VFD Motor Control

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CONCEPT OF OPERATIONS

REVISION – 0
15 September 2024

Concept of Operations
for
VFD Motor Controller

Team VFD Motor Control

Approved by:

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Project Leader Date

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0	9/15/2024	VFD Motor Control Team		Draft Release

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1. Executive Summary

The sponsor for this project is in need of a VFD motor controller for an AC induction motor. The VFD will control the speed and torque of the AC motor. This project will help to increase energy efficiency by ensuring that the motor isn't running at a higher speed than necessary. It also makes the system more reliable and sustainable by decreasing mechanical stress.

A Variable Frequency Drive (VFD) is a device that controls the speed of an electric motor by varying the frequency of the delivered voltage. VFDs are useful because they improve the energy efficiency, reliability, safety, stability, and controllability of a motor. The goal of this project is to make a VFD motor controller that will efficiently control the seed and torque of an electric motor.

2. Introduction

2.1 Background

VFD motor controllers have several beneficial functionalities that can improve the quality of a system. A VFD motor controller regulates the speed and torque of electric motors by controlling the frequency and voltage supplied. The speed is controlled by varying the frequency of the supply of electricity. It also allows for more efficient systems. By running at certain speeds, the VFD can reduce the power consumed, allowing for energy to be saved. It also reduces stress on the motor by allowing for soft starting and stopping. The VFD also has a functionality allowing it to shut off the motor if something is shorted, overheating, or overloaded. The VFD will replace a fixed speed motor in a mechanical system.

2.2 Overview

While fixed speed motor controllers are still useful in some applications, more often than not a VFD motor controller is a better alternative. It offers all the functionality of a fixed speed motor controller while also being able to vary the speed and torque of the motor if needed. In this project, our team will work to create a Variable Frequency Drive to control motor speed. In addition, we will consider several different factors such as user interface for the drive, and implementation of the drive in a closed and open loop. This upgrade will improve the energy efficiency, reliability, safety, stability, and controllability of the motor.

2.3 Referenced Documents and Standards

"The Advantages of Frequency Drive Operation in Submersible Pumps." *Grundfos*, www.grundfos.com/us/learn/ecademy/all-courses/the-sp-submersible-pump/the-advantages-of-frequency-drive-operation-in-submersible-pumps. Accessed 15 Sept. 2024.

By, and Dosupply. "What Do VFDS DO in HVAC Systems?: Do Supply Tech Support." *Do Supply Tech Support | Information and Troubleshooting on Allen-Bradley, Eaton, GE Fanuc, and More*, 11 Aug. 2022, www.dosupply.com/tech/2022/08/11/what-do-vfds-do-in-hvac-systems/.

Hoffman, Theresa. "What Are the Benefits of a Variable Frequency Drive?" Wolf Automation,www.wolfautomation.com/blog/what-are-the-benefits-of-a-variable-frequency-drive/. Accessed 15 Sept. 2024.

"Variable Frequency Drive for Conveyor and Material Handling." *Variable Frequency Drive for Conveyor and Material Handling-Darwin Motion*, darwinmotion.com/blogs/variable-frequency-drive-for-conveyor-and-material-handling#:~:text=The%20use%20of%20a%20Variable,belt%20speed%2C%20reducing%20energy%20consumption. Accessed 15 Sept. 2024.

IEEE 519-2014 Standard for Harmonics

3. Operating Concept

3.1 Scope

The VFD motor controller is intended to control the speed and torque of an AC motor by varying the frequency and voltage supplied. This project will use three phase power as the input that will be converted to DC and then transmitted to a microcontroller via optoelectronics and used to power a motor. The microcontroller also will send signals to the DC link, again using optoelectronics, that contain the desired frequency specified by the user on the user interface. This VFD shall be implemented to increase efficiency and save energy.

3.2 Operational Description and Constraints

The VFD motor controller is designed to vary the frequency and voltage supplied to an AC motor to control its speed and torque. It converts a three-phase AC input into DC using a rectifier and transmitting the power using a microcontroller.

- Microcontroller Function
  - The microcontroller is responsible for generating pulse-width modulation (PWM) signals which are used to adjust the frequency and voltage supplied to the motor.
  - The user can set the desired motor speeds via the user interface or the code itself. The microcontroller then ensures that the motor is running according to its specifications.
- Optoelectronics
  - LED lights are used to communicate between the high-voltage power components and the low-voltage microcontroller. This ensures that the signals are safely transmitted.
- User Interface
  - The microcontroller will have a potentiometer that allows the user to change the frequency of the three-phase PWM signal that is being output to the motor.
  - While the PCB is plugged into a computer, opening the output terminal in MPLab will allow the user to view debug statements such as the potentiometer’s value, output duty cycles to phases A, B, and C, sine wave table step size, and desired output frequency of the PWM sine wave.
- Constraints:
  - Sustainability
    - Humidity, dust, and temperatures outside of the specified range can cause the VFD to malfunction.
  - Noise levels
    - The VFD is noise sensitive and is susceptible to external electrical noise, which could decrease the reliability of the system.
  - Power
    - The VFD requires stable three-phase AC power. Spikes or fluctuations could damage some of the system’s components.
  - Mechanical wear and maintenance
    - All parts of the VFD are subject to general mechanical wear and tear over time, especially if operated under high loads or in challenging environments.

- Cost and installation
    - The VFD system can be expensive to produce, especially when considering large-scale applications. Consideration must be given to the specific needs of the project

3.3 System Description

The VFD motor controller is comprised of a DC link (includes a rectifier and DC bus), power controller, microcontroller, and optoelectronics. The DC link converts AC input into DC and minimizes the noise of the DC signal. The power controller controls the voltage. The microcontroller is used to produce PWM signals that will drive the motor. Optoelectronics allows for communication between the high voltage side and the low voltage microcontroller.

This is a four-person project, and the roles are be split into:

- Firmware:
    - Write code in C with MPLab that programs the microcontroller so that it functions with the rest of the VFD system according to desired specifications.
    - Use a potentiometer to allow user to change the frequency of three-phase PWM signal.
    - Debug statements output to terminal to allow user to view different variables as the program is running.
    - Test program on development board to ensure functionality then ensure proper integration with the project's microcontroller.
- Sensors:
    - The first part of the sensors portion includes two optoelectronic circuits. One of those takes digital signals in and directly converts them to analog. The second, being more complicated, takes analog input, then, using an opto-isolator, the circuit converts the input to digital signals to be sent to the microcontroller. The analog side of the project works with very high voltage, while the digital side works with low voltage. Because of this, the two sides cannot be connected or the microcontroller will be overpowered and break, so the optoelectronics send signals and data across using light.
    - The second part of the sensors portion is a constant current and voltage measurement. This will be done using a current sensing resistor, which has a very small resistance, and a simple voltage divider circuit. These measurements will then be sent back to the firmware.
    - Finally, there will be a tachometer that measures the RPMs of the motor that is also sent to the firmware.
- Microcontroller:
    - The MCU is supplied by the 15 VDC from the AC power supply fed by the main power. The voltage will then be stepped down to a usable 3.3V. It receives feedback through low-voltage analog signals that represent voltage and current. The MCU will then send out PWM signals to the H bridge and power control system which are used adjust the output voltage and frequency supplied to the motor.
- Rectifier and DC Link:
    - The rectifier takes in three-phase AC power and converts it into DC power. For each phase, there are parallel diodes acting as a one-way bridge for the current

allowing it to flow in only one direction. To maintain the correct current polarity the diode opens and closes in sequence as the AC waveform alternates. The DC output is then filtered by capacitors within the DC link to provide a stable DC voltage for the microprocessor.

3.4 Modes of Operations

There are three primary modes of operation for the variable frequency drive:

Constant Torque Mode: This mode maintains a constant torque across a diverse range of speeds by adjusting the voltage and frequency.

Variable Torque Mode: This mode varies torque and speed according to the load requirements.

Constant Power Mode: This mode maintains a constant power output and is usually used when the motor operates at higher speeds.

3.5 Users

The potential user for our VFD would be a plant operator or manager. The goal is to have it set up to ensure a seamless installation and programming process for use in a closed or open loop process. It is assumed that a plant operator would know and understand what both a VFD and PID loop are and what they do. There will be several simple controls that the user can change to make the VFD do what they want it to do such as a potentiometer for controlling the frequency of output signals, and a start/stop button.

3.6 Support

We plan to create a manual describing what the VFD does and how to use it. The VFD will support usage, programming, and debugging through MPLab X IDE. It will allow the user to control the motor's on/off function and its speed while showing the user several different variables including the measured motor speed from the tachometer.

4. Scenario(s)

4.1 HVAC

VFDs can be extremely useful in a Heating, Ventilation, and Air Conditioning (HVAC) system. VFDs can act as speed controllers for HVAC motors because they actively adjust the speed rate of those motors based on the building load demands. Without a VFD, an HVAC system will run at full power regardless of whether the system requires full power at that time. By running only as powerful as needed, energy and money are saved. Additionally, a VFD allows an HVAC motor to slowly get up to the full speed which is called a “soft start”. This lessens wear and tear on these HVAC motors, which helps them to last longer and saves money. VFDs can help HVAC systems to control temperature and pressure, among other measurements in a building, they help to save energy and extend the life of HVAC motors.

4.2 Conveyor Belt

In conveyors for production lines, a VFD allows an operator to control the belt's speed to match the production line's needs. This ensures that the belt is not moving too slow to decrease efficiency or too fast to risk injuring employees and consume copious amounts of energy. Wear and tear is also decreased by being able to run the belt at the most appropriate speed as to not overwork the parts or run the belt for too long. The slow start that a VFD can offer helps to reduce wear and tear on the conveyor parts so they can gradually get up to speed. There is the ability to gradually slow down the belt when turning off, which also extends the life of equipment. The VFD increases energy efficiency and reduces maintenance which both save money.

4.3 VFD Pump

VFDs are sought after for submersible pumps for several applications. The main benefit of a VFD in a water pump is the ability to keep a certain parameter constant. VFDs are commonly used in construction sites to keep groundwater at a constant level to build. The VFD does this by adjusting the speed of the motor controlling the water pump. Additionally, VFDs are useful in maintaining constant pressure in a water tank. VFDs are crucial in the operation of water pumps across many different disciplines because their speed control allows for constant parameters in the specified system.

5. Analysis

5.1 Summary of Proposed Improvements

Improvements:

- Extended life of parts: being able to vary frequency and torque help to reduce overloading equipment and, in turn, makes them last longer
- Increased efficiency: instead of a system having to run at a constant speed, a VFD allows the system to run only as fast as needed, which reduces energy consumption, and saves money
- Limits safety risks: having a system run at the proper speed and maintain a safe amount of torque helps decrease the risk of injury

5.2 Disadvantages and Limitations

Disadvantage:

- VFD can damage motor windings and bearings
- Can ruin insulation
- Creates harmonics (potentially interfering with communications and data processing)
- Can be very expensive
- Is prone to overheating if not in a properly ventilated area.
- Can create voltage spikes which could ruin the motor.

5.3 Alternatives

Alternatives to a VFD:

- Eddy Current Drive: induces a magnetic field that is adjustable to control the speed of a motor
- Soft Starters: Soft starters gradually increase the voltage to an AC motor during startup to reduce damage. They provide a more economical choice for applications where torque and speed control are only required during motor startup and stop.
- Cycloconverters: Cycloconverters convert the frequency of AC power from one frequency to another without having to convert to DC and back to AC. They are typically used in applications that require low speeds and high torque. This is a good alternative for when direct frequency conversion is more suitable than VFDs.

5.4 Impact

One environmental impact of a VFD is the ability to lower greenhouse gas emissions. By increasing the motor's energy efficiency through frequency adjustments to match load requirements, VFDs decrease the emissions released during the energy generation process.

A second environmental impact of a VFD is the degradation caused by mining the raw materials. While mining procures the rare metals needed for electronics, it also causes deforestation from the removal of forests, soil erosion from the disruption of the soil structure, and air pollution from the diesel emissions and dust particles generated by the machinery.

Another environmental impact of a VFD is the end-of-life disposal of electronic waste. Disposal of electronics can be challenging and, if done improperly, can contaminate soil and water with toxic metals. Alternatively, VFDs reduce this risk by reducing equipment wear, extending replacement intervals, and reducing disposal frequency.

A social impact of a VFD is the change in employment opportunities. The automation of the VFD reduces the need for operators who manually control the motor speed. Conversely, VFDs generate new roles including engineers who design the systems, miners who extract the raw materials, factory workers who assemble the components, and technicians who handle the maintenance.

Another social impact of a VFD is the safety risks. The VFD's automation of motor control within safe torque limits reduces the risk of accidents or injuries. However, if the VFD is improperly insulated or maintained, high voltages can pose a risk of electrical shock, and insulation breakdowns can pose a risk of short circuits and fire.

One ethical concern of a VFD is supply chain transparency. The raw materials for VFDs are often sourced from mines in countries with varying labor laws. In these mines, workers may face safety risks, including interacting with hazardous chemicals and dangerous machinery. Additionally, these mines should also avoid exploitative practices, including unfair compensation and unreasonable working hours.

A second ethical concern of a VFD is testing sufficiency. Before bringing a VFD to market, it should meet safety standards and demonstrate reliable operation. The testing process should include quality construction to prevent defects, comprehensive testing to identify defects, and clear documentation to resolve defects.

