WBG Devices-Based Matrix Converter for 3-Phase AC to DC Conversion in Industrial Computing Applications

Jack Alagood
Kyle Bedrich
Ian Farrar

CONCEPT OF OPERATIONS

REVISION – 1
15 September 2024

CONCEPT OF OPERATIONS
FOR
WBG Devices-Based Matrix Converter for 3-Phase AC to DC Conversion in Industrial Computing Applications

TEAM 403 URS HONORS ENJETI SECTION 1

APPROVED BY:

_Jack Alagood________9/15/2024_
Project Leader Date

____
Prof. Enjeti Date

____
T/A Date

Change Record

Rev.	Date	Originator	Approvals	Description
-	9/15/2024	Kyle Bedrich		Draft Release
1	9/15/2024	Jack Alagood Ian Farrar		Revision 1

Table of Contents

List of Figures

1. Executive Summary

This project is the execution and testing of the developed framework behind a 3-phase AC to DC converter for efficient power conversion in certain computing applications. Our motivation is to build, test, and prove the developed framework. Our problem is the design and manufacturing of the board that will be used to test the developed framework, including component selection and simulation. Our research question is, will the 3-phase AC-DC conversion being tested be more efficient than other solutions for power conversion in computing applications?

The importance of our research topic comes from the increased demand for more efficient power conversion, especially at large scales like in industrial computing, where CPUs and GPUs need massive amounts of power to perform computationally expensive tasks. Grid load would decrease with more efficient power conversion, saving consumers and businesses money.

This project differentiates itself in its current research field by being a new topology for this kind of power conversion. It differentiates itself from other power conversion topologies with the same goal by removing the need for multiple stages, increasing efficiency. It also allows for reverse functionality, if the customer ever wanted to supply power back to the grid.

The expected outcomes of this research project are (1) to have a functioning, tested board that successfully steps down 3-phase AC to DC and can supply a load source with sufficient power, and (2) to have members' gain knowledge of the design, simulation, manufacturing, and testing of the board and its components.

2. Introduction

This document outlines a 3x1 matrix converter for AC to DC conversion in supplying power to industrial computing applications. The proposed system aims to improve power delivery efficiency, reducing losses, strain on the power grid, and costs for the user. Reducing these problems in industrial computing will alleviate current limits on data processing and its impact on society.

2.1. Background

Recent trends suggest society's technological demands are pushing the limits of our outdated energy infrastructure. The rise of energy-intensive computing (AI model training, cloud computing, data centers, etc.) creates a need to optimize power delivery to these loads. While many solutions have been presented to the industry over the years, there remains much room for improvement when it comes to overall efficiency and, consequently, cost. Improving efficiency and decreasing costs for industrial computing centers would increase scalability and assist emerging technologies to test the limits of big data.

To address this issue, we will present a three-phase AC to DC matrix converter. This system is composed of a primary and secondary side with power transfer occurring across a high frequency transformer. On the primary side, a 3x1 matrix converter serves as a space- and power-efficient method of converting a lower frequency three-phase input to a high frequency one-phase output [1]. On the secondary side, a rectifier converts the AC signal produced by the matrix converter into a DC output.

A high frequency (HF) transformer allows for high-density power processing [2]. The type of component should be chosen according to rating and power loss, amongst other properties.

Wide-bandgap semiconductors (WBGs) are used for their ability to operate at higher voltages than their regular semiconductor counterparts [1]. The 3x1 matrix converter utilizes WBG MOSFETs to create bidirectional switches that allow power to flow both to and from the load [3]. Sensors send readings about voltage levels and current flow to the control system. This enables soft switching to minimize switching losses and improve efficiency.

A pulse-width-modulation (PWM) buck rectifier limits the overall size of the necessary filtering components [4]. When choosing/designing rectifiers, one must keep in mind the effects of time harmonics to ensure they do not prevent the circuit from behaving as intended [1]. The risk posed by time harmonics can be measured using total harmonic distortion (THD).

As this device is expected to interface with industrial-level computers, its specifications should be designed according to industry standards. Implementing our matrix converter should ideally result in more efficient power delivery to appropriate loads.

2.2 Overview

The hardware will consist of a 3-phase input power filter, digitally controlled 3x1 matrix converter, HF transformer, rectifier, and output filter. The control systems include C2000 microcontroller controlling the FETs in the 3x1 matrix converter and collecting voltage and current data from the test PCB.

2.3 Referenced Documents and Standards

[1] S. Ratanapanachote, Cha Han Ju, and P. N. Enjeti, "A digitally controlled switch mode power supply based on matrix converter," IEEE Transactions on Power Electronics, vol. 21, pp. 124-130, 2006.

[2] J. J. Sandoval, S. Essakiappan and P. Enjeti, "A bidirectional series resonant matrix converter topology for electric vehicle DC fast charging," 2015 IEEE Applied Power Electronics Conference and Exposition (APEC), Charlotte, NC, USA, 2015, pp. 3109-3116.

