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

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2 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.

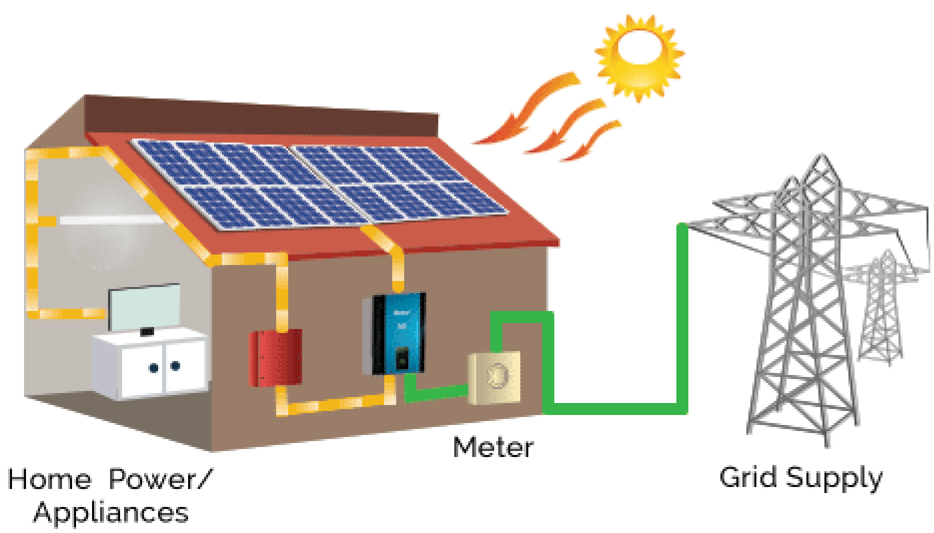

Figure 1-1: Grid Converter [1]

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.

There is no laboratory scale (3-5 kW) prototype convertors available in the market that fit all of the required applications. We need a plug and play convertor to fit the three power conversion applications. These converters will help out client to develop new power converter topologies and test new control schemes such as model predictive control.

In this project, we will be working on multilevel converters using Neutral point clamped topology with model predictive control. We will implement a prototype of multilevel neural-point clamped (NPC) converter for high power applications and test it using model predictive control. Our prototype power level is at 5kW. 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 1.

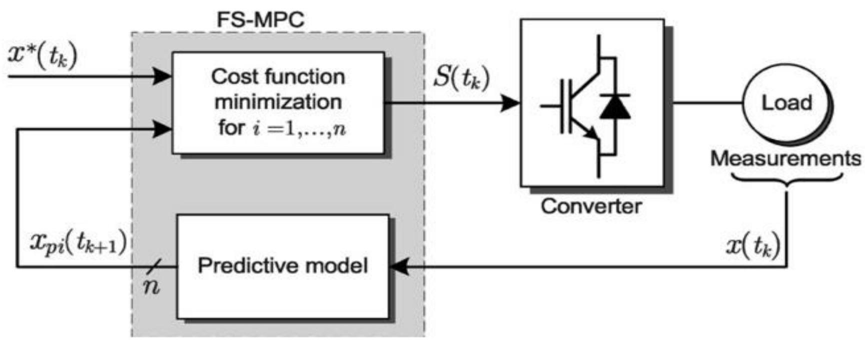

*Figure STYLEREF 1 \s 2 SEQ Figure * ARABIC \s 1 1: Block Diagram of Power Convertor with Model Predictive Control [2]*

5 Research Survey Section

2.1 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.

2.2 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.

2.3 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.

2.3.1 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.

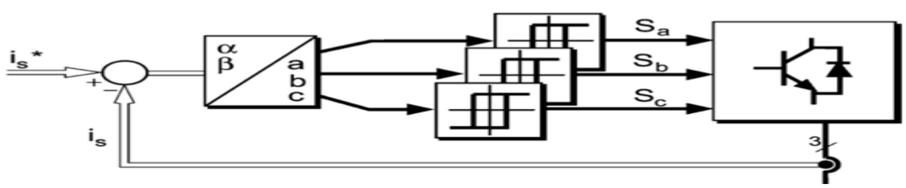

*Figure STYLEREF 1 \s 3 SEQ Figure * ARABIC \s 1 1: Hysteresis Current Control [12]*

2.3.2 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.