VFD Motor Control

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FUNCTIONAL SYSTEM REQUIREMENTS

REVISION – 0
26 September 2024

Functional System Requirements
for
VFD Motor Control

Prepared by:

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Author Date

Approved by:

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Project Leader Date

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John Lusher, P.E. Date

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T/A Date

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0	9/26/2024	VFD Motor Control Team		Draft Release
1	12/5/2024	VFD Motor Control Team		Reference documents updated

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1. Introduction

1.1. Purpose and Scope

The VFD motor controller is intended to control the speed and torque of an AC motor by varying the frequency and voltage supplied. This project will use three phase power as the input that will be converted to DC and then transmitted to a microcontroller via optoelectronics and used to power a motor. The microcontroller also will send signals to the DC link, again using optoelectronics, that contain the desired frequency. The VFD motor controller will come with a user interface that allows the user to input the frequency needed and start or stop the system as needed. This VFD shall be implemented to increase efficiency and save energy.

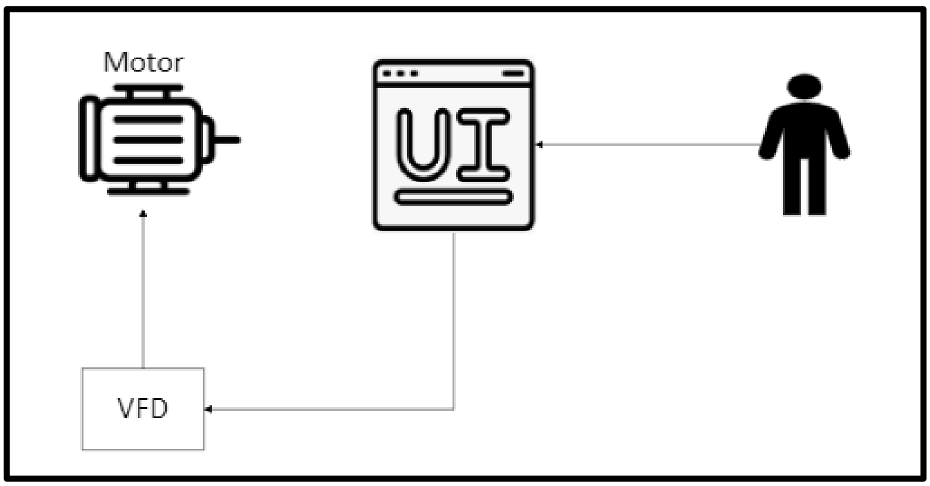

Figure 1: Project Conceptual Image

The following definitions differentiate between requirements and other statements.

Shall: This is the only verb used for the binding requirements.
Should/May: These verbs are used for stating non-mandatory goals.
Will: This verb is used for stating facts or declaration of purpose.

1.2. Responsibility and Change Authority

Briefly describe who has the responsibility for making sure the requirements are met (i.e., team leader) and who has the authority to make the changes (i.e., client and team leader).

Subsystem	**Team Member**

Optoelectronics & Monitoring	Mackenzie Miller
Microcontroller	Andrew Nguyen
Rectifier & DC Link	Aidan Rader (Team Leader)
Firmware	Ryan Regan

Table 1: Subsystem Designations

2. Applicable and Reference Documents

2.1 Applicable Documents

The following documents, of the exact issue and revision shown, form a part of this specification to the extent specified herein:

Document Number	Revision/Release Date	Document Title
IEEE 519-2014	3/27/2014	Standard for Harmonics
NFPA 70 Article 430	08/8/2023	Motors, Motor Circuits and Controllers

Table 2: Applicable Documents

2.2 Reference Documents

The following documents are reference documents utilized in the development of this specification. These documents do not form a part of this specification and are not controlled by their reference herein.

Document Number/ Publisher	Revision/Release Date	Document Title
Microsemi	Revision 0/11-03-2005	DM330030 Datasheet
Microchip Technology	Revision 11/06-2022	dsPIC33CK256MP508 Family Data Sheet
Texas Instruments	Revision 3/05-2016	LM2595 SIMPLE SWITCHER® Power Converter 150-kHz 1-A Step-Down Voltage Regulator datasheet
Skyworks	Revision B/09-2023	Si861x/2x Low-Power, Single- and Dual-Channel Digital Isolator
Infineon	Revision 2019-10-16	Control Integrated POwer System (CIPOS™) IKCM30F60GD
IXYS	Revision 2021	VUE75-06NO7
Mean Well	Revision 10-30-2024	IRM-15 series Datasheet

Table 3: Reference Documents

2.3 Order of Precedence

In the event of a conflict between the text of this specification and an applicable document cited herein, the text of this specification takes precedence without any exceptions.

All specifications, standards, exhibits, drawings or other documents that are invoked as “applicable” in this specification are incorporated as cited. All documents that are referred to within an applicable report are for guidance and information only, except ICDs that have their relevant documents considered to be incorporated as cited.

3. Requirements

3.1 System Definition

The VFD motor controller is comprised of a DC link (includes a rectifier and DC bus), power controller, microcontroller, and optoelectronics. The DC link converts AC input into DC and minimizes the noise of the DC signal. The power controller controls the voltage. The microcontroller is used to produce PWM signals that will drive the motor. Optoelectronics allows for communication between the high voltage side and the low voltage microcontroller.
This is a four-person project split into these roles:

Firmware (Ryan Regan):
Write code in C using MPLab X IDE that programs the microcontroller so that it functions with the rest of the VFD system according to desired specifications. Then, program a potentiometer to allow user to change the frequency of three-phase PWM signal. The firmware will also implement debug statements that output to MPLab's terminal to allow user to view different variables as the program is running. Before integrating with the microcontroller and other subsystems, the firmware will be tested on a development board to ensure functionality. After successful integration, the firmware will be updated to implement programing for tachometer outputs showing the actual (measured) motor speed. This speed will be used to form a feedback PID loop so that the motor can be set to run at a certain speed with minimal influence from outside factors.

Sensors (Mackenzie Miller):
The first part of the sensors portion includes two optoelectronic circuits. One of those takes digital signals in and directly converts them to analog. The second, being more complicated, takes analog input, then, using an opto-isolator, the circuit converts the input to digital signals to be sent to the microcontroller. The analog side of the project works with very high voltage, while the digital side works with low voltage. Because of this, the two sides cannot be connected or the microcontroller will be overpowered and break, so the optoelectronics send signals and data across using light. The second part of the sensors portion is a constant current and voltage measurement. This will be done using a current sensing resistor, which has a very small resistance, and a simple voltage divider circuit. These measurements will then be sent back to the firmware. Finally, there will be a tachometer that measures the RPMs of the motor that is also sent to the firmware.

Microcontroller (Andrew Nguyen):
The MCU is supplied by the 15 VDC from the AC power supply fed by the main power. The voltage will then be stepped down to a usable 3.3V. It receives feedback through low-voltage analog signals that represent voltage and current. The MCU will then send out PWM signals

to the H bridge and power control system which are used to control the inverter stage of the VFD which helps to adjust the output voltage and frequency supplied to the motor.

Rectifier and DC Link (Aidan Rader):
The rectifier takes in three-phase AC power and converts it into DC power. For each phase, there are parallel diodes acting as a one-way bridge for the current allowing it to flow in only one direction. To maintain the correct current polarity the diode opens and closes in sequence as the AC waveform alternates. The DC output is then filtered by capacitors within the DC link to provide a stable DC voltage for the microprocessor.

Figure 2: Block Diagram of System

3.2 Characteristics

3.2.1 Functional / Performance Requirements

3.2.1.1 Speed and Torque Requirement

The 0.25HP VFD motor shall run up to 1800RPM. The torque requirement for this is 73lb-ft of torque.

3.2.1.2 Frequency Requirement

The VFD motor controller shall be able to handle frequencies from 5Hz to 60Hz.
Rationale: American standard frequency for alternating current

3.2.1.3 Temperature Requirement

The VFD motor controller shall be able to operate at temperatures ranging from 0°C to 70°C.
Rationale: Commercial temperature rating standards

Commented [RD1]: update

Commented [RD2]: fix: numbering of characteristics

Commented [RD3]: fix: .25HP and 1800RPM should be 0.729444lb-ft

Commented [RD4]: fix: This is a motor requirement, but we are building a vfd. We need instead the vfd requirement to meet this motor requirement. The vfd requirement would be the voltage needed to run the motor at this motr requirement.

3.2.2 Physical Characteristics

3.2.2.1 TBD

3.2.3 Electrical Characteristics

3.2.3.1 Inputs

The presence or absence of any combination of the input signals in accordance with ICD specifications applied in any sequence shall not damage the VFD motor controller, reduce its life expectancy, or cause any malfunction, either when the unit is powered or when it is not.

No sequence of command shall damage the VFD, reduce its life expectancy, or cause any malfunction.

Rationale: By design, should limit the chance of damage or malfunction by user/technician error.

3.2.3.2 Input Voltage Level

The input voltage level for the VFD shall be three phase 208 VAC.

Rationale: VFD specification, Sponsor

Commented [RD5]: add somewhere: voltage level requirements for each component. i.e. rectifier chip, power control chip, etc.

3.2.3.3 Input Noise and Ripple

The maximum ripple allowed on the dsPIC33CK is 165mV peak to peak.

Rationale: The specifications from the dsPIC33CK datasheet at 3.3V

3.2.3.4 External Commands

The VFD Motor Control Team shall document all external commands in the appropriate ICD.

Rationale: The ICD will capture all interface details from the low level electrical to the high-level packet format.

3.2.3.5 Visual Output

The VFD shall include a Graphical User Interface that displays output measurements.

Rationale: Provides the ability to see the outputs when VFD is running

3.2.3.6 Connectors

The VFD shall use terminal blocks for all power and signal connections to ensure secure and vibration-resistant connections.

Rationale: Noise must be limited to maintain signal integrity

3.2.3.7 Failure Propagation

3.2.3.7.1 Overtemperature Shutdown

The VFD shall have a sensor that automatically shuts the system down if the temperature rises above 70 degrees Celsius.

3.2.3.7.2 TBD

3.2.3.8 Built in Test (BIT)

The VFD shall have an internal subsystem that will generate test signals and evaluate the VFD responses and determine if there is a failure.

Appendix A: Acronyms and Abbreviations

BIT	Built-In Test
CCA	Circuit Card Assembly
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EO/IR	Electro-optical Infrared
FOR	Field of Regard
FOV	Field of View
GPS	Global Positioning System
GUI	Graphical User Interface
Hz	Hertz
ICD	Interface Control Document
kHz	Kilohertz (1,000 Hz)
LCD	Liquid Crystal Display
LED	Light-emitting Diode
mA	Milliamp
MHz	Megahertz (1,000,000 Hz)
MTBF	Mean Time Between Failure
MTTR	Mean Time To Repair
mW	Milliwatt
PCB	Printed Circuit Board
RMS	Root Mean Square
TBD	To Be Determined
TTL	Transistor-Transistor Logic
USB	Universal Serial Bus
VFD	Variable Frequency Drive
VME	VERSA-Module Europe

Appendix B: Definition of Terms

VFD Motor Control

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INTERFACE CONTROL DOCUMENT

REVISION – 0
26 September 2024

INTERFACE CONTROL DOCUMENT

FOR

VFD Motor Control

PREPARED BY:

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Author Date

APPROVED BY:

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Project Leader Date

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John Lusher II, P.E. Date

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T/A Date

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1. Overview

This Interface Control Document (ICD) for the VFD Motor Controller provides an overview of the requirements and specifications for a Variable Frequency Drive that will be used to control a motor and it's speed. Created by Ryan Regan, Andew Nguyen, Mackenzie Miller, and Aiden Rader, this document describes the physical, electrical, thermal, and communication interfaces for the system.

Key Sections:

- Physical Interface: This section depicts the physical aspects of the VFD including weight, dimensions, and physical/spatial requirements.

- Thermal Interface: The VFD includes a thermal monitoring system using the VFO pin and ITRIP pins that will shut the system down if the temperature levels are too high

- Electrical Interface: The electrical specifications include motor power, DC supply voltage, and the microcontroller's stepped-down voltage supply. The DC voltage will be regulated by an H-bridge, and optoelectronic circuits will be used to isolate the microcontroller from the high voltage section of the system.

- User Interface: The VFD's firmware allows the user to control the on/off functionality of the system as well as the speed of the motor. The microcontroller can be plugged into a computer to view other different variables from the system, including tachometer readings that show the motor's actual measured speed.

- Communication Protocols: Optoelectronics will be used for communication between the high-voltage power control and the low-voltage microcontroller. Additionally, the system will use UART for serial communication and will have USB connectivity for programming and debugging.

2. References and Definitions

2.1 Definitions

AC	Alternating Current
DC	Direct Current
GUI	Graphical User Interface
ICD	Interface Control Document
MHz	Megahertz (1,000,000 Hz)
MCU	Micro Controller Unit
mA	Milliamp
mW	Milliwatt
N/A	Not Applicable
TBD	To Be Determined
VFD	Variable Frequency Drive

3. Physical Interface

3.1 Weight

The VFD motor controller may weigh up to 6lbs. The motor itself may weigh up to 13lbs.

3.2 Dimensions

3.2.1 Dimension of Optoelectronics and Feedback

Component	Diameter	Length	Width	Height
Digital Isolator	N/A	0.406”	0.406”	0.104”
Analog to Digital Optoisolator	N/A	0.442”	0.354”	0.158”
Operational Amplifier	N/A	TBD	TBD	TBD
Tachometer Disk	TBD	TBD	TBD	TBD

Table 1: Optoelectronics and Feedback Dimensions

3.2.2 Dimensions of MCU

Component	Diameter	Length	Width	Height
dsPIC33CK	N/A	0.394”	0.394”	0.039”
LM2595s-3.3 Buck Converter	N/A	0.400”	0.180”	0.450”
AC/DC Converter	N/A	TBD	TBD	TBD
20 Pin connector	N/A	TBD	TBD	TBD
Potentiometer	N/A	TBD	TBD	TBD

Table 2: MCU Dimensions

The physical dimensions of the subsystem will be relative to the size of the user’s laptop and the size of the motor, both should not exceed the size of a standard tabletop.