[3] H. S. Krishnamoorthy, P. Garg, and P. N. Enjeti, "A matrix converter-based topology for high power electric vehicle battery charging and V2G application," in 38th Annual Conference on IEEE Industrial Electronics Society, 2012, pp. 2866-2871.

[4] V. Vlatkovic, D. Borojevic, and F. C. Lee, "A zero-voltage switched, three-phase isolated PWM buck rectifier," IEEE Transactions on Power Electronics, vol. 10, pp. 148-157, 1995.

3. Operating Concept

3.1. Scope

This project serves to further knowledge and research in the field of power conversion and delivery by assembling a PCB with contemporary technologies. The target client is industrial grade computers operating on high voltages and large power demands. Details on which circuit components are selected will be included in the appropriate reports.

3.2. Operational Description and Constraints

Although this system can be used for other purposes, the intended use case for this system is to supply power for industrial computing in large data centers, servers, etc. The system is designed to handle 1 kVA of power and should not be used in applications where more power is needed.

3.3. System Description

The 3x1 matrix converter will be composed of 3 parts: a primary side containing the AC-AC matrix converter, a secondary side containing an AC-DC rectifier scheme, and a control system. A high frequency transformer will facilitate the transfer of power from the primary side to the secondary side of the power module. Wide-bandgap semiconductors will be utilized as switches in the matrix converter and rectifier.

The system will be controlled using a Texas Instruments C2000 microcontroller. Sensors will be implemented in the control scheme to maintain the desired output. The sensors will also be used to implement zero-voltage switching to improve efficiency. A custom PCB will be designed to house the final design. Below is the circuit schematic for our proposed system.

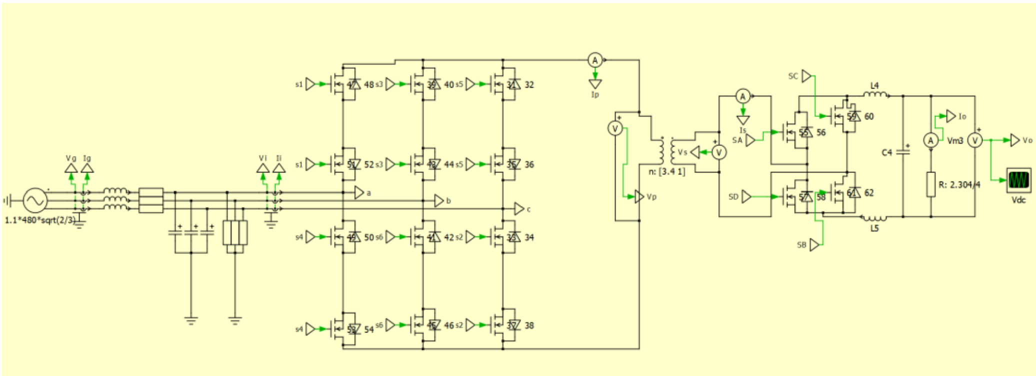


Figure 1: *Proposed 3x1 Matrix Converter Schematic*

3.4. Modes of Operations

The proposed system has two modes of operation. As a bidirectional system, the 3x1 matrix converter will be able to both consume power from the grid as well as supply it. This is useful in instances where the user has alternative power sources (installed solar panels, for example). When the alternative sources of power are able to meet the power demand and more, the 3x1 matrix converter will enter the Load to Grid mode of operation and begin supplying power instead of consuming.

3.5. Users

The primary user of our 3x1 matrix converter system is going to be large tech companies that have a need to supply power to their centralized data and computation centers. Due to the danger of the high voltages that this proposed system will interface with, electricians who have been trained to safely handle high voltage applications will be needed for installation.

This proposed system will most directly benefit the tech companies as they will be able to power their data centers at a reduced cost. This will also benefit society as a whole as reducing energy consumption alleviates strain on the power grid that all of society is dependent on.

3.6. Support

A user manual would be supplied to the user that describes how the 3x1 matrix converter interfaces with the grid (input) and the system being powered (output). A datasheet outlining system performance and behavior would also be provided so that the user can identify if the 3x1 matrix converter would suit their needs. A schematic similar to *Figure 1* would also be provided in this datasheet to aid in debugging if the user encounters issues in implementation.

4. Scenarios

4.1. Grid to Load

In a scenario where the user consuming power needs power from the grid, the proposed 3x1 matrix converter will operate in the Grid to Load mode of operation. Due to the heavy power consumption in the intended use case of this system (industrial computing), this scenario and mode of operation is where the system will be in the vast majority of the time.

4.2. Load to Grid

In a scenario where the user consuming power gets their needs met from alternative sources of power, the 3x1 matrix converter will enter the Load to Grid mode of operation. In this instance, the grid will be supplied by the excess produced by the alternative sources. This would likely only occur in an instance where the proposed 3x1 matrix converter is implemented outside of its intended use, supplying power for industrial computing. Another instance where this mode may be useful is in a case where a data center suffers damage to its computing infrastructure, wiping out the need for substantial power consumption.

