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Dear Dr. Yaramasu,

We would like to thank you again for sponsoring our Standalone Power Converter (SPC) project, it is an honor to be able to work under you. Our team has performed much work this semester and we would like to take a moment to inform you of the progress we have made thus far. Within this design review report you will find a problem definition section where we explain the general overview of the project, we will discuss what each of us have researched and learned about pertinent information regarding SPC's. A requirements and specifications sections will discuss requirements, constraints and wants for our implemented solution and we will conclude with possible design solutions and our final design proposal. A table of contents is provided so that you may easily find what information you are searching for.

Standalone Power Converter Project 2017

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Project Definition

With the depletion of the planets fossil fuels being predicted sometime within the next 100 years it is important for us to begin formulating approaches that will allow for a smooth transition from fossil fuel generators to photo-voltaic and wind turbine generators and with more people living in areas outside the grid there is a priority in trying to find ways to power remote dwellings. Standalone Power Systems (SPS) allow us to power households that lie beyond the grids reach, our SPS needs to be able to continuously produce a steady supply of power so that these households will receive power at all times. Creating an efficient converter will assist the overall system to ensure that the maximum amount of power is stored and transmitted during the conversions between alternating current (AC) and direct current (DC) and from low voltages to high voltages.

Currently much research is being invested into components of the standalone power system to determine how to increase efficiency, lower costs and make the standalone system more viable. Current power converters have many drawbacks that is preventing their use in practical situations, excessive power loss during switching and harmonic distortion cause current converters many issues. Adding too many legs makes the number of switches too large for simple microprocessors to work with and calculating the number of possible results also gets more difficult when we add more switches.

Power converters have many implementations, each implementation has its pros and cons and produce different results. Our team's goal is to preform research into a specific setup, the four leg, 3 phase converter so that we may help grow the amount of knowledge available on this subject to help further developments of future systems. Our power converter may also have potential applications in smaller scale converters for specialized systems such as motors large and small. Successfully constructing this converter and providing accurate and detailed data will help benefit the research community as they will be able to use our research to determine if our setup is a practical solution and what corrections need to be made in order to make our experimental setup more efficient. Our converter may also benefit many of the communities that lie beyond the grids reach such as the Navajo's as our research may help lead the way into developing a viable SPS. This converter will also serve to benefit Dr. Yaramasu as he will build upon his research into power converters by having the functional prototype for future projects.