3.2.3 Dimensions of Rectifier & DC Link

Component	Diameter	Length	Width	Height
VUE75-06NO7	N/A	1.850”	1.193”	0.799”
IKCM30F60GD	N/A	1.417”	0.827”	0.201”
Capacitor(s)	N/A	TBD	TBD	TBD
Inductor(s)	N/A	TBD	TBD	TBD

Table 3: Rectifier & DC Link Dimensions

4. Thermal Interface

4.1 Temperature Sensing

The power control shall monitor the temperature via the VFO pin, and if the VFD temperature rises above a safe value, the ITRIP pin will automatically shut the project down to avoid damaging parts.

5. Electrical Interface

5.1 Primary Input Power

The motor being used is 0.25HP producing 186.425W of power. The voltage supplied to the system is 295VDC which is then taken in by the H-bridge to generate a line-to-line voltage of 208V. 15VDC power is supplied to the MCU from the AC/DC power supply fed by the main power. This voltage will be stepped down to 3.3V for the MCU to use.

5.2 Voltage and Current Levels

Component	**Voltage (V)**	**Current (mA)**
dsPIC33CK	3.3V	50mA
IKCM30F60GD	600V	60A

Table 4: Maximum Voltage and Current Values

5.3 Signal Interfaces

Pulse Width Modules will be sent from the microcontroller to the power control of the VFD project using optoelectronic circuitry to ensure the microcontroller does not come into contact with the high voltage in the power control.
Three phase voltage values will be sent to the microprocessor from the power control using optoelectronic circuitry to ensure that the microprocessor does not come into contact with the high voltage in the power control.

5.4 User Control Interface

One feature of the VFD’s microcontroller will be a potentiometer that allows the user to control the frequency of the three phase PWM’s sine wave by increasing the step size that the program uses to step through a sine wave table. Increasing the PWM signal’s frequency will increase the speed of the motor. Another feature of the microcontroller is the start/stop button. This will give the user the option to turn the motor on and off without having to disconnect the system’s power. In addition to the physical user interface, the VFD will display several debug variables from the firmware in MPLab’s X IDE when connected to a computer. Later, a tachometer will be used to measure the actual speed of the motor.

Pin	**Function**
1	PWM1H
2	GPIO
3	PWM1L
4	GPIO
9	MCLR
11,32,50,70	VSS
12,31,51,71	VDD
17,19,22,39,42,44	GPIO
24	GPIO (LED 2)
25	AVDD
26	AVss
34	Clock input
37	GPIO (LED 1)
60	PGD1
61	PGC1
68	UART TX
69	UART RX
75	PWM3H
76	PWM3L
78	PWM2H
80	PWM2L

Table 5**:** Pin interface for DSPIC33CK256MP508 Microcontroller

6. Communications / Device Interface Protocols

6.1 Optoelectronic Communications

The high voltage power control of the VFD will communicate to the low voltage or MCU via optoelectronics, or light to ensure that the MCU is not overpowered by the 208 VAC in the analog power control side.

6.2 Firmware and MCU Communications

The microcontroller is programmed with C code through MPLab's X IDE and will have several firmware implementations such as an on/off button's functionality and a three-phase PWM wave's frequency control.

6.3 Device Peripheral Interface

The MCU will use UART interface for serial communication between devices. This is what will allow a laptop to communicate with the microcontroller through USB connection.

6.4 Host Device

The C code shall be ran on MPLab's X IDE, which should be downloaded on the users computer. This will be used to program the microcontroller and output any debug variables necessary while the system is running.

VFD Motor Control

Mackenzie Miller
Andrew Nguyen
Aidan Rader
Ryan Regan

EXECUTION AND VALIDATION PLAN

REVISION – 0
26 September 2024

Execution Plan

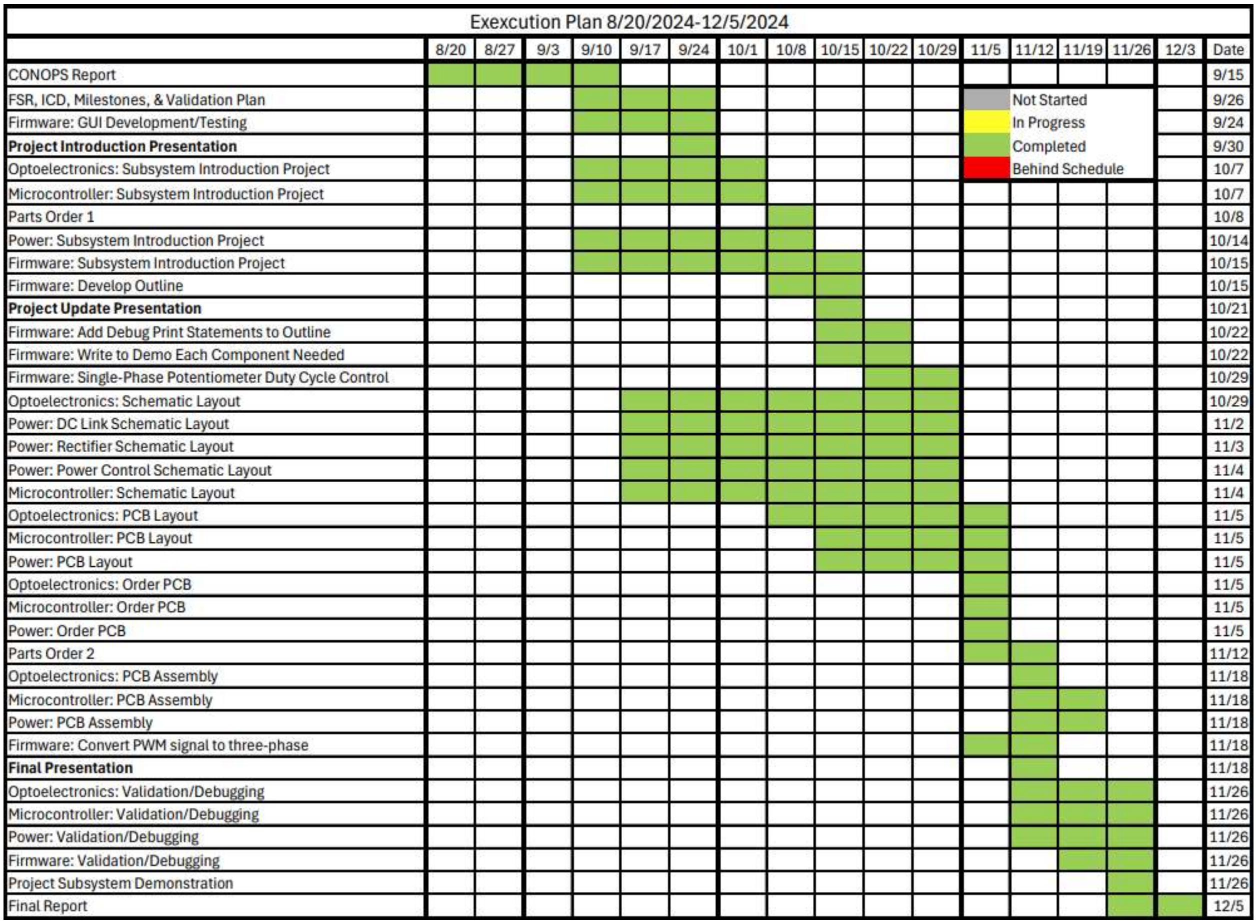

Figure 1: Execution Plan

Validation Plan

Paragraph #	Test Name	Success Criteria	Methodology	Status	Responsible Engineer(s)
3.2.1.1	Speed and Torque Requirement	Motor shall operate within speed range of 0RPM to 1800RPM and torque range of 0lb-ft to 0.729lb-ft.	Input motor with voltage and check if it achieves 0RPM and 0lb-ft . Repeat for 300RPM, 600RPM, 900RPM, 1200RPM, 1500RPM, 1800RPM.	Untested	Andrew, Ryan
3.2.1.2	Frequency Requirement	System shall operate within frequency range of 5Hz to 60Hz.	Input system with frequency generator set to 5Hz and check if the motor runs smoothly. Repeat for 10Hz, 20Hz, 30Hz, 40Hz, 50Hz, 60Hz.	Untested	All
3.2.1.3	Temperature Requirement	System shall operate within temperature range of 0˚C to 70˚C.	Place system in freezer set to 0˚C and check if the motor runs smoothly. Repeat with oven set to 70˚C.	Untested	All
3.2.3.2	Input Voltage Level	System input voltage shall be $208V_{AC}$.	Measure with multimeter and check if the voltage is $208V_{AC}$.	Untested	Aidan
3.2.3.3	Input Noise and Ripple	System shall not exceed ripple range of 0V to 0.165V.	Measure with multimeter and check if the voltage exceeds 0V to 0.165V.	Untested	Andrew

3.2.3.4	External Commands	External commands shall be documented in appropriate ICD.	Show to teaching team and check with them for approval.	Untested	All
3.2.3.5	Visual Output	Oscilloscope displays each of the three phases of the PWM sine wave.	Connect oscilloscope probes to the set output pins for the PWM signals, ensure that the signals' duty cycles span from 0-100% and are rougly separated by thirds.	Tested	Ryan
3.2.3.6	Connectors	System shall use terminal blocks for power and signal connections.	Observe power and signal connections and check if they are are terminal blocks.	Untested	Mackenzie, Andrew, Aidan
3.2.3.7	Overtemperature Shutdown	System shall automatically shut down if sensor exceeds temperature range of 0˚C to 70˚C.	Place sensor in freezer set to -1˚C and check if sensor is triggered. Repeat with oven set to 71˚C.	Untested	Mackenzie
3.2.3.8	Built in Test	System shall generate and evaluate test signals to assess failure status.	Compare generated values with known values and check if the failure statuses match. Repeat for six additional sets of values.	Untested	All
TBD	Inputs	The parameters are within the expected range.	Confirm that all electrical parameters (voltage, current, power) remain within safe and expected ranges under varying conditions.	Untested	All
TBD	Firmware Code Compiles	MPLab firmware successfully compiles without errors or warnings	Attempt to compile code in MPLab and examine output logs to check for errors or warnings	Tested	Ryan
TBD	Controller Performance	Motor spins according to user defined parameters.	Validate that the system operates efficiently and delivers accurate motor control across the expected range of operating conditions.	Untested	All
TBD	MCU Voltage Step Down	MCU converts the voltage it is given to 3.3V.	Measure the voltage of the signals being sent to the MCU and measure that the MCU converts it to 3.3V.	Untested	Mackenzie, Andrew
TBD	Rectifier Full System	System input voltage shall be rectified from $208V_{AC}$ to $295V_{DC}$.	Measure with multimeter and check if the voltage after the rectifier is $295V_{DC}$.	Untested	Aidan
TBD	Rectifier Power Subsystem	System input voltage shall be rectified from $5V_{AC}$ to $7.1\ V_{DC}$.	Input $5V_{AC}$ at differing angles of 120˚ on three waveform generators. Measure with multimeter and check if the voltage after the rectifier is $7.1\ V_{DC}$.	Tested	Aidan
TBD	Isolated 15V Conversion	System shall convert $15V_{DC}$ to isolated $15V_{DC}$.	Input $15V_{DC}$ on a dc power supply. Measure with multimeter and check if the voltage after the converter is $15V_{DC}$.	Tested	Aidan
TBD	Isolated 5V Conversion	System shall convert $3.3V_{DC}$ to isolated $5V_{DC}$.	Input $3.3V_{DC}$ on a dc power supply. Measure with multimeter and check if the voltage after the converter is $5V_{DC}$.	Untested	Aidan
TBD	User Interface	User is able to change the speed of the rotating PWM values by turning the potentiometer.	Change potentiometer position to lowest, highest, and middle notch to observe that the target frequency of the system is close to 60, 10, and 35 respectively, and the rotating PWM values change pace accordingly	Tested	Ryan
TBD	Frequency Testing	Code properly changes the frequency of the PWM signals	Use oscilloscope or a timer to measure the PWM waves to ensure that the program's target frequency is similar to the actual frequency of the PWM signals.	Untested	Ryan
TBD	Debugger connection	The Microcontroller shall be able to properly communicate with Pickit4 debugger	Connect the Pickit4 Debugger to microcontroller PCB using the 5-pin connector and ensure that MPLAB X IDE can recognize the device.	Untested	Andrew

VFD Motor Control

Mackenzie Miller
Andrew Nguyen
Aidan Rader
Ryan Regan

SUBSYSTEM REPORT

REVISION – 0
5 December 2024

SUBSYSTEM REPORT
FOR
VFD Motor Control

PREPARED BY:

Author Date

APPROVED BY:

Project Leader Date

John Lusher, P.E. Date

T/A Date

Change Record

Rev.	Date	Originator	Approvals	Description
0	12/5/2024	VFD Motor Control Team		Draft Release

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1. Introduction

The VFD motor controller is designed to regulate the speed and torque of an AC motor by adjusting the frequency and voltage it receives. This project utilizes three-phase power as the input, which will be converted to DC and transmitted a microcontroller to power the motor. The microcontroller will also send and receive signals, via optoelectronics, to the DC link to deliver the user-specified frequency set through the user interface. The VFD is intended to enhance efficiency and conserve energy.

2. Optoelectronics Subsystem Report

2.1. Subsystem Introduction

The optoelectronics subsystem of the VFD serves as the go between for the microcontroller and the motor and power electronics. The microcontroller and high voltage side cannot come into contact with one another because the microcontroller operates at 3.3V, and the power electronics and motor operate at a maximum of 208 VAC. The optoelectronics help transport voltages from the power control to the microcontroller and PWMs from the microcontroller to the power control.