5. Analysis

5.1. Summary of Proposed Improvements

The main improvement that this proposed system provides is that it is highly efficient, reducing energy consumption and costs for the user. This is achieved through utilizing zero voltage switching and a matrix converter which improves power factor more reliably than a typical electrolytic capacitor. This system also allows for bidirectional power flow, although this likely has little benefit for its intended use in industrial computing.

5.2. Disadvantages and Limitations

It’s worth noting the limitations of using a matrix converter, those being a capped voltage transfer ratio according to the input/output signals and notable vulnerability to power surges. Matrix converters also involve more semiconductor devices than their traditional counterparts, and for our specific case, finding and obtaining the necessary components will be a challenge unto itself.

5.3. Alternatives

As has been mentioned in previous sections, the common alternative to a 3x1 matrix converter is a phase-controlled converter which sacrifices control and efficiency for simplicity and affordability. While very applicable in industrial computing, these converters fail to optimize power delivery in part due to the need for multiple energy storage components.

5.4. Impact

One concern with the rise of industrial computing is the energy demand and the emissions produced in supplying that energy. This proposed system will reduce the energy loss in converting AC to DC power for data centers, decreasing energy consumption and emission production. Decreasing energy consumption also makes the computationally intensive tasks handled in data centers cheaper, meaning problems we face today that require a large amount of computation to solve can be solved quicker and cheaper.

WBG Devices-Based Matrix Converter for 3-Phase AC to DC Conversion in Industrial Computing Applications

Jack Alagood
Kyle Bedrich
Ian Farrar

FUNCTIONAL SYSTEM REQUIREMENTS

REVISION – 1
26 September 2024

FUNCTIONAL SYSTEM REQUIREMENTS
FOR
WBG Devices-Based Matrix Converter for 3-Phase AC to DC Conversion in Industrial Computing Applications

PREPARED BY:

____
Author Date

APPROVED BY:

_Jack Alagood_________9/26/2024_
Project Leader Date

____
John Lusher II, P.E. Date

____
T/A Date

Change Record

Rev.	Date	Originator	Approvals	Description
-	9/26/2024	Jack Alagood		Draft Release

Table of Contents

List of Figures

1. Introduction

1.1. Purpose and Scope

This specification defines the technical requirements for the development items and support subsystems delivered to the client for the project. Figure 2 shows a representative integration of the project in the proposed CONOPS. The verification requirements for the project are contained in a separate Verification and Validation Plan.

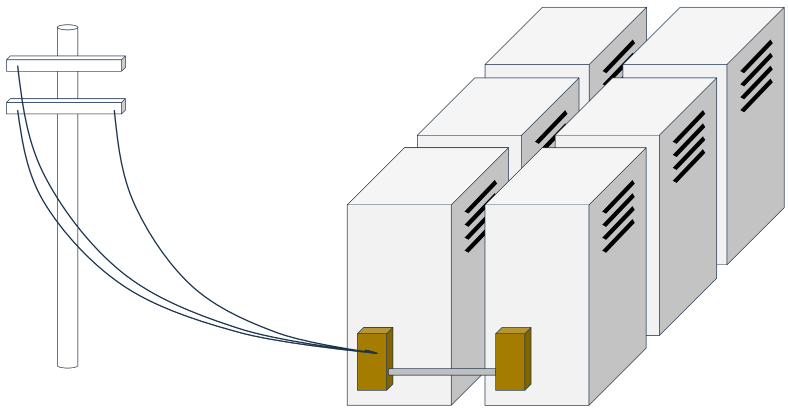


Figure 2. Conceptual application of 3x1 matrix converter

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

Team leader Jack Alagood shall be responsible for ensuring all requirements are met. Any proposed changes in the design or deliverables shall be approved by Peng-Hao Huang and Jack Alagood. Kyle Bedrich is responsible for the controls subsystem. Jack Alagood is responsible for the primary side of the power electronics module. Ian Farrar is responsible for the transformer and secondary side of the power electronics.

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-1547-2018	2/15/2018	IEEE Standard for Interconnection and Interoperability of Distributed Energy Sources with Associated Electric Power Systems Interfaces
IEEE 519-2022	05/13/2022	IEEE Standard for Harmonic Control in Electric Power Systems
IEEE 1100-2005	12/09/2005	IEEE Recommended Practice for Powering and Grounding Electronic Equipment
ANSI/TIA-942	05/07/2024	Telecommunications Infrastructure Standard for Data Centers
IEC 61558	09/29/2017	Safety of Transformers, Reactors, Power Supply Units, and Combinations Thereof

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	Revision/Release Date	Document Title
SBAA565	Nov 2022	A Basic Guide to I2C

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 considered to be 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 project includes the design, fabrication, and testing of a 3-1 matrix converter topology. A PCB will be fabricated consisting of the components needed to operate, and a DSP or FPGA controller will be used to switch the 3-1 matrix converter.

Subsystems include:

- The power circuitry, which consists of FETs, LC tanks, a transformer and a rectifier circuit
- The control system, which controls the FETs in the 3-1 matrix converter
- The test board design, layout, and fabrication

These subsystems working in conjunction with each other create an operational system that can be tested with multiple 3-phase input voltage signals in any load condition.

