NORTHERN ARIZONA UNIVERSITY
College of Engineering, Forestry & Natural Sciences

Oct.13.2017
Dr. Venkata Yaramasu
Assistant Professor
School of Information, Computing and Cyber Systems
1295 S Knoles Dr
Flagstaff, AZ, 86001

Dear Dr. Yaramasu,

We would like to take this opportunity to thank you for your kindness and generosity in sponsoring our engineering team project. The project's main aim is to design and develop a digital controller grid that connects multilevel converters. We have chosen this project because this project is a combination of control and power systems and all of our team member are interested in this field. Secondly this project is in research phase so we will get enough opportunity to contribute in the research work related to power convertors. We are extremely honored to be a part of a team that will benefit from this sponsorship. The enthusiasm expressed by every member of our team on the proposed project was impressive. Our team is ready to make a commitment to complete this project successfully because of the interest of all our team members in the control and power theory. Practical applications of power convertors, introduction of novel approach by controlling power convertors using controller and funding provided for this project are some of the factors that boost the confidence of our team members as this project will contribute in the technical development of our team as well as contribution in the field of research. This report is based on following sections that is Introduction, Problem Statement, Research Survey, Requirement and Specification, and conclusion.

Thank you again for the generous sponsorship.
Sincerely,

Mohammad Abu Radhi
Sayaf Almari
Di Miao
Fahad Alghareeb
Kaiqiong Ji

Real-Time Implementation of Predictive Current Control for Grid Connected Neutral-Point Clamped Converter

Team Members	**NAU Email**
Sayaf Almari	ssa65@nau.edu
Mohammad Abu Radhi	mka222@nau.edu
Di Miao	dm2357@nau.edu
Fahad Alghareeb	fsa45@nau.edu
Kaiqiong Ji	kj569@nau.edu

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1 Introduction

The grid connected converters are used in various power conversion applications such as wind energy conversion systems, photovoltaic energy systems, variable-speed motor drives, fast and normal charging of electric vehicles, distributed generation, micro grid, smart grid, etc. At the completion of the project, the designed and developed system can be utilized in a renewable energy machine to transmit the generated power to the utility grid. The project has two parts software and hardware so, using MATLAB for software part and use the Altium program for the hardware part on the project. Therefore, the project was proposed with an objective of showing that self-tuned grid controllers can combine well with motors to produce high performance and efficient systems. The team hopes that digital controller grid that connects multilevel converters will solve the problem of inefficiency and errors associated with the current machines. The mathematical modeling of single-phase and three-phase grid connected converters will be performed in synchronous and stationary reference frames. The digital control schemes such as decoupled voltage oriented control, decoupled virtual-flux oriented control, and predictive current control will be developed for grid connected converters. The performance of the digital control schemes will be analyzed by simulation and experimental results.

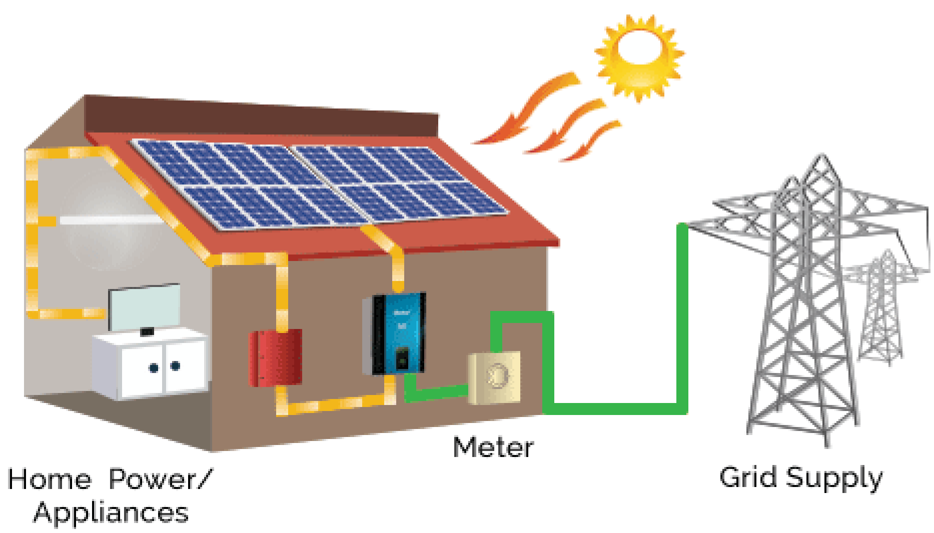

Figure 1-1: Grid Converter [1]

2 Problem Statement

Efficient power conversion for high-power applications is one of the biggest issue for decades. Multilevel power converters are used for efficient high-power conversion and one of the preferred choices for industry and academia. Currently these multilevel converters are used in many applications such as pumps, fans, grinding mills and extruders. Basic multilevel converters have three topologies: Neutral Point Clamped (NPC), flying capacitor (FLC), and cascade H-bridge. Because of its wide industrial application, researchers all over the world are working to improve its efficiency, reliability, cost, power density and simplicity of multilevel converters.