2.2. Subsystem Details

The power to digital side includes three circuits that convert whatever voltages are received to around 15V so the microcontroller can process them. The first circuit takes the output of the DC rectifier, the second circuit is for the current and voltage monitoring, and the third circuit is for temperature control. These three measurements are essentially transported across an isolation barrier using light via emitters and receivers made into an integrated circuit. Below, in Figure 1, one of the circuits can be seen.

There are also three circuits that take pulse width modules (PWMs) in and transport them across another isolation barrier. The first is the PWM high signal for each of the three phases, the second is the low signal for each phase, and the third takes interrupt signals from the microprocessor and transports them to the power control. This segment is necessary in order to maintain the integrity of separating the power and digital sides. The schematic of this circuit can be seen in below in Figure 2.

There will be a tachometer that is attached directly to the motor, and that is sent to the microcontroller which is to be displayed on the user interface. The tachometer is used to measure the revolutions per minute (RPMs) of the motor.

These circuits are executed on a printed circuit board (PCB). There are a total of seven parts to this PCB design: the three power to digital circuits, the three digital to power circuits, and the tachometer. This yields a very compact PCB with a lot of hardware components.

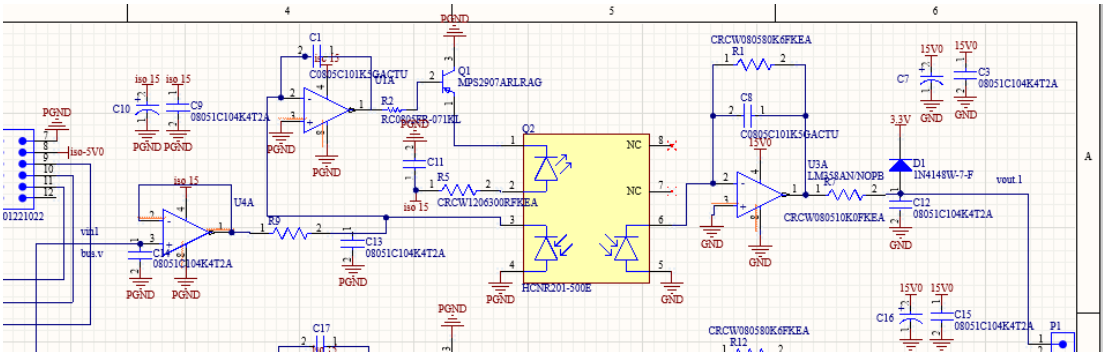

Figure 1: Power to Digital Schematic

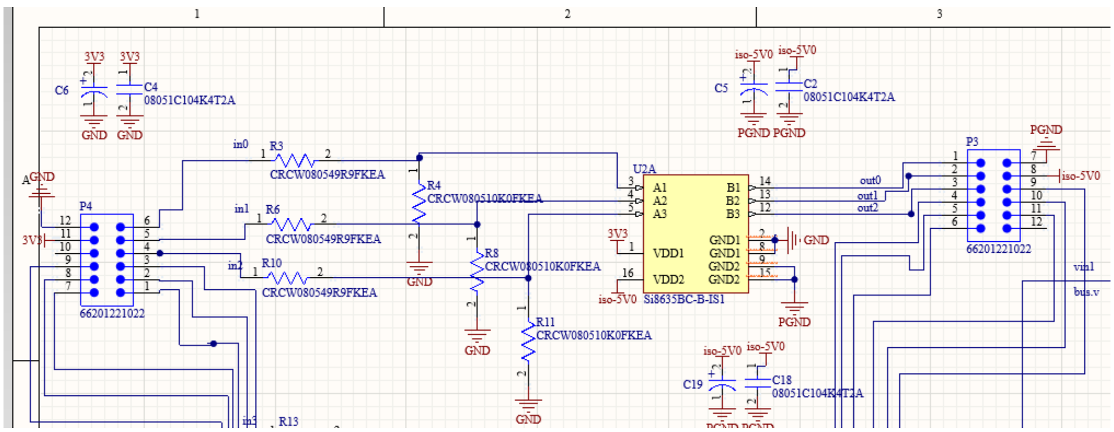

Figure 2: Digital to Power Schematic

2.3. Subsystem Validation

In preliminary testing, it appeared that pin 8 of one of the 8 pin connectors had been damaged either due to solder or another reason. This led the PCB to behave very poorly when powered up since the damaged pin was PGND, the ground of the power side. This connector was removed from the board and switched with an identical connector on the other side that does not use pin 8, and the problem was solved. Additionally, one of the digital isolation packages seems to also be malfunctioning, in that it does not work. The other two packages and circuits work correctly by transporting the voltage across the barrier, but the first one seems to drop all voltage. It is most likely soldered incorrectly or was damaged in the soldering process. For testing purposes, when 5V is supplied to the power circuits, there is around 0.5V on the other side of the isolation barrier. While this could not be tested at full power because of limited equipment at the moment, there is voltage on both sides of the isolation barrier which means that the circuit works. For the digital to power side, again, there is voltage on both sides of the isolation, but the voltage across the isolation IC is zero, meaning that the voltage is being transported via optoelectronics. This indicates that the PCB is designed correctly, and barring a few components that need to be replaced, it works appropriately.

2.4. Subsystem Conclusion

Overall, the circuits work as expected. There will be another PCB designed and assembled in the near future in order to improve the design and replace any broken parts. Another step in the near future is to implement the tachometer onto the motor and plug it into the PCB once the motor becomes available to use.

3. Microcontroller Subsystem Report

3.1. Subsystem Introduction

This subsystem refers to the hardware of the microcontroller portion of the VFD motor controller. In order for the firmware to control the motor, the microcontroller must be implemented properly. This subsystem is powered by two of the three phase AC power supply which is sent to the MCU for functionality.

3.2. Subsystem Details

The DSPIC33CK256MP508 microcontroller was selected for this project. It has an adequate amount of analog and digital pins to support the VFD motor and the required PWM signals necessary. This MCU has 80 pins however only 32 are needed for this application. The MCU is supplied by the 15 VDC from the AC power supply fed by the main power. The voltage will then be stepped down to a usable 3.3V using a 3.3V fixed buck converter. The buck converter takes the 15V from the AC/DC converter to a usable voltage for the microcontroller. This 3.3V is needed for the microcontroller along with the Pickit4 debugger and the UART serial interfaces.

The MCU subsystem receives feedback through low-voltage analog signals representing voltage and current. The MCU then sends out PWM signals to the H bridge and power control system which are used to control the inverter stage of the VFD which helps to adjust the output voltage and frequency supplied to the motor.

The hardware necessary for the application is placed onto a PCB and the firmware will be coded onto the MCU to control the PWM signals. A potentiometer is included to vary the frequency of these PWM signals. A push button will also be used to turn the motor on and off which is indicated by a green LED. A 5 pin connector is used to connect to the Pickit4 debugger which is used to code onto the MCU. A 3 pin connector is used for UART serial communication using a cable to connect to a PC. Finally, a 20 pin connector is used to send the PWM signals back to the H bridge and to connect to the GPIO pins. This PCB will later be connected to the power and optoelectronics subsystems.

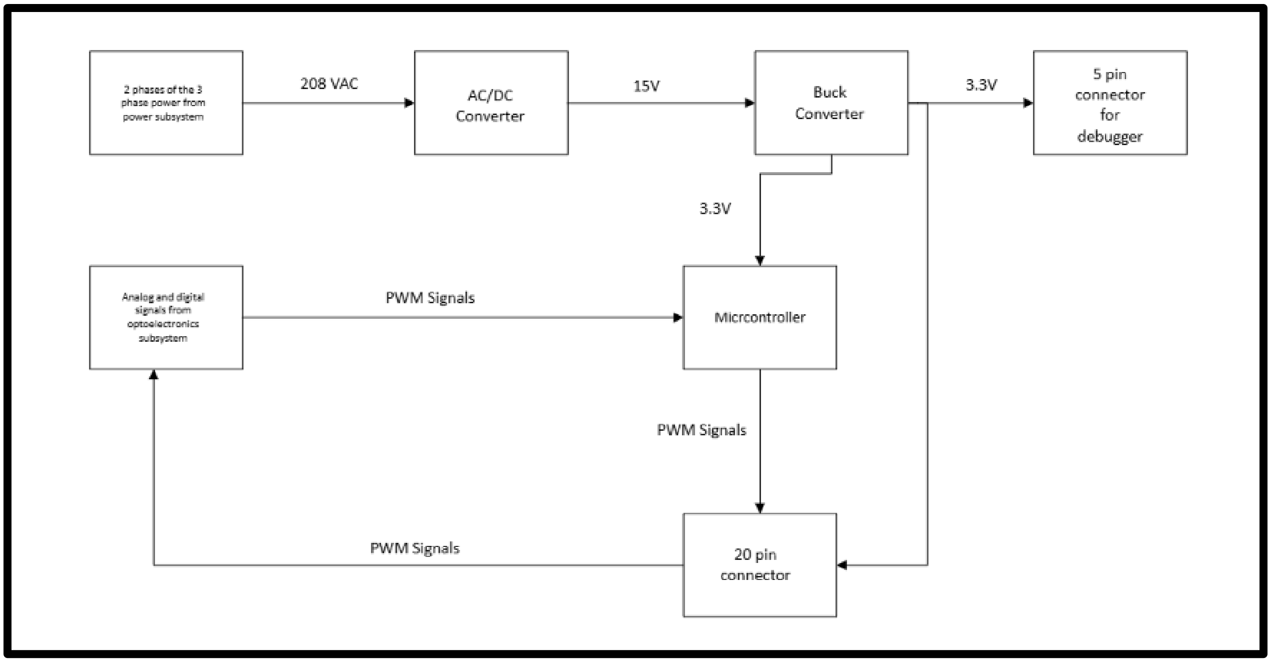

Figure 3: Block diagram of the microcontroller subsystem

Pin	Function
1	PWM1H
2	GPIO
3	PWM1L
4	GPIO
9	MCLR
11,32,50,70	VSS
12,31,51,71	VDD
17,19,22,39,42,44	GPIO
24	GPIO (LED 2)
25	AVDD
26	AVss
34	Clock input
37	GPIO (LED 1)
60	PGD1

61	PGC1
68	UART TX
69	UART RX
75	PWM3H
76	PWM3L
78	PWM2H
80	PWM2L

Table **1***: Pin interface for DSPIC33CK256MP508 Microcontroller*

3.3. Subsystem Validation

The microcontroller subsystem was validated to meet all the requirements. The process for validation went as follows: the buck converter was tested by applying 15V using a DC supply and running it through to the MCU to ensure that the proper 3.3V was powering the PCB board. A code was also to be tested to ensure that the MCU was responding correctly to the GPIO pins using MPLAB X IDE. The results of the validation is as follows: the 3.3V was not properly sent to the MCU, a probable reason for this is an error that was found in the schematic which ultimately led to improper routing. The buck converter did step down the voltage but not to the 3.3V as intended. This also prohibited the use of the Pickit4 debugger as it needs the 3.3V to operate. However, the curiosity board – which also uses the DSPIC33CK256MP508 MCU – was used to test the code and it was able to function properly and respond to the correct GPIO pins.

3.4. Subsystem Conclusion

The buck converter portion of the subsystem was not functioning properly, leading to problems interfacing with the microcontroller. The correct pins are used on the microcontroller and were able to be confirmed using the curiosity board which uses the same microcontroller. Going forward, before the next semester, the schematic and PCB routing will need to be updated. The buck converter portion will need to be fixed, and the rest will be checked as well to ensure the same mistake does not occur again. A new PCB board will need to be printed and rebuilt to continue and have a fully functioning subsystem for integration.

4. Power Electronics Subsystem Report

4.1. Subsystem Introduction

The power subsystem of the VFD motor control is responsible for supplying power to both an AC induction motor and the entire system. It is designed to operate with 208 V_{AC} three-phase power and has been tested to ensure safe and reliable performance. The following sections present an analysis of the subsystem's operation and validation.

4.2. Subsystem Validation

4.2.1. Rectifier and DC Link Validation

A rectifier converts AC to DC, while a DC link filters the output. In Figure 4, the rectifier schematic is shown. First, a power input connector receives the desired three-phase power. Next, a set of capacitors in parallel with varistors is connected across each phase. The capacitors filter the voltage to reduce noise, and the varistors provide protection against voltage surges. Finally, a full-wave rectifier converts the AC to DC.