3.2. Characteristics

3.2.1. Functional / Performance Requirements

3.2.1.1. Unity Power Factor

Unity power factor is the number one priority in any AC-DC conversion circuit, since it minimizes power loss due to reactive load, which results in money wasted.

- **Risk mitigation:** Extensive testing through simulations and bench testing will be done during and after control logic design and implementation to verify the simulations and unity power factor.

3.2.1.2. >1kW Load Capability

To meet the goal of this project, which is to supply servers that demand up to 1kW of power, this performance requirement must be met.

- **Risk mitigation:** FOS > 1.1 is required when selecting or designing components like FETs, transformers, or rectifier components.

3.2.1.3. Protection Circuitry

Since large AC voltages are being used in this project, protection circuitry will be used to protect the circuit from failure and the team from shocks.

- **Risk mitigation:** Protection circuitry will be implemented in the power circuitry and control logic/circuitry.

3.2.1.4. Inputs

a. Inputs to the control DSP/FPGA will be protected. One of the inputs is the 3-phase transmission line, whose signal is fed into a PLL which then goes to generate the 3-1 matrix converter switching signals.
b. Inputs to the power circuitry include an LC tank.

Rationale: Safety for the team, design, and customer are requirements.

3.2.1.4.1 Power Consumption

a. The maximum power provided to the load shall not exceed 1kW.

Rationale: This is a requirement specified by our customer due to constraints of their system as defined by the project.

3.2.1.4.2 Input Voltage Level

The input voltage level shall be between +120VAC to +230VAC.

Rationale: This is a system requirement defined by the customer, and is also a limitation of current materials technology.

3.2.1.5. Outputs

3.2.1.5.1 Performance Output

The control circuitry shall analyze the input and output signal/power to output efficiency, power factor, and other metrics important to the customer.

Rationale: The verification of system functionality and performance is a requirement to the customer.

4. Scenarios

The environment where this circuitry will be used in consist of:

- Operating at grid voltage with fluctuating voltage and frequency
- All load cases from 0W up to 1kW
- Hot enclosures with adequate airflow

The customer would use this type of circuit in an industrial computing application to power a server not exclusively but related to data storage, machine learning, CPU/GPU rendering, and cloud hosting/computing.

Appendix A: Acronyms and Abbreviations

AC	Alternating Current
CMOS	Complementary Metal Oxide Transistor
CPU	Central Processing Unit
DC	Direct Current
EN	Enable
FET	Field Effect Transistor
FPGA	Field Programmable Gate Array
GaN	Gallium Nitride
GPU	Graphics Processing Unit
IC	Integrated Circuit
IMS	Insulated Metal Substrate
I/O	Input/Output
MC	Microcontroller
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
PCB	Printed Circuit Board
PWM	Pulse Width Modulation
RMS	Root Mean Square
SMT	Surface Mount
SR	Slew Rate
TIM	Thermal Interface Material
TH	Through Hole
THD	Total Harmonic Distortion
TTL	Transistor-Transistor Logic
V	Voltage
WBG	Wide Band Gap
3x1	Three to One
3-Φ	Three Phase

Appendix B: Definition of Terms

Boost	Increase in the context of voltage or current
Buck	Lower in the context of voltage or current
Duty Cycle	The fraction of a period in which a pulse is on
Power Density	The concentration of power per unit volume
Primary side	The main component(s) of the circuit
Pulse Width Modulation	Transform DC signals to AC
Rectify	Transform AC signals to DC
Secondary side	Supporting elements of a circuit
Step Down	Lower in the context of voltage or current
Step Up	Increase in the context of voltage or current
Topology	The structure or arrangement of circuitry
Total Harmonic Distortion	The distortion from an amplifier given as harmonic signals

WBG Devices-Based Matrix Converter for 3-Phase AC to DC Conversion in Industrial Computing Applications

Jack Alagood
Kyle Bedrich
Ian Farrar

INTERFACE CONTROL DOCUMENT

REVISION – 1
26 September 2024

INTERFACE CONTROL DOCUMENT

FOR

WBG Devices-Based Matrix Converter for 3-Phase AC to DC Conversion in Industrial Computing Applications

PREPARED BY:

____
Author Date

APPROVED BY:

_Jack Alagood________9/26/2024_
Project Leader Date

____
John Lusher II, P.E. Date

____
T/A Date

Change Record

Rev.	Date	Originator	Approvals	Description
-	9/26/2024	Jack Alagood		Draft Release

Table of Contents

1. Overview

The Interface Control Document (ICD) for the 3x1 Matrix Converter provides quantitative data for the primary and secondary subsystems as well as listing what controls are in place for monitoring circuit behavior. Also included are the methods in which these pieces come together to accomplish the tasks set out in previous reports.

