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

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CONCEPT OF OPERATIONS

REVISION – 1
15 September 2024

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FOR

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

TEAM 403 URS HONORS ENJETI SECTION 1

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Change Record

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

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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.

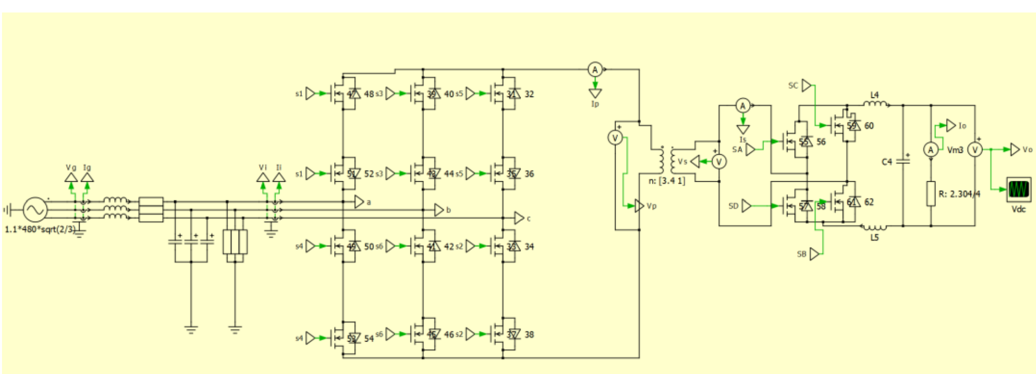

Figure 1: *Proposed 3x1 Matrix Converter Schematic*

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. Scenario(s)

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.