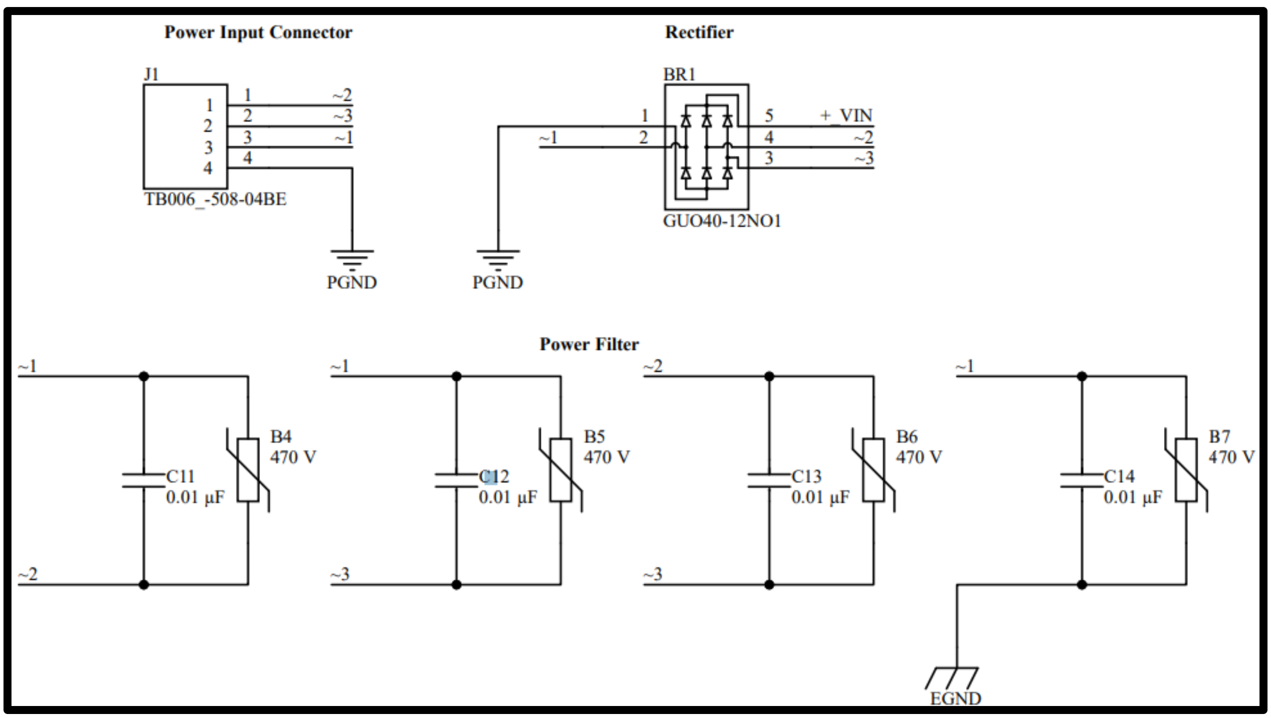

Figure 4: Rectifier Schematic

In Figure 5, the dc link schematic is shown. First, a fuse provides protection against overcurrent. Next, a varistor in parallel with a set of capacitors is connected to ground. The varistor provides protection against voltage surges, and the capacitors filter the voltage to reduce noise.

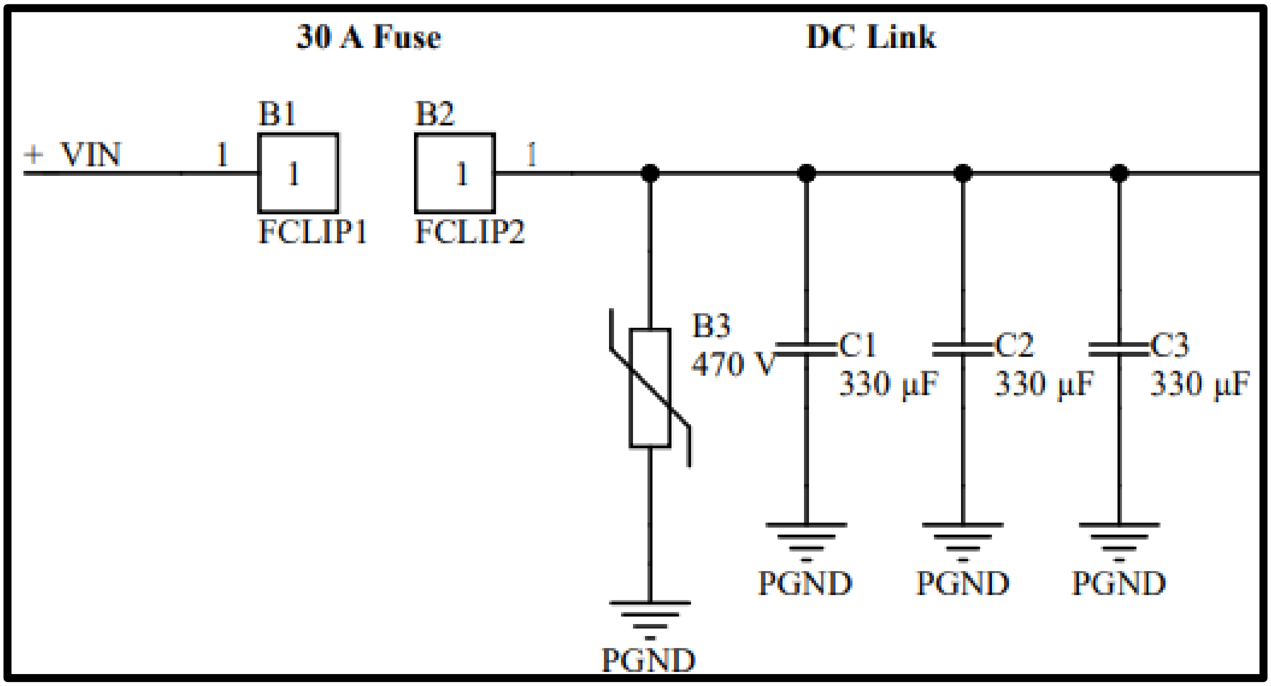

Figure 5: DC Link Schematic

The rectifier and DC link were validated by supplying an input AC voltage and measuring the output DC voltage, as shown in Figure 6. While the integrated system is designed to operate at 208 V_{AC}, the validation testing was conducted at 10 V_{AC}. The three-phase AC was generated using three waveform generators, with phase A and phase B values in Figure 7 and phase C values in Figure 8. An amplitude of 3.536 V_{rms} was used to produce the desired voltage. Additionally, each phase was offset by 120˚ to simulate a three-phase system, with phase C further adjusted due to the waveform generators not being synchronized.

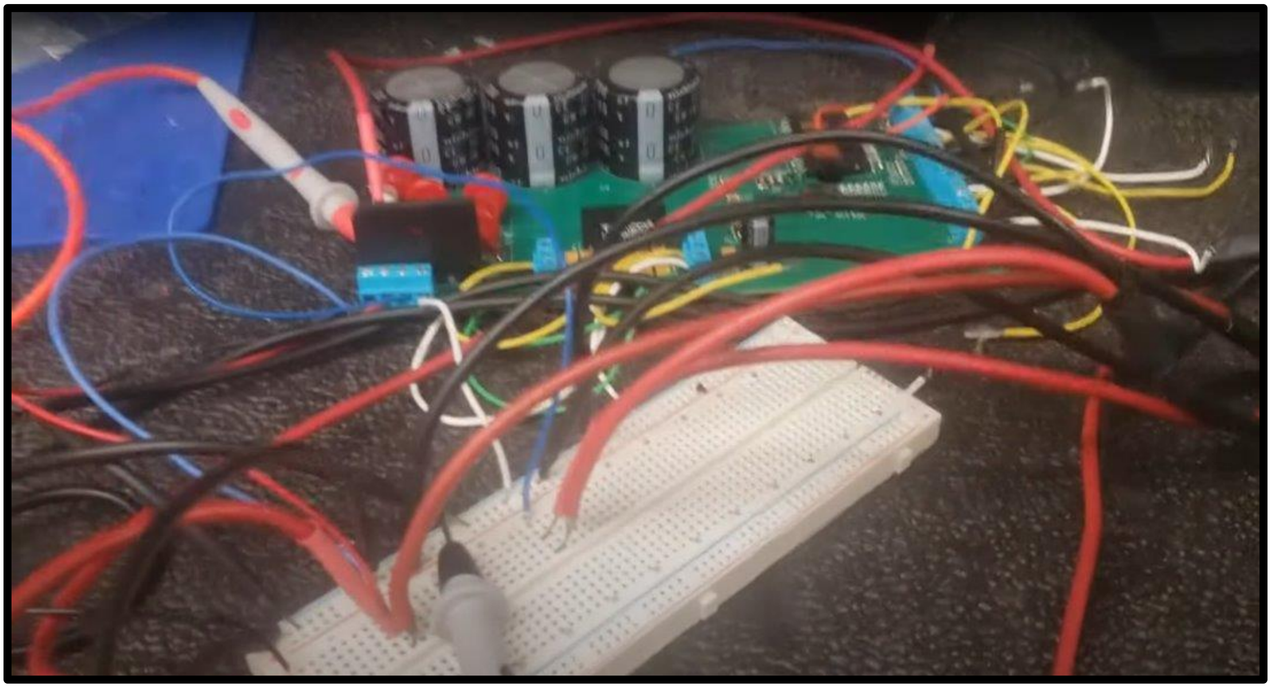

Figure 6: Rectifier and DC Link Circuit

Figure 7: Input Phase A and Phase B

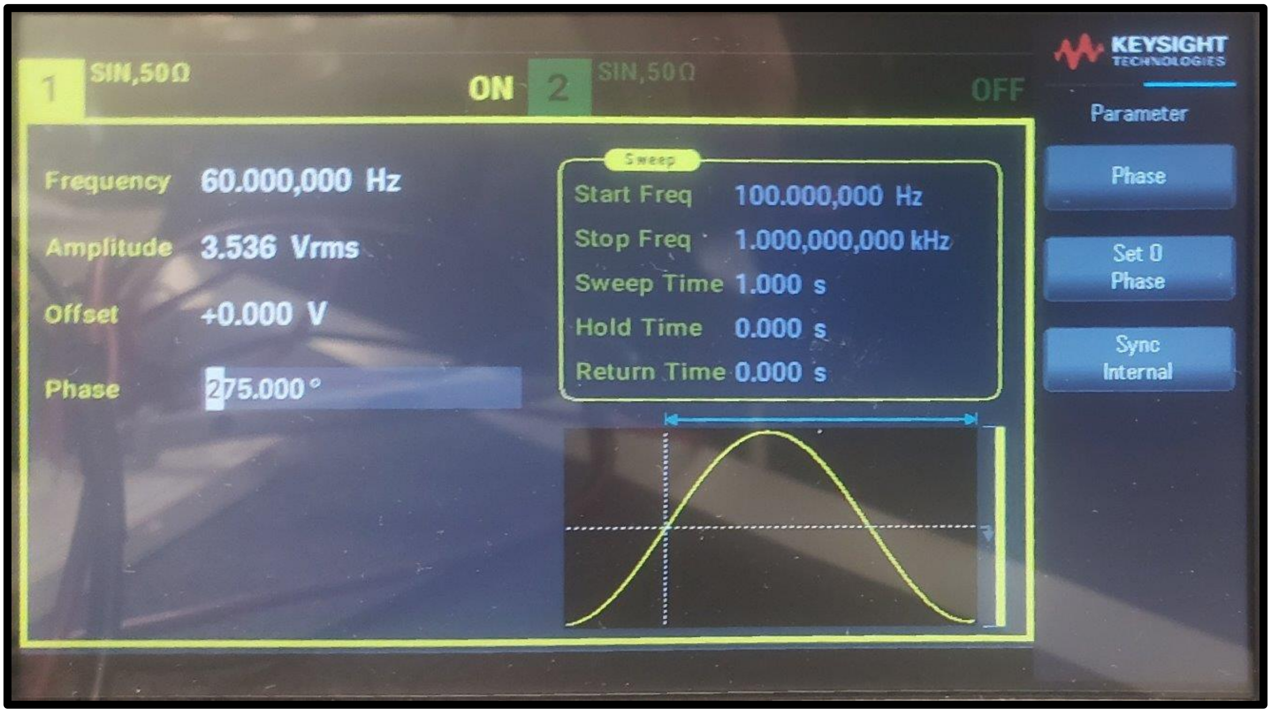

Figure 8: Input Phase C

Upon measuring the input AC waveforms shown in Figure 9, the green (phase A), blue (phase B), and purple (phase C) sinusoidal waves demonstrate a phase shift of 120 degrees and an amplitude of 10 VAC. Furthermore, the measured DC output is 9.6 VDC with 600 mV of noise. This differs slightly from the expected output of 12 VDC .This discrepancy can be attributed to the forward voltage drop across the rectifier diodes and losses within the rectifier and DC link circuitry. Despite these factors, the measured value remains within an acceptable range for the system's operation.