2. References and Definitions

2.1. References

IEEE Standard for Interconnection and Interoperability of Distributed Energy Sources with Associated Electric Power Systems Interfaces (IEEE-1547-2018)
15 Feb 2018

IEEE Standard for Harmonic Control in Electric Power Systems (IEEE 519-2022)
13 May 2022

IEEE Recommended Practice for Powering and Grounding Electronic Equipment (IEEE 1100-2005)
9 Dec 2005

Telecommunications Infrastructure Standard for Data Centers (ANSI/TIA-942)
7 May 2024

Safety of Transformers, Reactors, Power Supply Units, and Combinations Thereof (IEC 61558)
29 Sep 2017

2.2. Definitions

FPGA	Field-Programmable Gate Array
DSP	Digital Signal Processor
PCB	Printed Circuit Board
GaN	Gallium Nitride
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
PWM	Pulse Width Modulation
WBG	Wide Band Gap
AC	Alternating Current
DC	Direct Current

3. Physical Interface

3.1. Weight

The majority of the weight in this power module will come from the transformer. Using a transformer similar to what will be using, the transformer should weight around 30-35 pounds and the system as a whole should be less than 50 pounds.

3.2. Dimensions

3.2.1. C2000 Development Board

- 2300 mil X 5500 mil

3.2.2. FPGA

- 9.5” X 7.53” X 0.061”

3.2.3. High Frequency Transformer

- 8.13” X 6.38” X 6.00”

4. Thermal Interface

Due to the high power passing through this power module, thermal management techniques need to be applied to cool the heat generating components like inductors, transformers, and MOSFET’s. Heat sinks shall be placed on the PCB to help distribute heat. Data centers utilize specialized air condition units, fans, and other cooling techniques to keep the computing racks cool. This power module should be provided with similar resources to maintain a cool operating temperature.

5. Electrical Interface

5.1. Primary Input Power

Power for the matrix converter is supplied by 12V sources which can be stepped down to 5V or 3.3V using buck converters.

5.2. Voltage Sensors

The AMC3330 voltage sensor runs off of 3.3V or 5V and is responsible for tracking the performance of the matrix converter with precise voltage measurements. The device operates within the range of temperatures expected in its application(s).

5.3. User Interface for Performance Analysis

The TI F2837x board will be used to analyze the performance metrics of the 3x1 matrix converter, including but not limited to power factor, input and output factor.

6. Communications / Device Interface Protocols

6.1. Universal Serial Bus (USB)

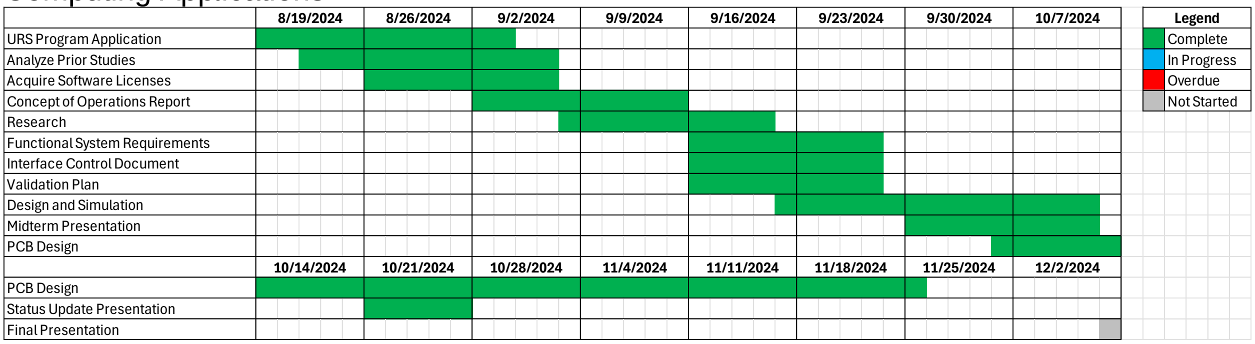
In order to program the DSP or FPGA used to control the FET gates in the 3-1 matrix converter, USB must be used to connect and program it. USB will also be used in the final design to communicate with a PC to analyze performance metrics.

WBG Devices-Based Matrix Converter for 3-Phase AC to DC Conversion in Industrial Computing Applications

Jack Alagood
Kyle Bedrich
Ian Farrar

EXECUTION PLAN

REVISION – 2
5 December 2024


8/19/2024
8/26/2024
9/2/2024
9/9/2024
9/16/2024
9/23/2024
9/30/2024
10/7/2024
Legend
Complete
In Progress
Overdue
Not Started
URS Program Application
Analyze Prior Studies
Acquire Software Licenses
Concept of Operations Report
Research
Functional System Requirements
Interface Control Document
Validation Plan
Design and Simulation
Midterm Presentation
PCB Design
10/14/2024
10/21/2024
10/28/2024
11/4/2024
11/11/2024
11/18/2024
11/25/2024
12/2/2024
PCB Design
Status Update Presentation
Final Presentation

WBG Devices-Based Matrix Converter for 3-Phase AC to DC Conversion in Industrial Computing Applications