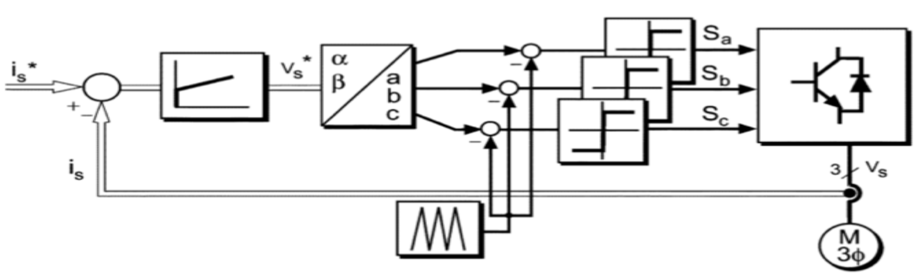

*Figure STYLEREF 1 \s 3 SEQ Figure * ARABIC \s 1 2: PWM Current Control Method [12]*

2.4 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].

3 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.

3.1 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

3.2 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

3.3 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. dSPACE DS1103 is a work platform developed and tested by dSPACE company based on MATLAB/Simulink control system to achieve a completely seamless connection with MATLAB/Simulink.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. SEMIKRON offers IGBT (insulated-gate bipolar transistor) modules in SEMITRANS, SEMiX, SKiM, MiniSKiiP and SEMITOP packages in different topologies, current and voltage ratings. 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

3.4 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

3.5 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.

3.6 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. Designing the grid converter using different layers enables our client to reuse each layer for different power applications.The client's requirement for the team is to preference the digital control schemes will analyze by simulation and hardware. The converter should fit three major power applications.

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) a plug and play converter

5 Project Breakdown

5.1 Overall Design Review

The team implemente a prototype converter for high power applications. At the same time, test the converter to use the model predictive control. For design our product, the team first stage is to design PCB, then we will simulate and test. The team design PCB to consists of 8 layers. The layers mainly include ground layers and others seven PCB layers. Layers will be on top of each other. For size of layers parameters, the width is 132.30 mm, and the length is 228.60 mm. The team stack the layers which can reduce weight, height and size of the converter. Each layers can be reused for other power conversion applications. The voltage and current sensors as shows in the figure 1. PCB layers will be connected using a built in 60 pins connector simplifying the design by reducing wiring. The team PCB's design will run all the input and output signals to the 60 Pins connector which shown in figure 2 and 3. The team design the grid converter using different layers enables our client to reuse each layer for different power applications. The figure 4 is shows the no hanging wires design.