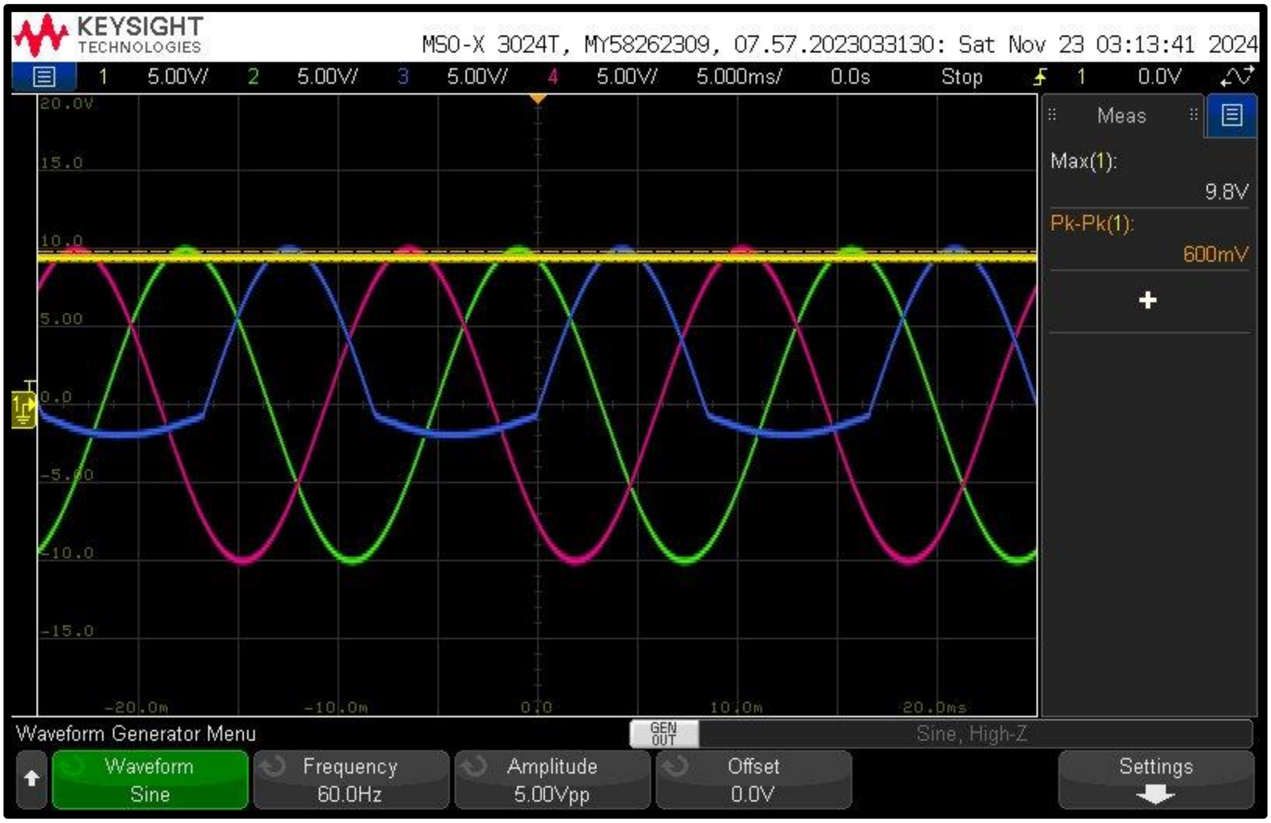

Figure 9: Input Phase A, Phase B, Phase C; Output DC

4.2.2. Power Control Validation

The power control takes an input of DC voltage from the DC Link and, based on the incoming PWM signals from the microcontroller, inverts the DC voltage into the appropriate AC voltage to power the motor.

Unfortunately, the only control was short-circuited without enough time for a new unit to be delivered, and thus this portion of the validation is not complete. The validation would consist of applying an input dc voltage and PWM signals and measuring an output waveform. In Figure 10, the circuit is shown, and in Figure 11, the output waveforms are shown to be approximately zero, aligning with the chip not working. In Figure 12, the high and low PWM signals for a single phase were generated for full validation. Furthermore, Figure 13, is the measured input power supply voltages show the power flow of current through the circuitry surrounding the power control and that the only short circuit is the power control itself.