Jack Alagood
Kyle Bedrich
Ian Farrar

VALIDATION PLAN

REVISION – 2
5 December 2024

Task	Deadline	Status
URS Program Application	9/3/2024	Complete
Analyze Prior Studies	9/5/2024	Complete
Acquire Software Licenses	9/5/2024	Complete
Concept of Operations Report	9/15/2024	Complete
Research	9/19/2024	Complete
Functional System Requirements	9/26/2024	Complete
Interface Control Document	9/26/2024	Complete
Validation Plan	9/26/2024	Complete
Design and Simulation	10/10/2024	Complete
Status Update Presentation	10/23/2024	Complete
Midterm Presentation	10/10/2024	Complete
PCB Design	11/25/2024	Complete
Final Presentation	12/9/2024	Not Started

Legend
Complete
In Progress
Overdue
Not Started

WBG Devices-Based Matrix Converter for 3-Phase AC to DC Conversion in Industrial Computing Applications

Jack Alagood
Kyle Bedrich
Ian Farrar

SUBSYSTEM REPORTS

REVISION – 1
4 December 2024

SUBSYSTEM REPORTS

FOR

WBG Devices-Based Matrix Converter for 3-Phase AC to DC Conversion in Industrial Computing Applications

PREPARED BY:

____
Author Date

APPROVED BY:

_Jack Alagood________12/5/2024_
Project Leader Date

____
John Lusher II, P.E. Date

____
T/A Date

Change Record

Rev.	Date	Originator	Approvals	Description
-	12/4/2024	Jack Alagood		Draft Release

Table of Contents

List of Figures

1. Introduction

The 3x1 matrix converter functions as a step down AC/DC converter and is intended for use in high voltage environments such as data centers. The system is divided into three subsystems: primary side, secondary side, and controls.

2. Primary Side Subsystem Report

2.1. Subsystem Introduction

The primary side circuitry consists of (1) input filter, (2) gate driver, (3) bidirectional switches, and (4) voltage sensor. Before testing the 3-phase matrix converter, it seemed like a good idea to confirm the functionality of just one leg, then scale it up, so as to avoid ordering many components in the case the device doesn't operate correctly.

In order to have an easier time soldering the board, smaller components were resized to 1206 wherever possible.

2.2. Subsystem Details

The converter begins with the input filter, a 33 μH inductor and 8 μF capacitor rated for 30 A and 630 V, respectively. These ratings satisfy our 230 V and 20.8 A minimum. The filtered signal (labeled "Vac_in_filtered" in *Figure 1*) then reaches the gallium nitride FETs, each of which has its own appropriately rated RC snubber to protect against spikes in voltage (*Figure 2*).

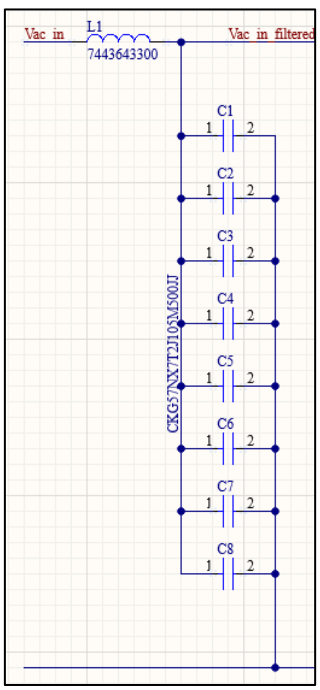


Figure 1. Input filter schematic

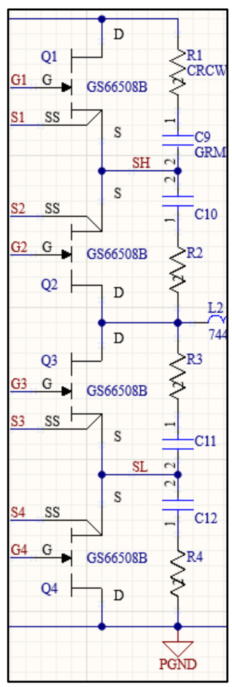


Figure 3. GaN FET and RC snubber schematic (one leg of matrix converter)

Each GaN FET is controlled by a gate driver whose power supply is provided with +12 volts and operates by a PWM signal from the controls subsystem. The positive and negative voltages labeled VDD and VEE respectively pass through a 10 kΩ resistor before continuing to the gate and source terminals.