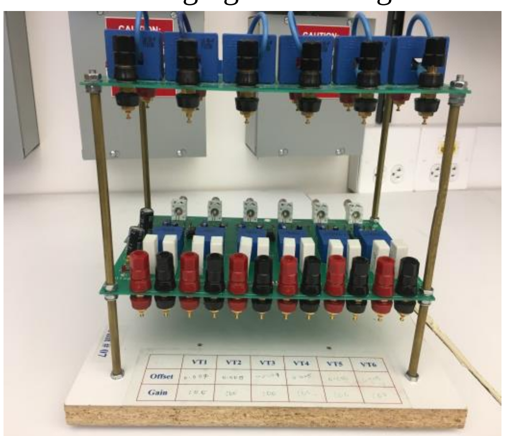

Figure 1

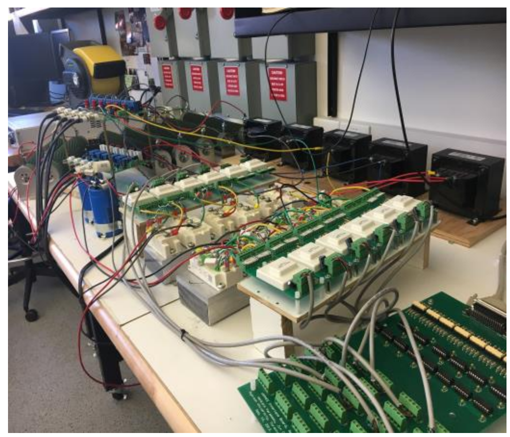

Figure 4

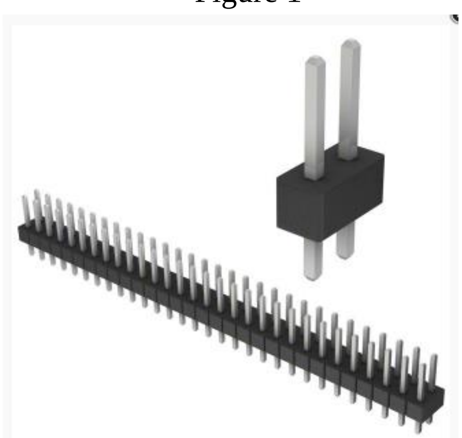

Figure 2

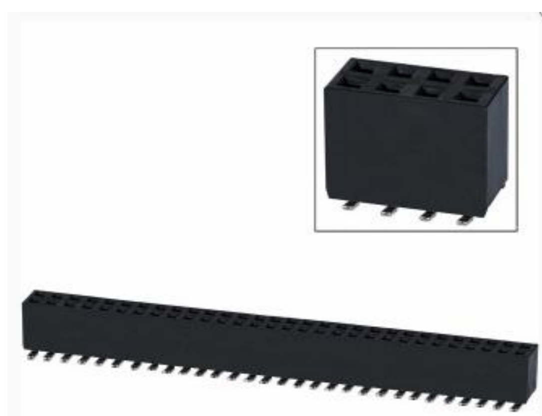

Figure 3

5.2 Subsystems

Layer 1 (Heat Sink)

Heat sink is used in electronic circuit to disperse heat from the component to the surrounding medium and help them to improve their performance, reliability and avoid premature failure of the components. Heat sink work on the principle of conduction, convection and radiation. It helps to cool all the components in electronic circuit and plays very vital role in high power applications. Heat generation in electronic circuit for high power application is very large and therefore it is very important to select a reliable heat sink that disperses the heat very effectively and keep all the component below the required temperature.
There are different types of heat sink available like

1- Active Heat Sinks
2- Passive Heat Sinks
3- Aluminium Heat Sinks

Active Heat Sinks

These heat sinks use active sources for cooling purpose. Fan is a perfect example of active heat sinks. Performance of active heat sink is excellent but it's not good for long term purpose as they need a power source and contains a moving part as well.

Passive Heat Sinks

They don't use any active source for cooling purpose. It used convection process to dissipate heat to the surrounding. It is a most commonly used heat sink as it doesn't require any power source and have no mechanical part as well. It can be used for long term applications as well.

Aluminum Heat Sinks

Normally passive heat sink can be made of any metal but in aluminum heat sink we used aluminum metal as a heat sink. We know that for metal greater the thermal conductivity more efficiently it will transfer heat. Aluminum is a metal with very high thermal conductivity, is very lightweight and inexpensive. Thermal conductivity of aluminum is
235 W/mK.
We will be using aluminum heat sink in our prototype and complete layer 1 is made up of aluminum to absorb all the heat generated by other electronic component and disperses it to the surrounding.

5.2.1 NPC Power Board

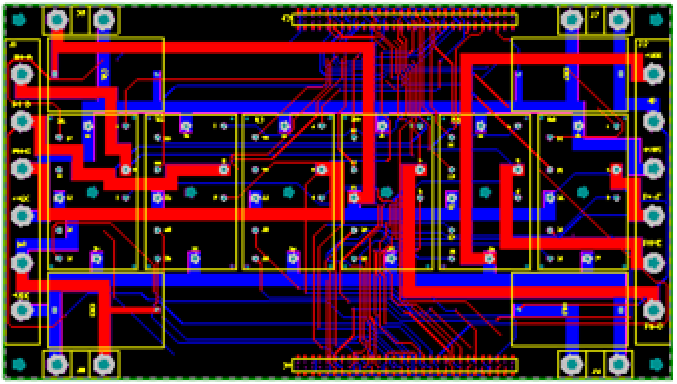

Figure [8]: NPC Power Board

- **What and why**

NPC power board converse three phase power into DC using three "SK20MLI066" switches devices every device has 4 IGBTs models. Furthermore, the NPC power board will be reused for three main high power applications. First application is Motor Drives: AC (fixed v and f) => DC => AC (variable v and f). This application use six switches devices so the input will be AC with fixed voltage and frequency enter to the first three switches devices they convert three phases into DC and the other three switches devices convert DC back into AC with variable voltage and variable frequency. Second application is Wind Energy Systems: AC (variable v and f) => DC => AC (fixed v and f). This application use six switches devices so the input will be AC variable voltage and frequency from the wind generator enter to the first three switches devices that converted to DC and converted back to AC by the other three switches devices with fixed voltage and frequency. Third application is Photovoltaic Energy Systems: DC => AC (fixed v and f). Convert DC to AC with fixed voltage and frequency just by using just three switches devices.

