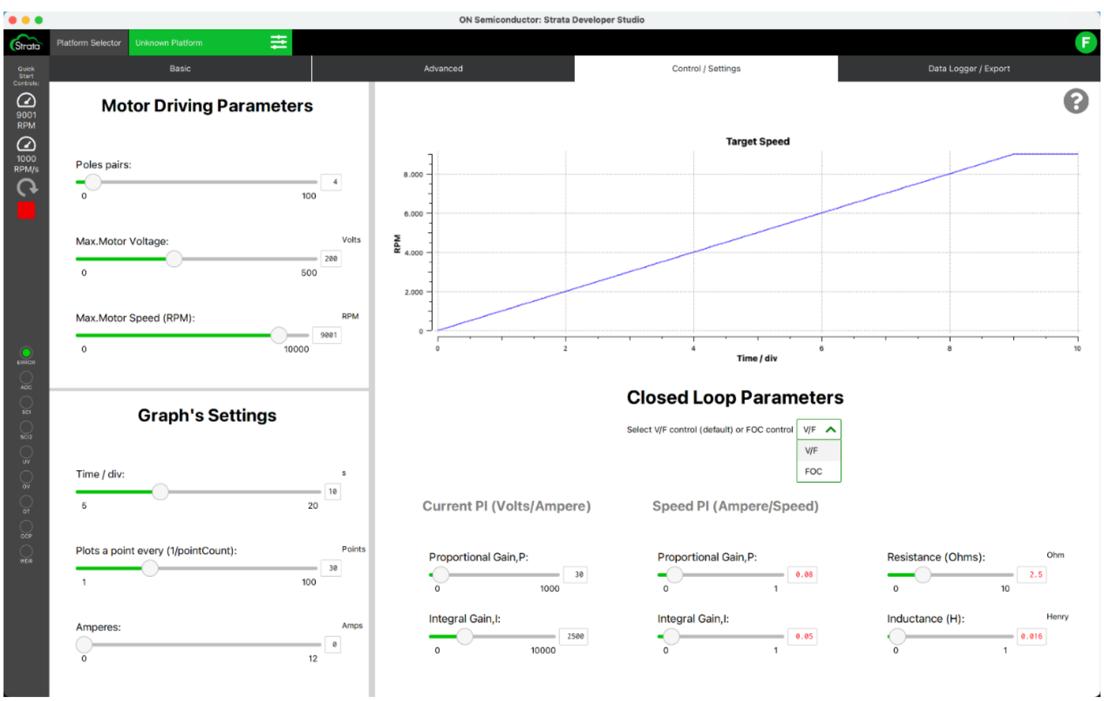

Figure 24. Strata app (User Interface) – Control and Settings

4. <u>Data Logger / Export</u>
   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.

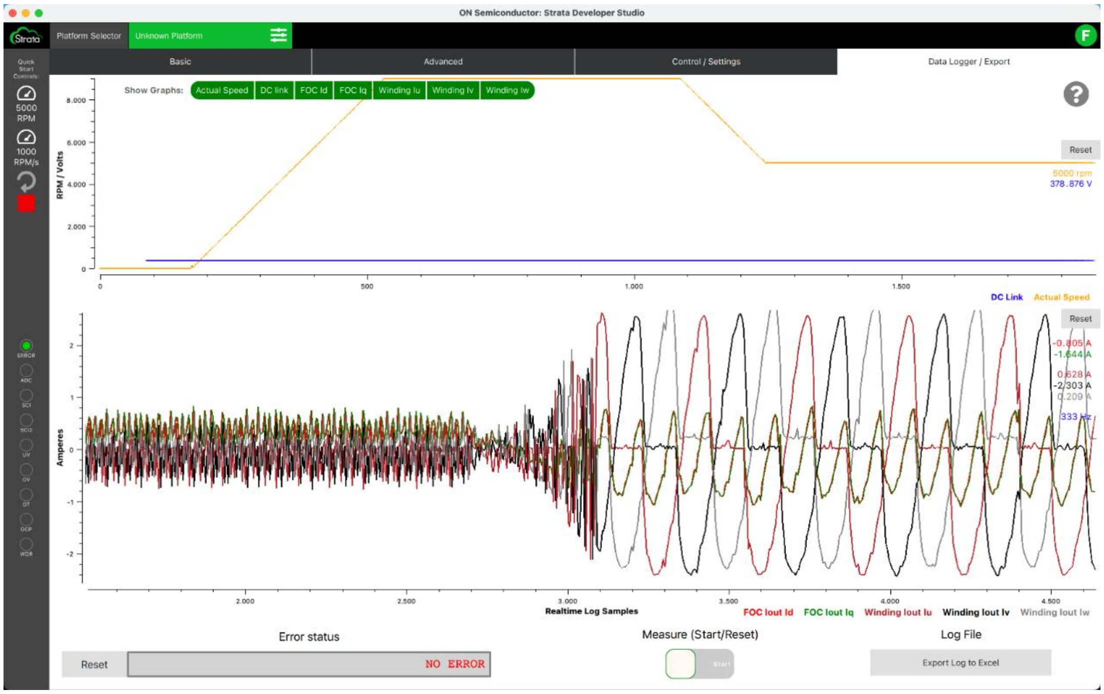

Figure 25. Strata app (User Interface) – Data Logger and Export

REFERENCES

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[11] Boot from flash

[12] Boot-image download link

[13] Strata Developer Studio

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