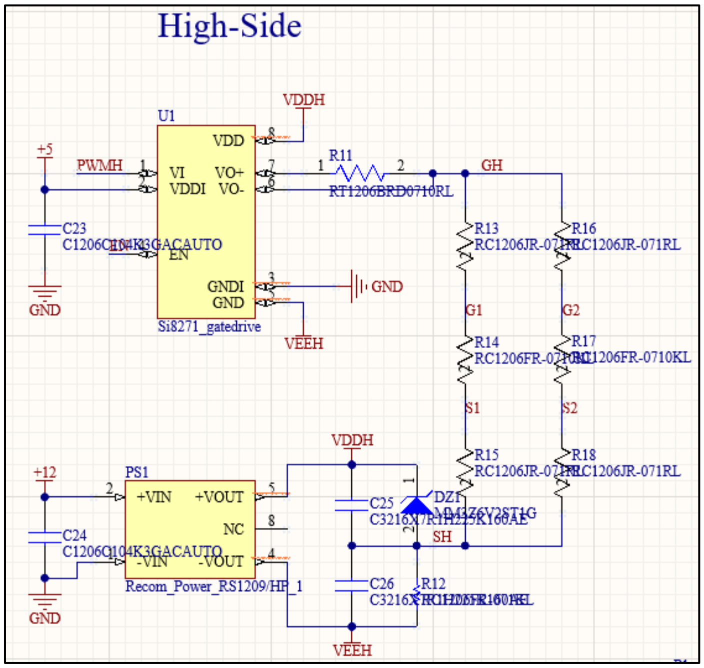


Figure 3. Gate driver schematic (the “H” in net labels indicates high-side)

The voltage through the GaN FETs is filtered once more in the same manner described above, and both the input and output voltages are read by the voltage sensor. If we have 230 volts in, we expect to see 48 volts out.

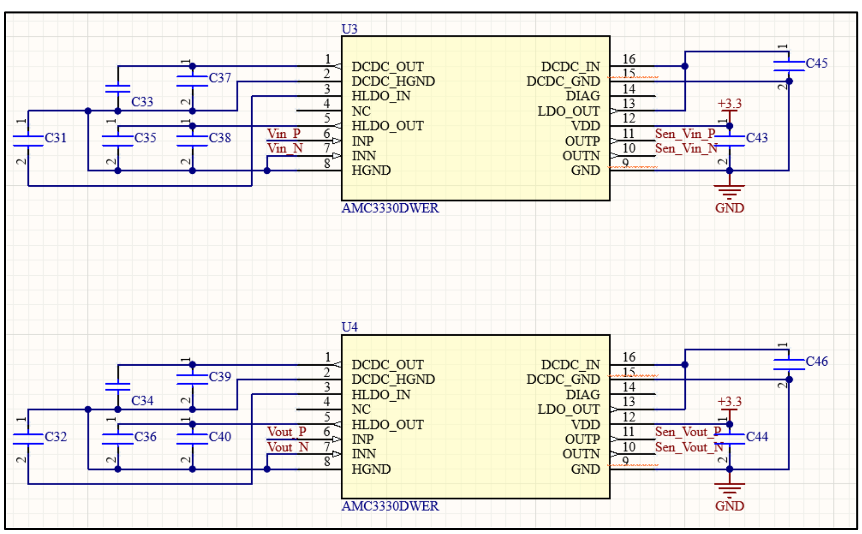


Figure 4. Voltage sensor schematic (top is input, bottom is output)

2.3. Subsystem Validation

The main challenge encountered when designing the PCB was figuring out how to organize components in a way that is both simple and compact. While no concrete limitations on the dimensions were in place, it is necessary to shorten certain traces in order for the gate driver to function.

In *Figure 5* one can observe that the board is arranged such that the low voltage components reside on the outside of the board and the high voltage components are contained near the middle. It’s important to always keep these two regions separated by ample amounts of space so as to not damage the low voltage systems. These regions are only connected by the gate drivers located in the gold copper pours and the voltage sensors shown in green.