In this project, we will be working on multilevel converters using Neutral point clamped topology with model predictive control. We are using predictive control because with the help of predictive control we can handle system non-linearity and predictive control algorithm will provide better switching as compare to previous technique. In past decades, there is a great revolution in processor technologies. Inexpensive microprocessor had been introduced with very fast processing speed and can be used to control high frequency power converter switches very efficiently and will be very flexible as compare to previous approaches. So, in this project we will be controlling switches using control technology name as model predictive control. Basic block diagram for power convertor with model predictive control is shown in Figure 2-1.

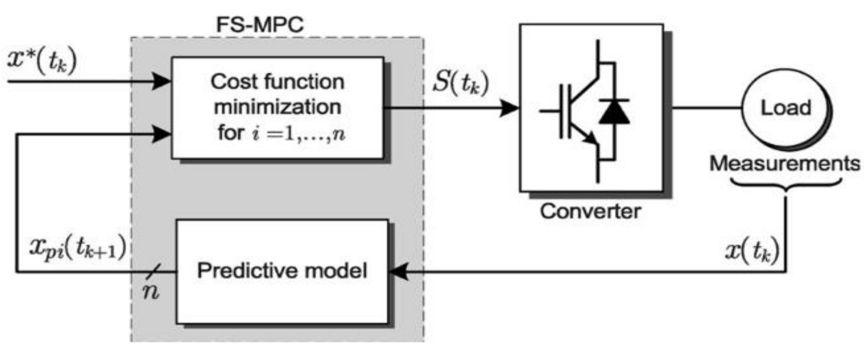

Figure 2-1: Block Diagram of Power Convertor with Model Predictive Control [2]

3 Research Survey Section

3.1 Current State of the Art and Technologies Inherent to Project

Multilevel conversion is a process of high power conversion in small voltage steps using the higher number of switches. This concept was introduced about 20 years ago and have several advantages as compare to traditional power conversion. The small steps conversion produce high power quality waveform with less stresses on load. In multilevel convertors switches are connected in series type configuration which allows its operation at higher voltage, reduces switching frequency and switching losses. One disadvantage of multilevel convertors in the use of high number of switches which increases the cost significantly as compare to two level approach.

Multilevel converters had proven efficient power conversion for high-power applications and attract attention of many researchers to work for the improvement of these convertors. Many industrialists are also investing in the production of multilevel converters on large scale [3-5]. Although multilevel converters had been a proven technology but it presents large amount of challenges and offer wide range of possibilities that their research and development is still growing. In past many publications had been addressed traditional multilevel converter topologies like NPC, FC, and H-bridge in depth [6-9]. Many modulation methods had also been proposed to control these multilevel converters.

But because of the advancement in processing technology and new revolution in the form of high speed microprocessor turn the attention of the researcher to control high frequency switching using different control techniques like hysteresis current control and linear current control with PWM.

3.2 Multilevel Converter

The grid connected power converter relies on the concept of multilevel converters. Hence, the team have done a lot of research on this concept to fully understand how multilevel converters work. The grid connected converter would use three level converters. The three level converter will produce three output voltage levels: positive, negative, and zero voltages. It is more convenient to use three level converters instead of two levels converters because when simulating the converter results, we will get an output curve that is approximately sinusoidal. Hence, more stability. One of the useful articles about this subject is an IEEE published article [10]. The article talks about three level converters, their structure, features, and applications in power systems.

3.3 Predictive control

Power converters use controller units to control generated voltages. The grid connected converter will use an under research topology called predictive control. The digital control unit will be implemented based on the predictive control topology. This method enables the grid converter to predict the future behavior and act based on these future predictions. Predictions will be calculated through mathematical prediction models. One of the great resources about this topic is a book provided to us by Dr.Yaramasu [11]. It illustrates how predictive control method works, how to implement it, and how to simulate results using MATLAB/Simulink software.