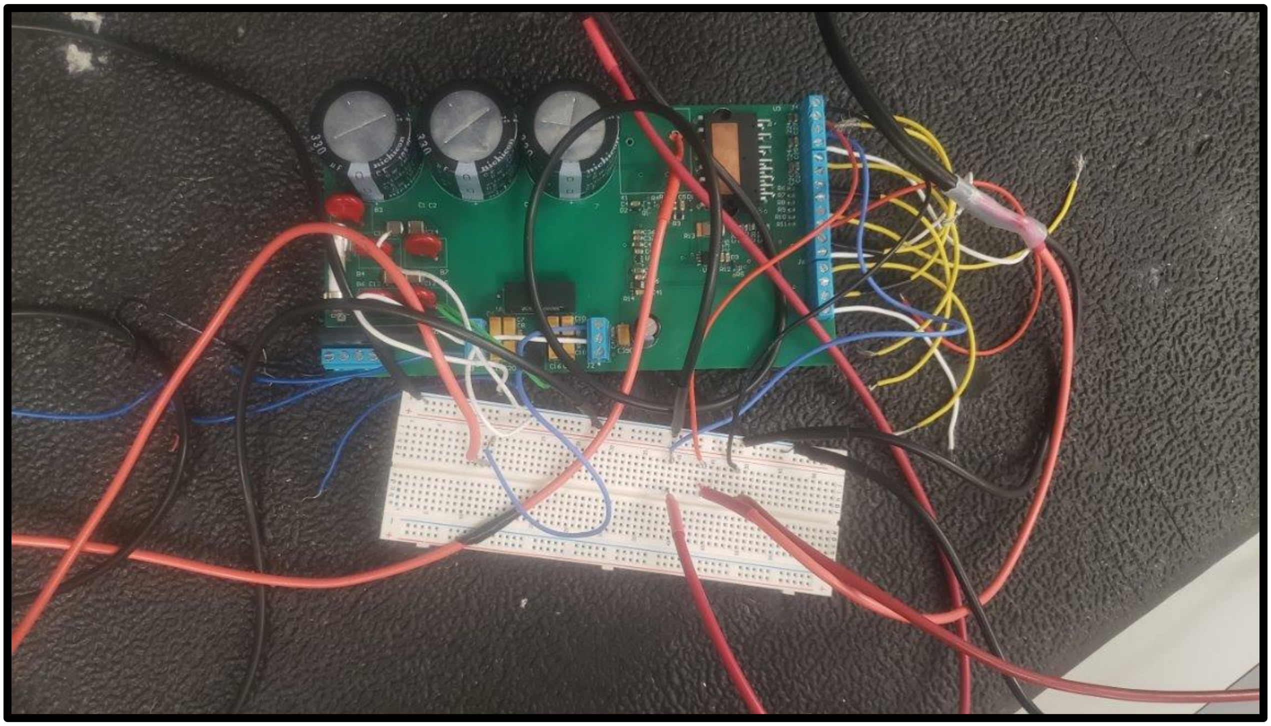

Figure 10: Power Control Circuit

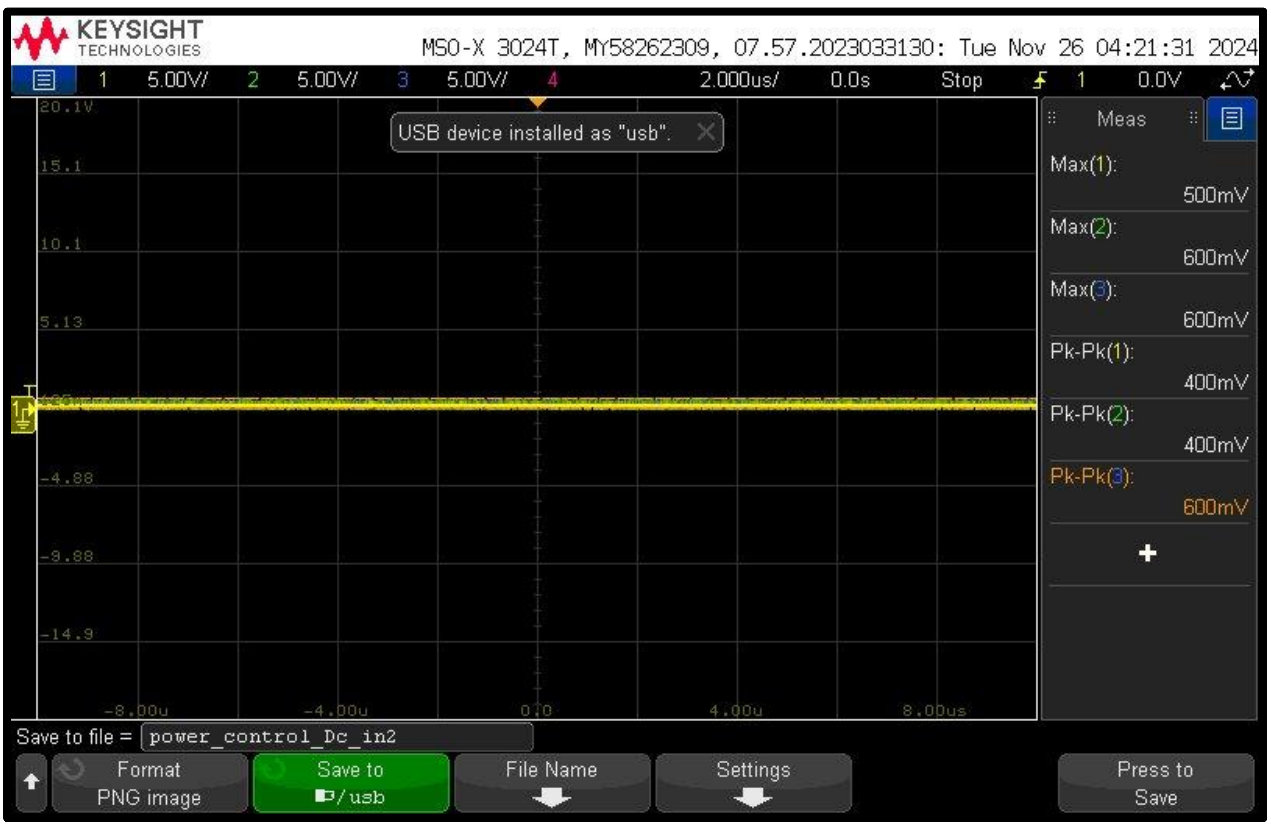

Figure 11: Power Control Output

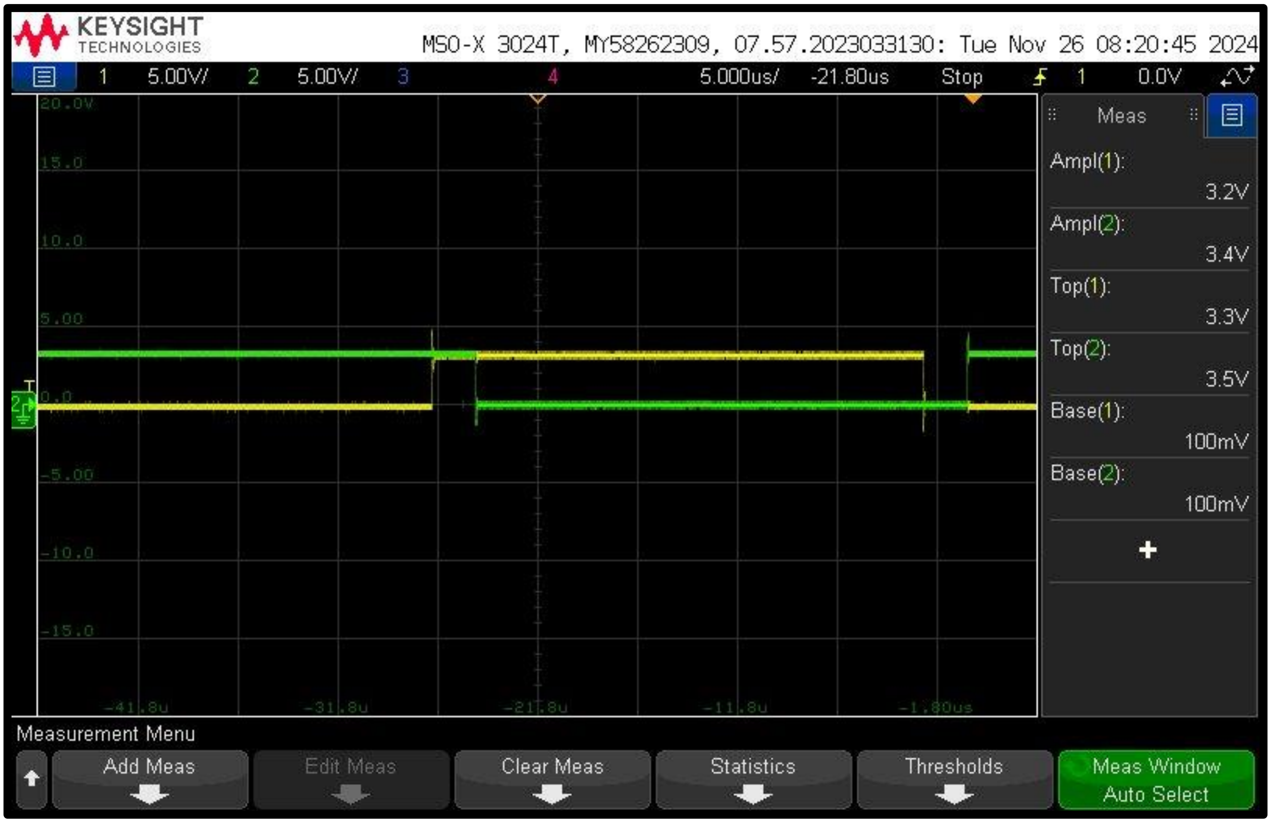

Figure 12: Single Phase PWM Signals

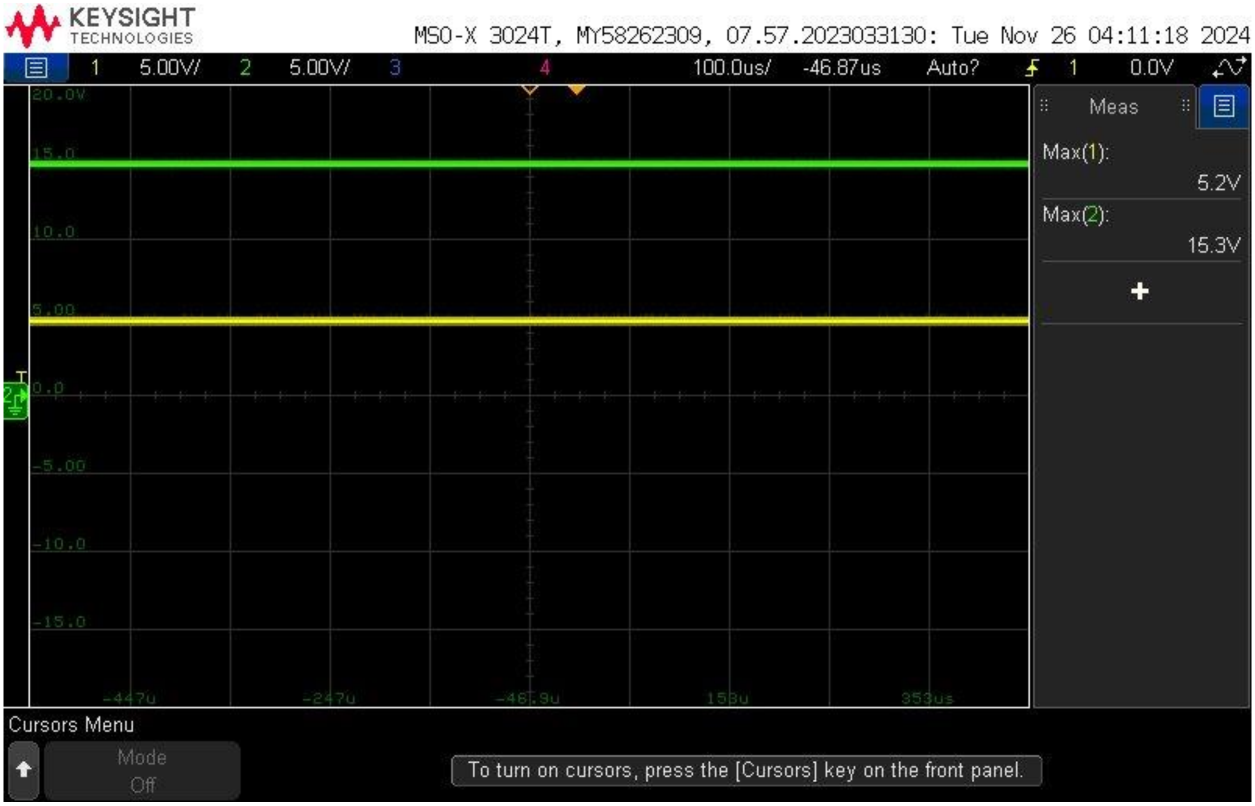

Figure 13: Input Voltage Power Control

4.2.3. 3.3 V to Iso-5 V Power Converter Validation

The 3.3 V to Iso-5 V power converter converts 3.3 V_{DC} to isolated 5 V_{DC}. In Figure 14, the 3.3V/ISO_5V converter schematic is shown. First, an input connector receives the input 3.3 V. Next, a set of capacitors in parallel is connected to ground to filter the voltage and reduce noise. Then, a power converter steps up and isolates the 3.3 V to 5 V. Finally, another set of capacitors in parallel is connected to ground to filter the voltage and reduce noise.

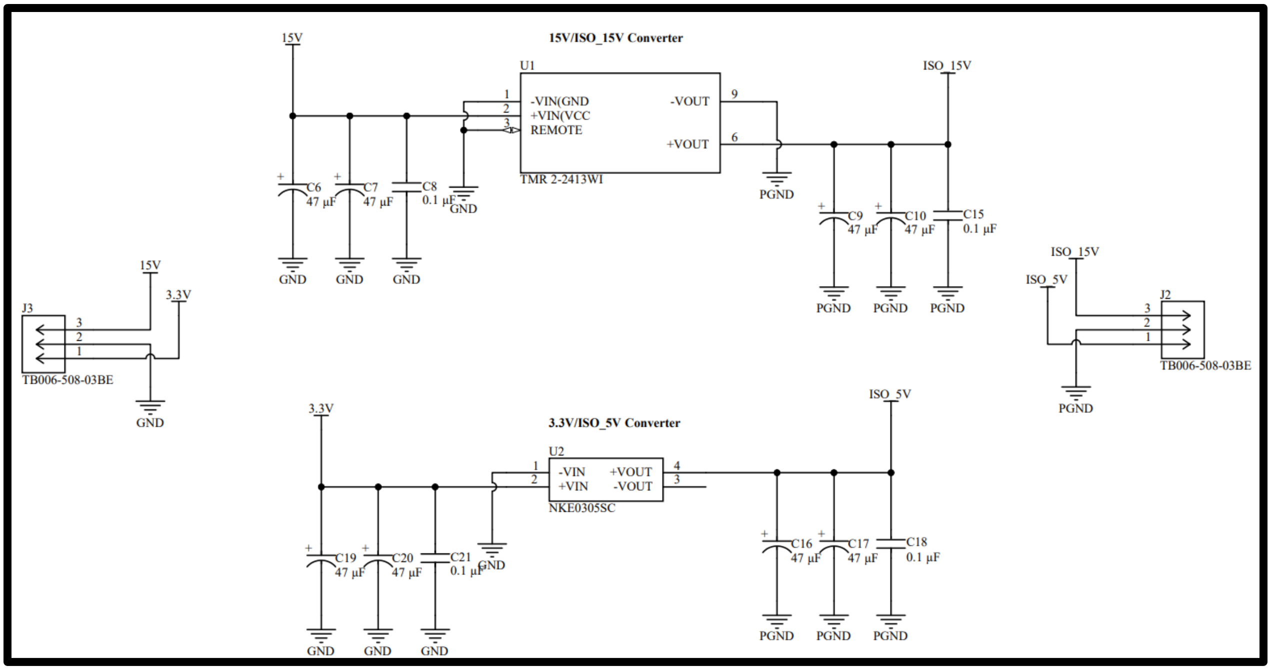

Figure 14: 3.3V/ISO_5V Converter and 15V/ISO_5V Converter Schematics

The 3.3 V to Iso-5V power converter was validated by supplying an input voltage and measuring the output voltage, as shown in Figure 15. The validation testing was conducted at the operating voltage of 3.3 V and was generated using a DC power supply with the values in Figure 16. The amperage of 0.04 A was used per the average operating current in the datasheet.

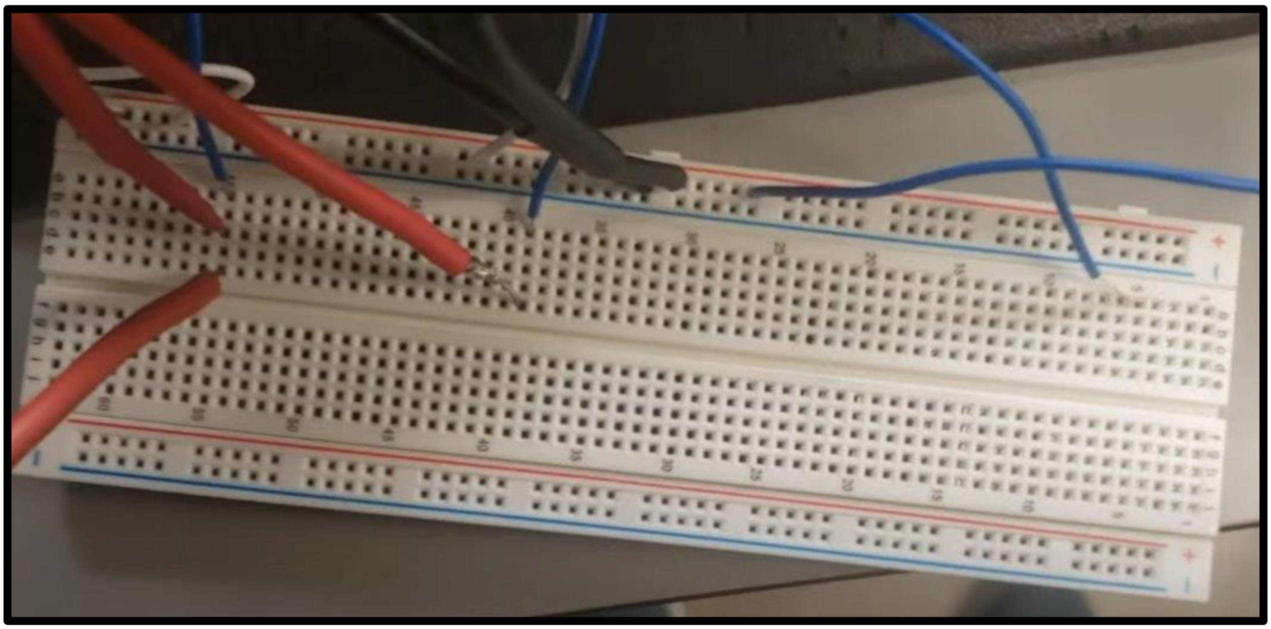

Figure 15: 3.3V/ISO_5V Converter Circuit

Figure 16: Input 3.3 V

Upon measuring the input 3.3V shown in Figure 17, the green horizontal line shows an amplitude of 3.2 V with 400 mV of noise. Furthermore, the measured output is 200 mV with 400 mV of noise. This differs greatly from the expected output of 5 V. This discrepancy can be attributed to a missing trace between the converter pin 3 and ground.

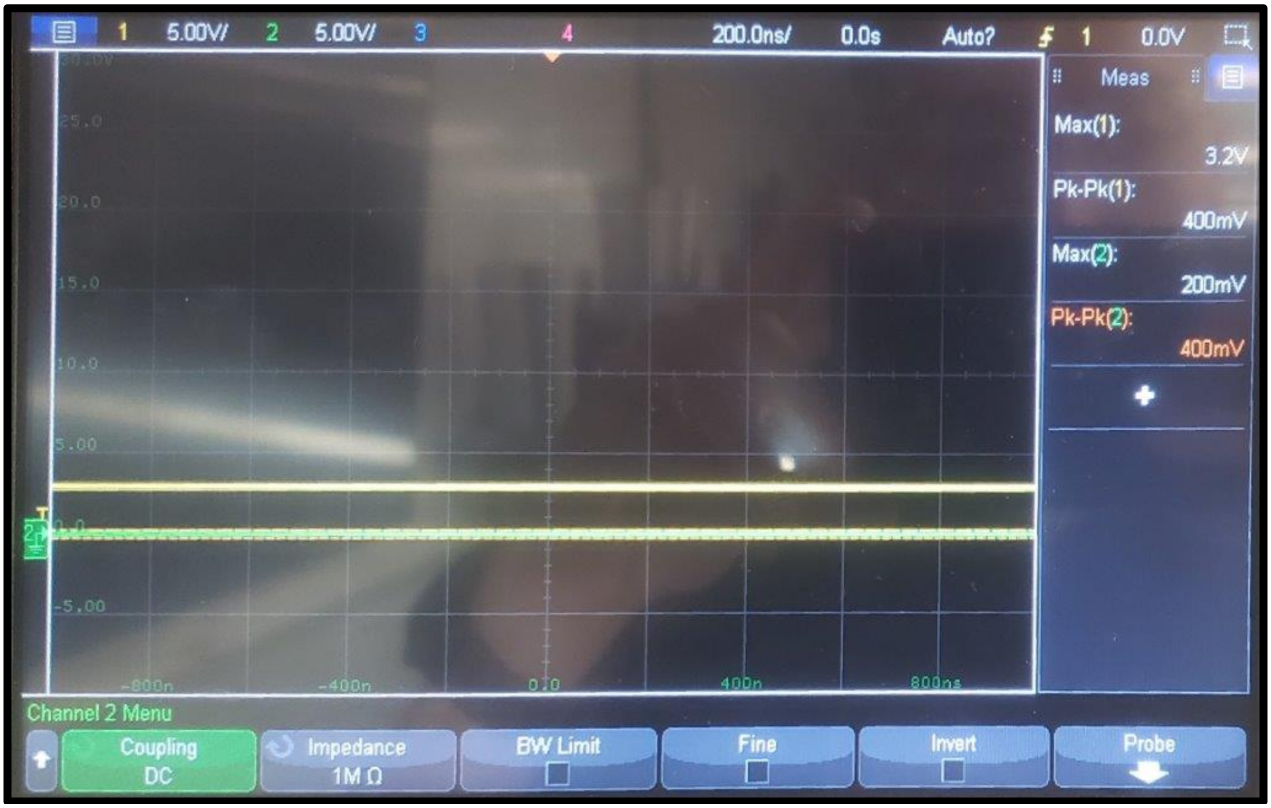

Figure 17: Input 3.3 V, Output Iso 5 V

4.2.4. 15 V to Iso-15 V Power Converter Validation

The 15 V to Iso-15 V power converter converts 15 V_{DC} to isolated 15 V_{DC}. In Figure 15, the 15V/ISO_5V converter schematic is shown. First, an input connector receives the input 15 V. Next, a set of capacitors in parallel is connected to ground to filter the voltage and reduce noise. Then, a power converter steps up and isolates the 15 V to 15 V. Finally, another set of capacitors in parallel is connected to ground to filter the voltage and reduce noise.

The 15 V to Iso-5 V power converter was validated by supplying an input voltage and measuring the output voltage, as shown in Figure 18. The validation testing was conducted at the operating voltage of 15 V and was generated using a DC power supply with the values in Figure 19. The amperage of 0.11 A was used per the average operating current in the datasheet.