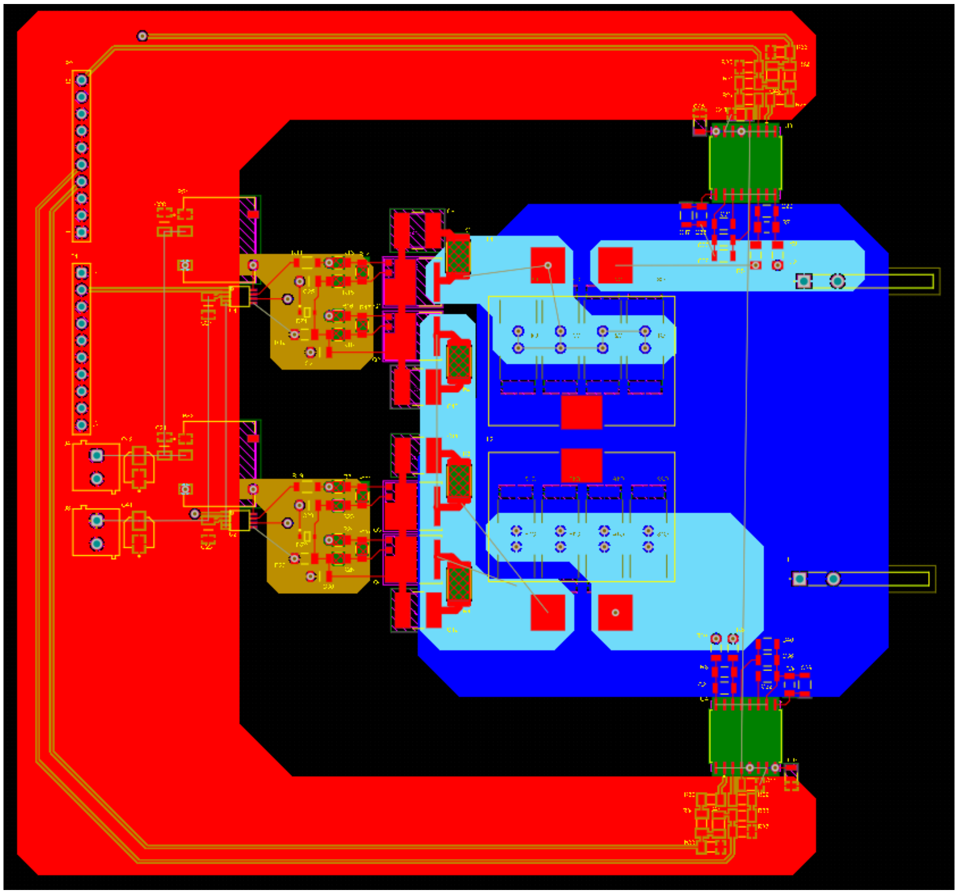


Figure 5. Single-phase primary side matrix converter PCB layout; the I/O pins are located on the right while the PWM signal enters from the left

2.4. Subsystem Conclusion

The designs presented have undergone countless revisions, but there’s still more to be done, most notably confirming the control system is able to read the provided signals. It’s almost certain new issues will arise during testing, but the work done thus far should suffice as a foundation for tweaking and expanding.

3. Secondary Side Subsystem Report

3.1. Subsystem Introduction

3.2. Subsystem Details

3.3. Subsystem Validation

3.4. Subsystem Conclusion

4. Controls Subsystem Report

4.1. Subsystem Introduction

The controls subsystem is the control logic and circuitry that controls the gate drivers. It is connected to the 3-1 matrix converter, which converts a 3-phase signal into an AC signal.

4.2. Subsystem Details

The control subsystem is comprised of logic and hardware. The logic converts a 3-phase signal to an AC signal using a logic circuit consisting of a PLL, sine wave generators, PWM generators, and digital logic.

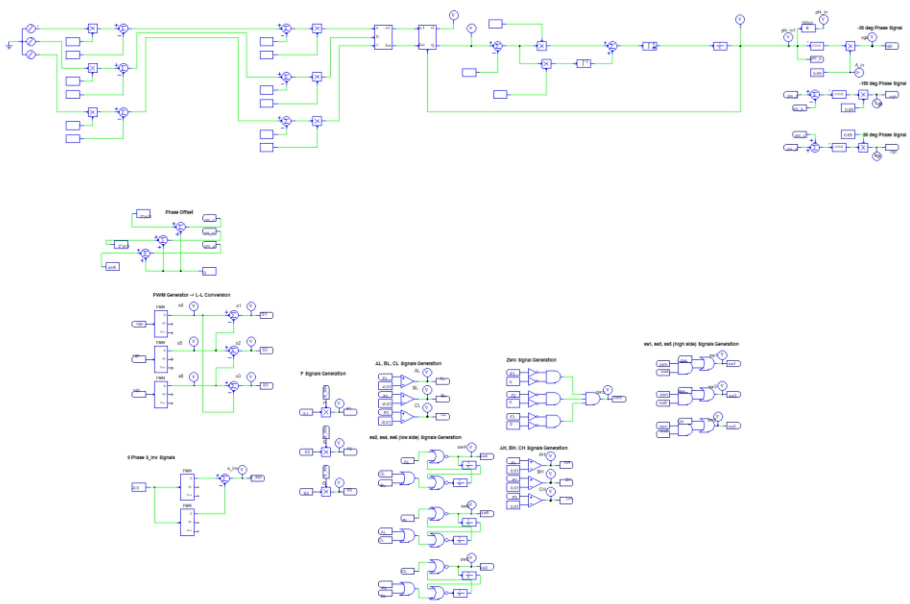


Figure 6. Control system logic in PowerSim

To create the signal in real life, a TI F28379D controlCard in conjunction with a expansion board with ADC, DAC, and GPIO is used. The input to the control logic is inputted to the ADC, and the switching signal for the gate drivers is outputted from the GPIO pins.

Figure 7. TI F28379D Experimenter's Kit used for control logic processing

4.3. Subsystem Validation

Control subsystem validation will occur in 3 stages: logic validation, hardware validation, and logic + hardware validation.

Logic validation consists of implementing the control logic along with the power circuitry in PowerSim and simulating how the logic controls the simulated circuit.

Hardware validation consists of testing code generation, compiling, uploading, and testing on the TI F28379D controlCard. This ensures that the board is able to handle the logic and successfully input and output signals.

Logic + hardware validation consists of implementing the control logic, code generation, and hardware together and testing the entire system. In this validation, HIL (hardware-in-the-loop) testing is conducted using the entire controls subsystem to validate the functionality of the subsystem before it is fully implemented with the other subsystems.

Figure 8. PLECS RT Box for hardware-in-the-loop testing

4.4. Subsystem Conclusion

The control logic design and the first 2 stages of subsystem validation have been completed. The logic + hardware validation is ongoing. So far, this subsystem is showing good performance and can be easily implemented with the other subsystems.