3.3.1 Hysteresis Current Control

In hysteresis current control, load current is compared with reference current using hysteresis comparator to determine the switching rate of the inverter such that load current will remain within hysteresis band. Basic block diagram of this configuration is shown in Figure 3-1. The major drawback of this method is that it cannot handle variable switching frequency and cause resonance problem.

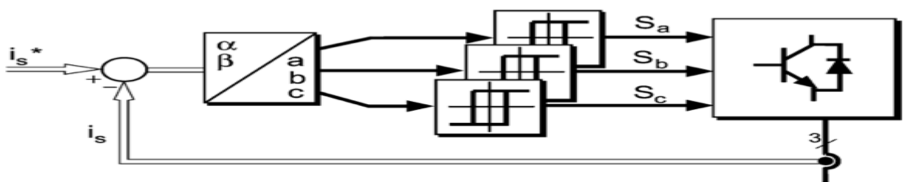

Figure 3-1: Hysteresis Current Control [12]

3.3.2 PWM Control Scheme

In PWM control scheme, proportional integral (PI) controller is used which generates reference load voltages by using the error signal from reference and measured load current. PI controller is a proportional integral controller in which integral action eliminate the offset and compensate the weakness of proportional part of controller. The modulator is used to generate a drive signal for the inverter by comparing the reference load voltage with triangular carrier signal. The basic block diagram for this configuration is shown in Figure 3-2. The major drawback of this configuration is it doesn’t work for sinusoidal references and may be unacceptable for certain applications.

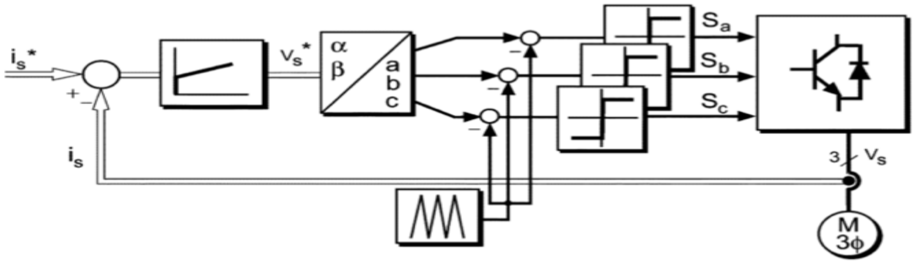

Figure 3-2: PWM Current Control Method [12]

3.4 Designing Printed Circuit Boards (PCB’s)

Implementing the grid connected converter requires us to learn about designing printed circuit boards. Our project will have four different electrical circuits that needs to be designed individually at first. In the final stage of the project, we will combine them together by wiring them properly. The designing tool we will be using for this project is Altium Designer software. Learning designing PCB’s using the Altium Designer software is a broad area. Hence, I have conducted a research on how to use this software. The internet is full of resources about the Altium Designer software. One of the great resources is a pdf tutorial called “pdf name”. It is a great document that would get us started on designing our first PCB [13].

4 Requirements and Specifications Section

There are different approaches to design and build a grid connected converter. Taking into account wants, needs, and constraints, designing options are constrained by these aspects. Hence, in order to complete the project successfully and satisfy our client, we had to list and analyze these specifications. In this section, we will be discussing requirements and specifications based on six different categories: mechanical, electrical, software, documentation, environmental and general.

4.1 Mechanical

The client did not emphasize on mechanical requirements and constraints other than specific length, width, and height ranges. The grid converter consists of eight different layers. Layers are designed to be connected on top of each other forming the overall shape of the grid converter. The first layer is a heat sink layer, and the other layers are electronic PCB layers. The client Dr.Yaramasu prefers all layers to have the same width and length. Also, he provided specific width, length values for layers. On the other hand, even though the client Dr.Yaramasu did not specify a specific value for the overall height of the grid converter, client wants the design to have the smallest possible height. Hence, the team decided that the height should not go over 280 mm. Table 1, displayed below, and provides a brief description of our Mechanical Specifications.

Table 1: Mechanical Specifications

Criteria	Specifications
Layer’s width	228.60 mm
Layer’s length	132.30 mm
Overall height	less than 280 mm

4.2 Electrical

For the electrical requirements, the grid converter should use 5 kW of power. Also, the system needs to operate at 60Hz frequency level. In addition, Dr.Yaramasu prefers surface mounted electrical components when designing the circuit board instead of through whole components. The difference is that surface mount component can be connected to the circuit board without digging a hole in the board. Another electrical constraint is connection simplicity .Dr.Yaramasu emphasized on keeping the design as simple as possible by eliminating unnecessary wires, and using simple circuit designs. Table 2, displayed below, illustrates our electrical constraints and specification.