- **Three possible solution**

There are three possible solution are good to use it with our NPC power board. First solution is using "SK20MLI066" this switch device has small size the width=31.00mm and the length=55.00mm and cost around $28.66. Also, the one of "SK20MLI066" switch device has 4 IGBTs so that will reducing the number of switches devices Instead of using 12 of "SKM75GB123D" or "SKM150GM12T4G". Figure [9]. Second solution is using "SKM150GM12T4G" this switch device has big size the width=61.4mm and the length=106.4mm and cost around $111.83. Furthermore, "SKM150GM12T4G" switch device has just 2 IGBTs so if the team chose this switch device we will use 12 switches devices so increasing the board weight and the size. Figure [10]. Third solution is using "SKM75GB123D" switch device, this device has medium size the width=34mm and the length= 94mm and the cost around $47.48. The "SKM75GB123D" switch device has 2 IGBTs so the team have to use 12 of them. Figure [11]. Finally, the best solution for NPC power board is "SKM20MLI066" because it is the cheapest switch device and have 4 IGBTs in one device so that will reducing the weight and size of the NPC power board.

1. **SK20MLI066**

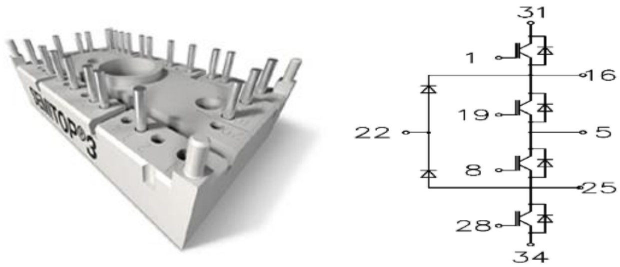

Figure [9]: SK20MLI066 Switch device & schematic

Features

- Compact design
- One screw mounting
- Heat transfer and isolation through direct copper bonded aluminum oxide ceramic (DCB)

2. **SKM150GM12T4G**

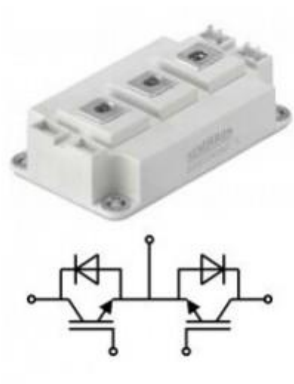

Figure [10]: SKM150GM12T4G Switch device & schematic

Features

- IGBT4 = 4 generation fast trench IGBT (Infineon)
- CAL4 = soft switching 4 generation CAL-diode
- Isolated copper baseplate using direct bonded copper technology
- Increased power cycling capability
- With integrated gate resistor

3. SKM75GB123D

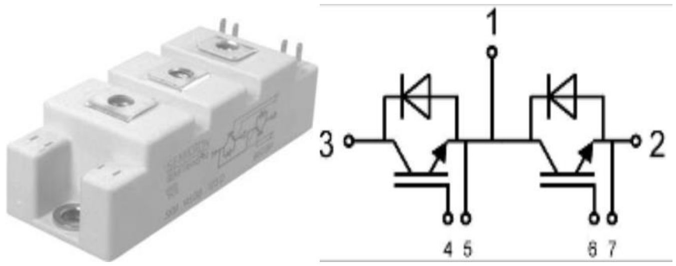

Figure [11]: SKM75GB123D Switch device & schematic

Features

- MOS input (voltage controlled)
- Low inductance case
- Very low tail current with low temperature dependence
- High short circuit capability
- Fast and soft inverse CAL diodes
- Isolated copper baseplate using direct bonded copper technology

Table 7. Decision Matrix

Switches Devices	Cost (30%)	Size (30%)	Number of IGBTs (40%)	Total
SK20MLI066	8	9	7	7.9
SKM150GM12T4G	2	2	5	3.2
SKM75GB123D	5	4	5	4.7

The rating scale is out of 10. 10 is the best and 0 is the worst. The table 7 show that the "SK20MLI066" is the best switch device for our NPC power board because its take 7.9 of 10. And the worst switch device is the "SKM150GM12T4G" because its take 3.2 of 10 as the table 7 shown.