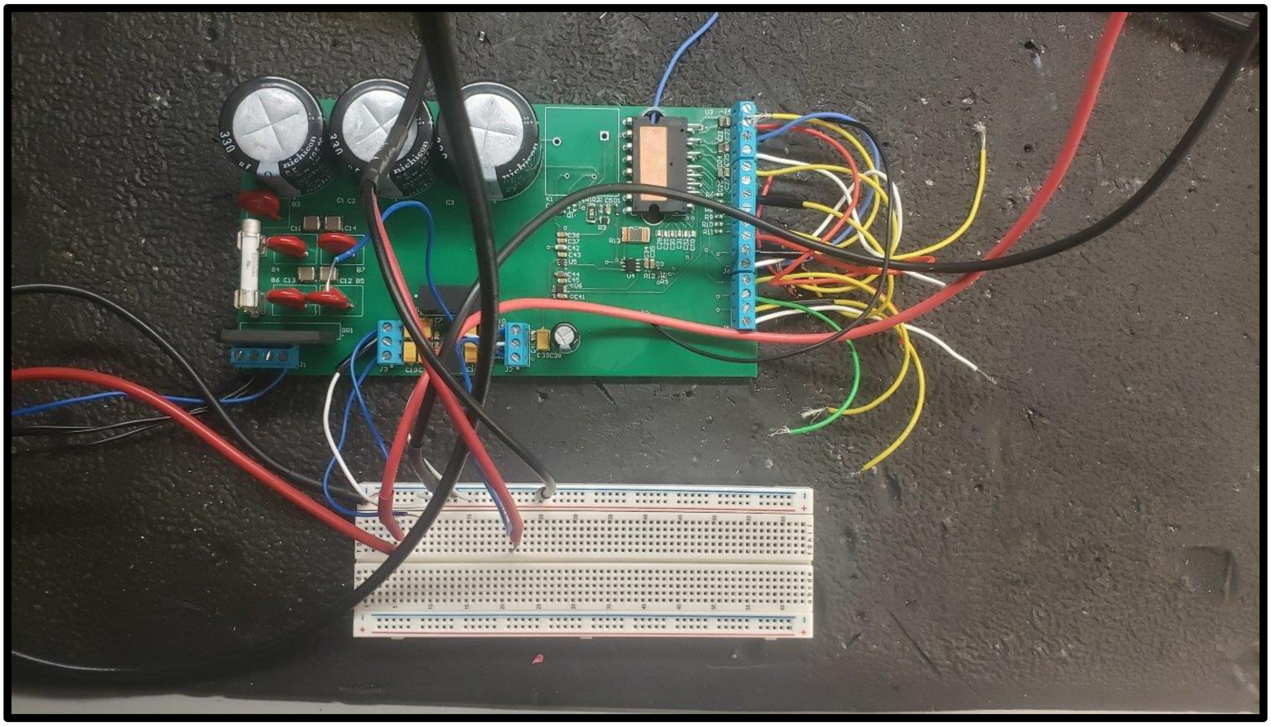

Figure 18: 15V/ISO_15V Converter Circuit

Figure 19: Input 15V

Upon measuring the input 15 V shown in Figure 20, the green horizontal line shows an amplitude of 15.1 V with 600 mV of noise. Furthermore, the measured output is 15.3 V with

800 mV of noise. This aligns greatly with the expected output of 15 V. To further validate the power converter, its performance was measured across its full range. In Table 2, the current was kept constant while the voltage was incrementally increased. In Table 3, the voltage was kept constant while the current was incrementally increased. The power converter behaved as expected for its full range of voltage and current values.

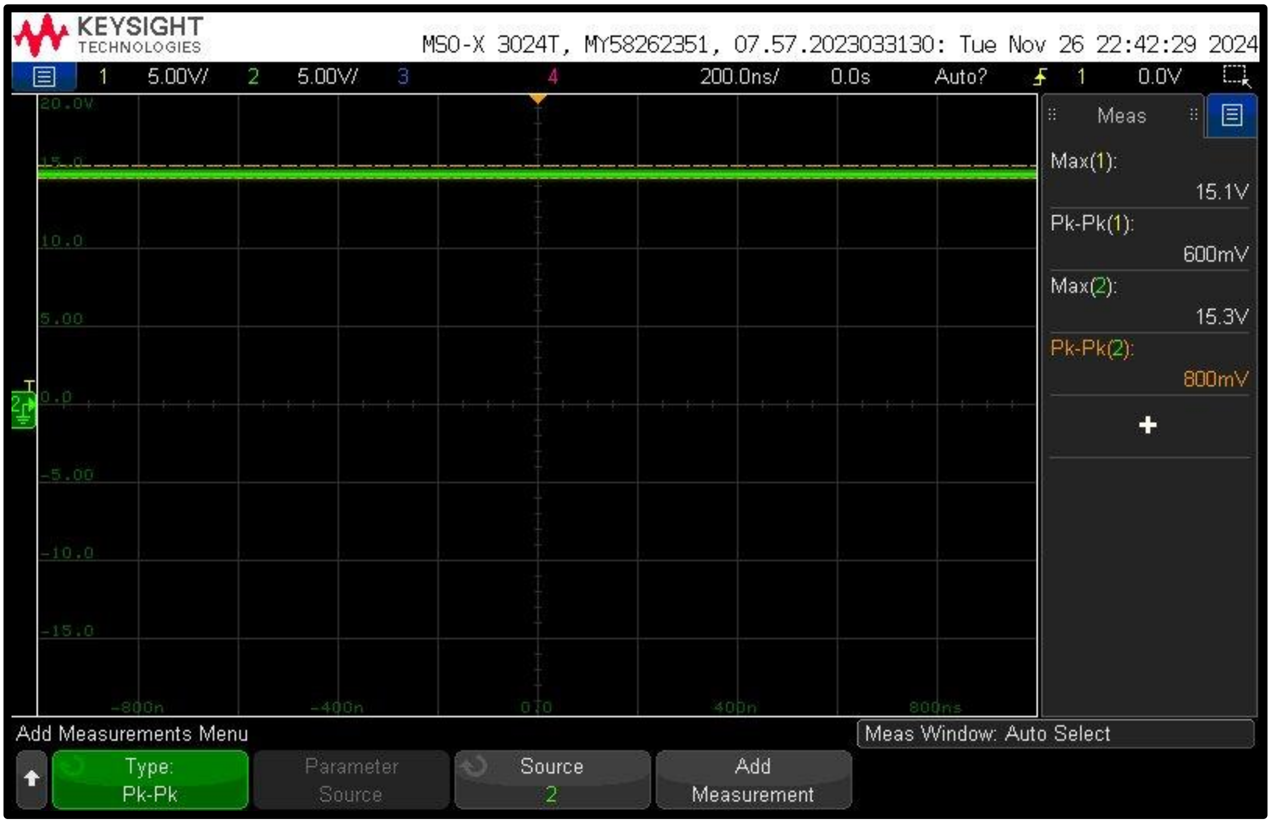

Figure 20: Input 15 V, Output Iso 15 V

Input V (V)	Output V (V)	Output Noise (mV)
9.0	15.3	800
12.1	15.3	800
15.1	15.3	800
18.1	15.3	800
24.5	15.4	1000

Table 2: 15V/ISO_15V Constant Current

Input I (mA)	Output V (V)	Output Noise (mV)
1	6	400
40	15.2	600
80	15.2	400
110	15	400

150	15	400
190	15	400
220	15	400

Table 3: 15V/ISO_15V Constant Voltage

4.3. Subsystem Conclusion

In conclusion the rectifier, DC link, and 15 V to iso 15V converter are all working properly. On the other hand, the power control and 3.3V to iso 5V converter are not working properly. The power control will require a new chip before being tested and integrated into the full system as well as purchase of backup parts to avoid the time delay of needing to order emergency new parts. The 3.3V to iso 5V converter will require a new circuit board to add in the missing trace.

5. Firmware Subsystem Report

5.1. Subsystem Introduction

This subsystem entails all programming required to make the microcontroller work. Without the microcontroller and its firmware, the remainder of the VFD's subsystems will not function by themselves or together to control the motor. The firmware will also be responsible for allowing the user to control different aspects of the VFD.

5.2. Subsystem Details

This semester, the firmware was all written, tested, and demonstrated in MPLAB's X IDE in the C language using a DSPIC33CK256MP508 microcontroller on a dsPIC33CK Curiosity Development Board (part number DM330030). This semester's objective was to program the development board's potentiometer to allow the user to control frequency of a three-phase PWM signal. This objective was met, and the resulting PWM signal can be shown with three channels of an oscilloscope.

The program works by continuously reading the potentiometer's value and using that to calculate the desired frequency (10-60Hz) that should be outputted to the motor via the PWM signal. To generate the three-phase PWM signal and the different frequencies as the program runs, it makes a sine table that can be iterated through and converted into duty cycle percentages. The offsets of the three outputs are 120 degrees apart from each other to make them three-phase, and the speed that the program iterates through the sine table depends on the calculated target frequency.

5.3. Subsystem Validation

To validate my subsystem, I tested it on the dsPIC33CK Curiosity Board. I was able to get it to properly display three different phases of a PWM signal iterating through a sine waveform of duty cycles that were all correctly offset by 120 degrees. I was also able to program the complete functionality of the potentiometer so that it can increase and decrease the frequency of the PWM signal. Though the duty cycles of the PWM waves continuously change, the oscilloscope's output of these three phases in a single frame of the loop is shown in the figure below. This validation shows that the firmware is ready for subsystem integration next semester.

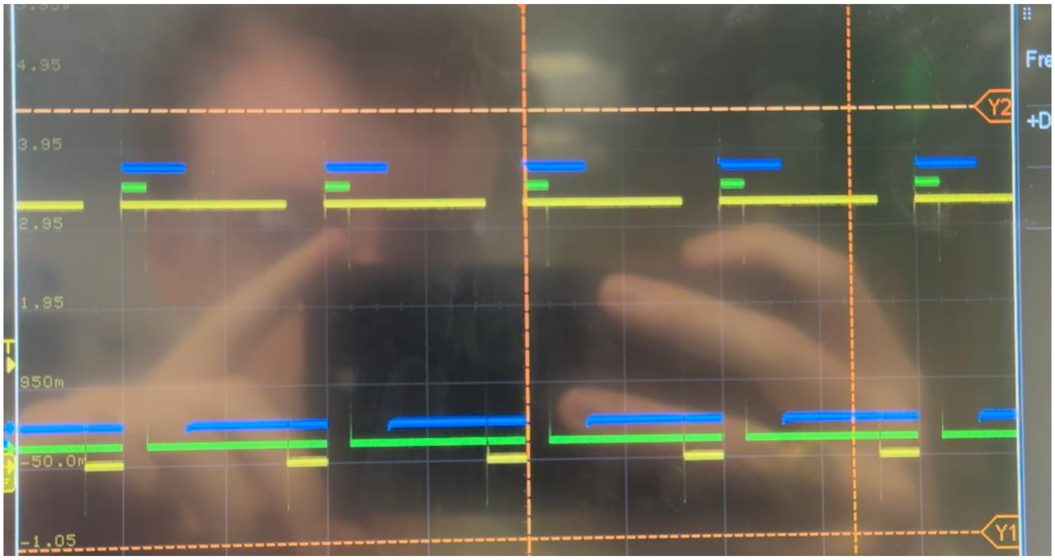

Figure 21: Oscilloscope Output of PWM Signals Produced by Development Board

When the program is running on my development board, it also prints several variables in each iteration of the while loop to a terminal window that can be opened in MPLAB. The variables output in each iteration are shown in the figure below.

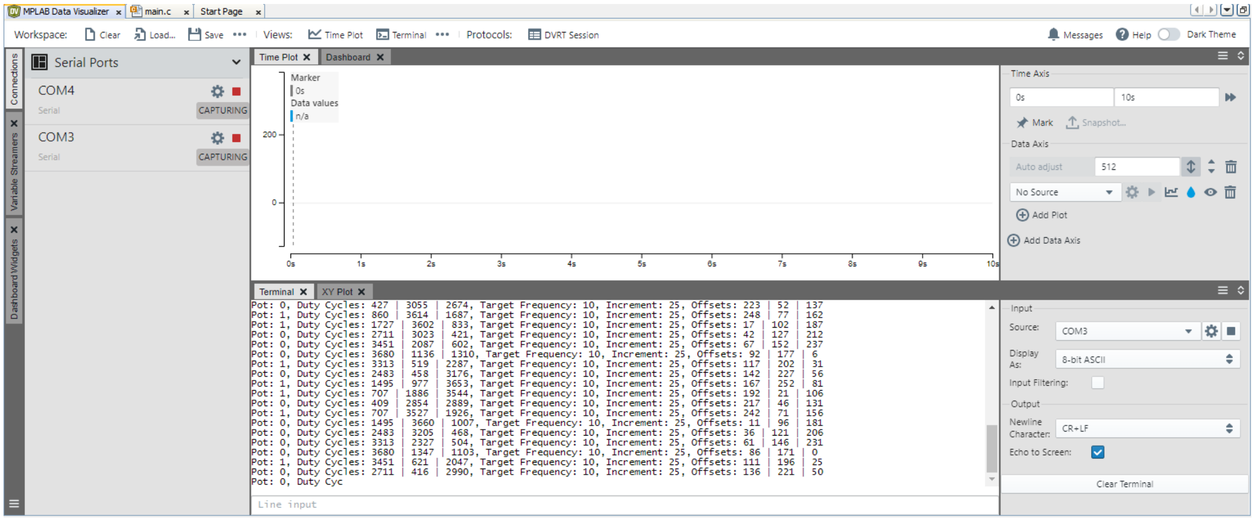

Figure 22: Debug Print Statements (Potentiometer at 0)

5.4. Subsystem Conclusion

The objective next semester is to integrate the development board's firmware onto the microcontroller subsystem. This should only involve changing pin names and calibrating for the other two subsystems, but there are likely to be more challenges, so I will need to continue adding comments and print statements to ensure a clean debugging process.

Another addition I will need to make to my code is to have a low signal for each of the three phases of my PWM signal. Upon communicating with the other members of my group, they have requested that I generate these extra three signals.

One potential problem that may arise during integration is the need to calibrate the PWM signal's frequency needed by the motor. I know I will need to calibrate this signal and do some troubleshooting because the program currently prints that its target frequencies are between 10-60Hz; upon observation of the output PWM waveforms on the oscilloscope, however, the signals are a lot slower than that.

Overall I have completed this semester's objective for my subsystem and am ready to integrate with the other subsystems in the Spring in ECEN 404.