Table 2: Electrical Specifications

Criteria	Specifications
Power	5 kW
Voltage	Three phase voltage
Frequency	60 Hz
Electrical components parts	Surface mount
Circuit design	simple

4.3 Software

MATLAB/Simulink software with SimPowerSystems Toolbox can function as simulation. It can implement the stationary frame predictive current control (PCC) scheme and implement the synchronous frame predictive current control scheme for a two-level voltage source converter (2L-VSC) feeding an inductive-resistive load. In addition, we will use Altium Designer software to design Interface board PCB design. Design the schematic diagram according to the function of the circuit and the diagram is mainly based on the electrical properties of components according to the need of reasonable structures. The map can accurately reflect the important function of the PCB circuit board, and the relationship between the various components. Table 3, displayed below, shows a brief description of our software specifications.

Table 3: Software/GUI Specifications

Criteria	Specifications
MATLAB/Simulink software	Simulation
Altium Designer	Printed Circuit Board design
Semikron modules	Hardware prototype development
dSPACE DS1103	Rapid prototyping for digital control

4.4 Documentation

There are accessible high voltages present on the board. It operates at voltages and currents that may cause shock if not properly handled or applies. Use the equipment with necessary caution and appropriate safeguards to avoid injuring yourself or damaging property. Some components may reach high temperatures when the board is powered on. The user must not touch the board at any point during operation or immediately after operating, as high temperatures may be present. Table 4, displayed below, demonstrates specifications related to the documentation.

Table 4: Documentation Specifications

Documentation
Operator's Manual
Make sure that the power supply is off before connecting the main cable to the inverter input. Check if control power is off, when connecting the control power to the inverter.
User's Guide
Control power should be supplied prior to main power to operate inverter.
Maintenance Manual
Warranties on this product are based on the time of contract on the supply. However, within the warranty period, the warranty will be void if the fault is due to; (1) Incorrect use as directed in this manual or attempted repair by unauthorized personnel. (2) In the case that the reason of fault is out of the inverter. (3) Using the unit beyond the limits of the specification. (4) Natural disaster

4.5 Environmental

For the environmental requirements, it's not very important than electrical and software requirements. All inverters have an operable temperature range rating, but the implications of this rating can prove rather elusive. There are a range of possible scenarios which could occur upon exiting this range including damage to the inverter, production of poor quality power affecting the customer facility and other facilities connected to the power system, and partial or complete curtailment of output power. Inverters are designed to maintain a certain degree of power quality within their rated temperature range. If an inverter is unable to produce the required quality of power, it will reduce output or cease production entirely. Since the power system and customer facilities are unaffected in these situations, there is no concern from the utility standpoint. However, customer revenue is at risk of being affected by an inverter with too narrow of a temperature range.

Table 5: Environmental Specifications

Criteria	Specifications
Temperature range	Effecting to the power system. Operating temperature range: -20 C ~ +50 C.
Warranty	2 years. The deadline is to guarantee the power system does not relation to the environmental influence
Protection	Current protection and temperature protection.

4.6 General

There are some general effects on reliability and customer preferences. According to the reliability of grid converter, step by step to procedure for the calculation and exploring the grid circuit converter. Every step need to accurate and the cost functions would evaluate the errors between the references and grid circuit, and finally, sets the minimum error. The client's requirement for the team is to preference the digital control schemes will analyze by simulation and hardware.

Table 6: General Specifications

Criteria	Specifications
Reliability	The reliability analysis of the power electronic converters for grid-connected system based on the semiconductor power losses.
Client Preferences	1)DC/ AC inverter 2)three-phase grid connected converters 3)digital control schemes

5 Conclusion

The team has been research a lot of data about Digital Control of Grid-Connected Multilevel Converter project. Every team member finished their own researches about the project. For Required Marketing Requirement, the team research Mechanical Specifications, Electrical and Software/GUI. For the project, Grid-connected converters (DC / AC inverters) are common and critical factors in renewable energy systems that not only provide power generation to the utility grid, but also meet stringent grid specifications. The team learned a lot from Dr. Yaramasu. Therefore, the team would like to thanks again in sponsoring our engineering team project.

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