6.1.2 Gate Drivers

Gate drivers are used in high power applications such as wind power systems, photovoltaic systems, and motor drives. NPC power converters are based on the concept of switch mode power electronics. Power switching devices are typically MOSFET's or IGPT's.For the grid-connected converters, IGPT's are used as switches. Converters use a controlling unit that access these switching devices to control switching frequencies. The team is planning to use dSPACE device as a controlling unit. The output voltage of our controlling unit is 5v. On the other hand, the voltage going through the switching devices is around 400v. The low voltage output of the digital controlling unit is not adequate to properly turn on and off switches. Therefore, connecting the controlling unit and the switching devices using gate drivers enables the controller unit to control switches. A gate driver will take the low voltage input from dSPACE. Then, it will provide enough voltage to turn on or off the connected switch. Hence, the first function of a gate driver is that it is the muscle that helps the controlling unit to properly control switches.

In addition, using gate drivers is important due to its electrical isolation features. The cost of the dSPACE is around $15,000. Connecting a 5v digital device to a 400v converter directly puts us in a risk of burning an expensive controlling unit. The ability of gate drivers to help in protecting the dSPACE from being destroyed is enough reason of having such subsystem.

Possible solutions

The design of our NPC converter consists of six voltage phases in total. Three voltage phases are used in the rectifier, and the other three phases are for the inverter. Each phase contains four IGPT's. The total number of IGPT's for the NPC converter is 24. A one gate driver is required for each IGPT. Hence, we need 24 gate drivers for the whole design. The market is filled with various options of gate drivers. Some gate drivers can fit two IGPT's. Three types of gate drivers are analyzed in the following sections to determine which one fits more into our design.

Possible Solutions

The first option is the SKHI 22B R from SEMIKRON. The SKHI 22B R costs around $143.12 [17]. Although the cost is moderate compared to other gate drivers in the market, it has more features. It has a built-in intelligent protection system. This protection system includes the electrical isolation feature between input and output sides which is important for our design. In addition, this type of gate drivers fits two IGPT's. Thus, a total of 12 gate drivers can be used instead of 24. This feature will reduce the size and weight of our converter due to using less gate drivers. According to the datasheet, one disadvantage is that this type of gate drivers require some other components to function properly. These components include additional resistors and capacitors.

Another possible solution is the SKHI 71 R. The cost of buying this type of gate drivers is around $213.36 [18]. The SKHI 71 R is more expensive than the previous one, but this is due to having three channels that can fit three IGPT's at once. This is a great advantage that will reduce the number of gate drivers required to 8. In addition to its high cost, the size is bigger than the SKHI 22B R. Although this gate driver has three channels, its isolation capabilities is lower compared to the SKHI 22B R. Also, it requires some additional electrical components to function properly. Hence, the design has more complexity.

The third option is the SKHI 23/17 R. What is special about this gate driver is that it comes as a one package. All additional electrical components are already included .Hence, it is less complex and ready to use. A trade off is the cost. The SKHI 23/17 R costs around $291.62[19]. Also, it comes with two channels fitting two IGPT's. Moreover, the SKHI 23/17 R has the same isolation capabilities of the SKHI 22B R.

Decision Matrix

A decision matrix is used to determine the best option out of the three options the team might use. The decision matrix is based on four main criteria that are most important to our team. The four main aspects are cost, isolation capabilities, size, and design complexity.

Table 8. Decision Matrix

Gate Driver	Cost (30%)	Isolation (25%)	Size (30%)	Complexity (15%)	Total
SKHI 22B R	8	6	8	4	6.9
SKHI 71 R	4	8	5	4	5.3
SKHI 23/17 R	3	6	6	8	5.4

The rating scale is out of 10. A 10 rating category means the item is good for that specific criteria. The lowest rated gate driver is the SKHI 71 R. This is mainly due to its high cost and big size. On the other hand, SKHI 23/17 R is also scoring low because of its high score. It can be clearly seen that our best option is the SKHI22B R gate driver. The cost of SKHI22B R is medium and has a smaller size compared to the other two gate drivers.

6.1.3 Layer 6 (dSPACE Interface Board)

What and why

dSPACE Interface Board is used for real time implementation of model predictive control. This will Convert TTL logic signals from the dSPACE DS1103-based to CMOS logic (MC14504 component). In order to use the dSPACE there are three different possible solution types of dSPACE available like

1: DS4121 ECU Interface Board, which is available in the market.

2: First generation prototype dSPACE

3: Second generation dSPACE that's fits our requirements.

DS4121 ECU Interface Board

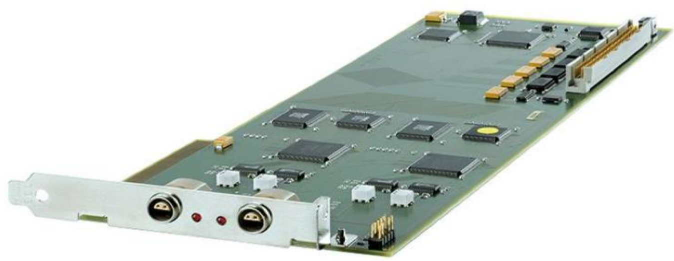

Figure [12] DS4121 ECU Interface Board

●

The DS4121 ECU Interface Board, it's used to connect two electronic control units (ECUs) with a dSPACE modular system [20] . But we can't just use any dSPACE Interface Board available in the market. This is because it has to fit our requirements. Smaller size and it has to have 32 headers to independently control 32 IGBT modules for future use for Dr. Venkata Yaramasu

First generation prototype dSPACE

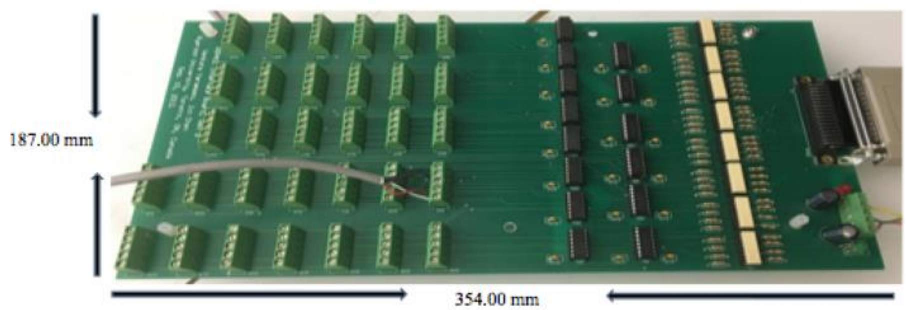

Figure [13] First generation dSPACE Interface Board

- The First generation prototype dSPACE has bigger space, weight and there is not many functions are incorporated with then the board. This will not going to help us because our design will need less space and less weight. This will not make all the stacked layers reduce size, height, and weight of the converter.

Second generation dSPACE

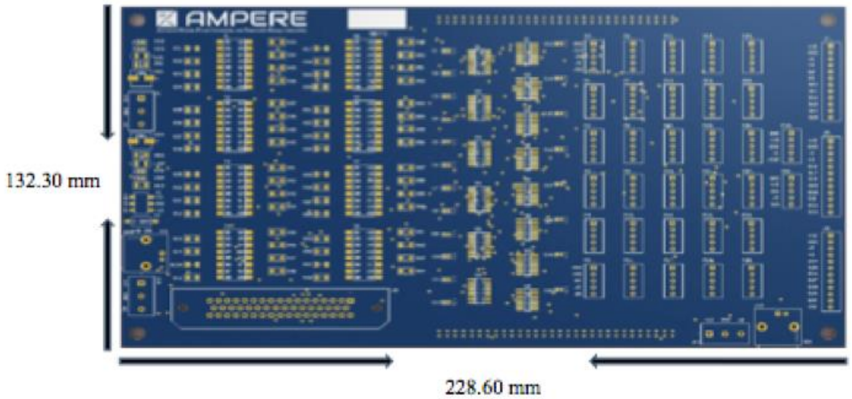

Figure [14] dSPACE Interface Board (DS1103)

- The second generation we needed to design has smaller size and weight. Also, it has more than half of the first generation, yet more functions are incorporated. This will reduce size, height, and weight of the converter. All the Stacked layers will have less space between them and this will reducing wiring complexity, which Dr. Venkata Yaramasu one of his important priority.

6.1.4 Voltage Sensors and Current Sensors

- **What and why**

Our project is a kind of feedback control, which occurs when outputs of a system are routed back as inputs as part of a chain of cause-and-effect that forms a circuit or loop. [1] Feedback is extensively used in control theory, using a variety of methods including state space (controls), full state feedback (also known as pole placement), and so forth. [2] Because our controlling method is based on feedback control, in order to get the feedback of our design, we will use sensors to achieve it. There are three kinds of sensors we probably use.

- **Three Possible solutions**

1) Voltage sensor

Voltage sensor can convert measured power parameters into DC current, DC voltage and isolated output analog signal or digital signal. The voltage sensor is used to measure the voltage or current signal with more serious waveform distortion in the power network. It can also measure non-sinusoidal waveforms such as square wave and triangular wave. Compared with the traditional transformer and shunt voltage sensor has the advantages of high precision, fast response, good linearity, wide frequency band, strong overload and no loss of measurement energy, the voltage sensor has been widely used in electric power, electronics, inverter, switching power supply, AC frequency control and many other areas.

2) Current sensor

Current sensor is a detection device that can sense the current information, and can detect the sensing of the information, according to a certain law into a certain standard of electrical signals or other forms of information required to meet the output information transmission, processing, storage, display, recording and control requirements. Hall current sensor, including open-loop and closed-loop two, the open-loop Hall current sensor is Hall direct open principle, the closed-loop Hall current sensor is based on the principle of magnetic balance. High-precision Hall current sensors are mostly closed-loop. In our project, we will use closed loop current sensor because of its high sensitivity and temperature stability.

3) Pressure sensor

The pressure sensor is able to detect the pressure signal, and according to certain laws of the pressure signal into a useful output of the electrical signal device. Pressure sensor error is unavoidable, we can only choose high-precision production equipment, the use of high-tech to reduce these errors, but also when the factory for some error calibration, to the greatest extent possible to reduce the error to meet the customer need. In addition, it is hard to implement the pressure sensor on the PCB. However, for current and voltage sensors, it is easy to install them on PCB and available on Digi-Key website.

In our project, layers 7 and 8 are current and voltage Sensors which are shown in Fig.1. Layer 8 is current sensor, which is on the top of voltage sensor layer. Each of them has six sensors as shown in the Fig.2. For voltage sensors, three of them are used to measure three phase grid voltages and two DC link voltages are measured by another two sensors. The left one is a backup sensor. For current sensors, it is used to measure three-phase generator currents and three-phase grid currents. Current is measured when flowing through the wire from the red pin input to the black pin output.

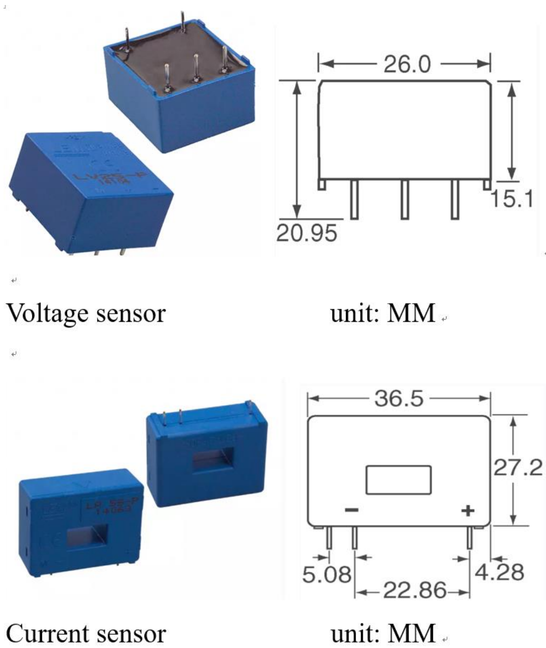

Fig. 1

Fig. 2

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6 Conclusion

The team has been research a lot of data about Digital Control of Grid-Connected Multilevel Converter project. The team implement a prototype converter, and a plug and play converter will be delivered to our client Dr.Yaramasu. The team has two fields which are PCB and simulation. The team completed PCB's design. The second stage which is simulate and test it. For our report, every team member finished their own researches about the project. The team learned a lot from Dr. Yaramasu. Therefore, the team would like to thanks again in sponsoring our engineering team project. We believe that we have capable design product well and satisfies our client.

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