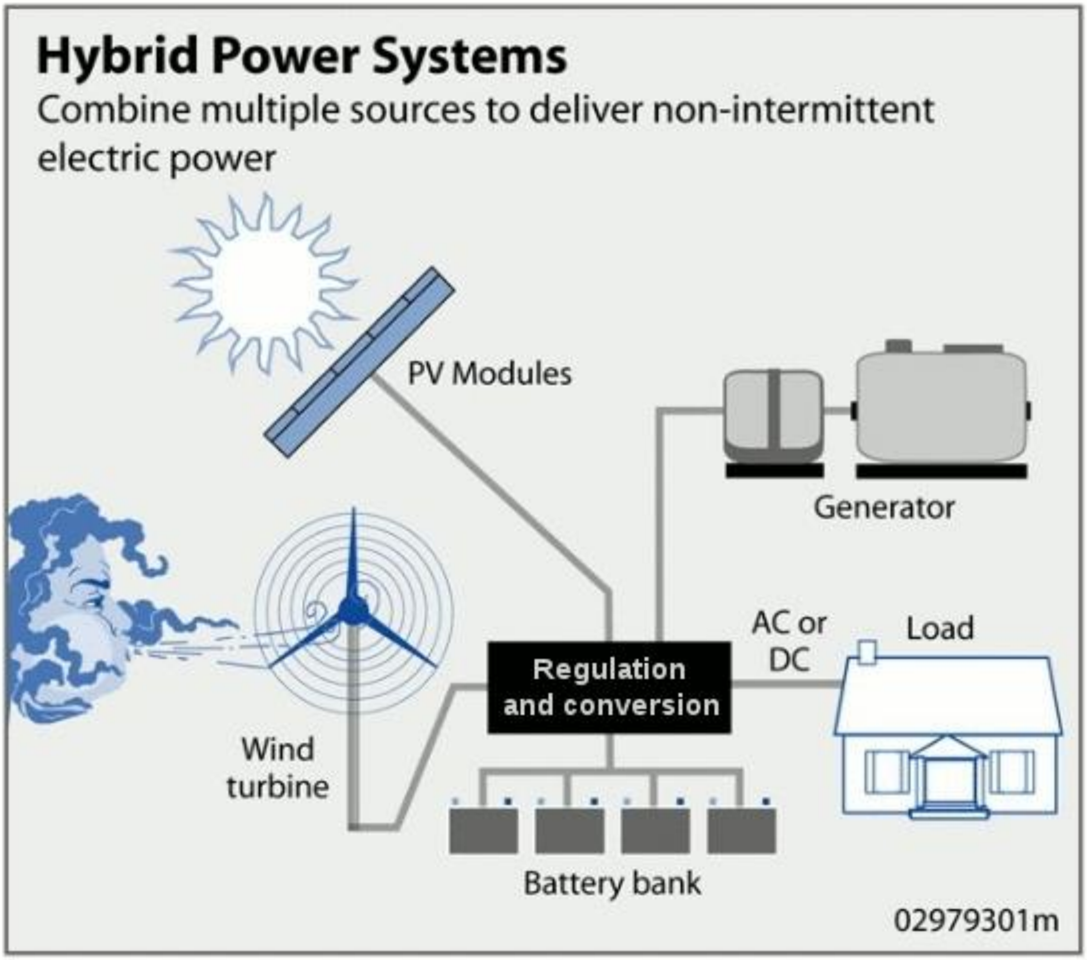

Figure 1. Example SAPS

In Figure 1, we see a brief illustration of the Standalone power system, our team's research is focused on the regulation and conversion portion of the SPS. First a source is needed in order to generate power, this can occur within the form of solar panels (PV Modules), Wind turbines and diesel/gasoline generators. Once the power is generated it excess energy needs to be stored for when the sources are not producing enough energy. Ac power needs to be converted to dc power so that it can be stored within battery banks. Once stored the energy can be used as is, but in most cases the energy must be converted again before it can be used by the consumer. The user interface will be a series of insulated-gate bipolar transistors (IGBT) that will be used as switches which are controlled by a controller utilizing model predictive control to optimize switching. The regulation and conversion block contains the power converters that our team will experiment with to try and determine if our converter setup will yield optimal results.

Research Survey Section

Background

Current SPS utilize two level and three level with three phase converter topologies. These converters convert power from renewable or unrenewable sources (gas powered generator), and batteries store the excess power. The stored power then is converted and filtered into a form that will meet load requirements. While SPCs are useful in low voltage applications, such as street signs, the drawbacks of these topologies become more glaring as the voltage level increases. High power losses and harmonic distortion become a problem causing the converter to be less efficient and large inrush currents that occur while the capacitors charge risk damaging and even destroying legs of the converter if not handled properly [1]. While relays and switches in parallel to a thermistor help protect the circuit, the power losses from these safety measures are too large preventing SPSs from becoming a viable solution for mid and high voltage applications [1].

The technology inherent to our project is model predictive control which will drive our IGBT modules to control the switching in our converter. We will also utilize various capacitors, varistors, thermistors and relays to build our experimental setup onto printed circuit boards (PCB). Board to board connectors will pass signals from one board to another, spacers will lift the boards up over another and a heatsink at the bottom will dissipate the heat generated. We will also utilize various software's such as Altium for board development, MATLAB for virtual simulations and DSpace to run physical simulations. The below sections will highlight important technologies and concepts that our team will need to be familiar with in order to competently build our own converter.

Simulink Research

MATLAB's Simulink technology is a program within MATLAB that allows developers to create circuits on an interface and run simulations as if they had the actual circuit in front of them. Simulink is filled with libraries that contain many forms of circuit elements from simple elements as the voltage source and resistors to more complicated elements such as the 3 leg loads. Simulink also allows developers the ability to create their own libraries and symbols if they element they need is not yet developed. To help us understand how to work with the Simulink software we viewed Siva Naga's YouTube video series Simulink tutorial for electrical engineers [2]. This tutorial goes over creating simple circuits, how to find circuit elements and how to run simulations. However due to the fact that MATLAB changes the architecture of its libraries yearly some of the symbols in Naga's videos are not in those directories, and some elements are no longer compatible with other ones. We will have to do independent research into the MATLAB documentation to figure out what we need to do.

Simulink mainly include analysis instructions, masking procedures, model construction and module library three parts. Simulink supports discrete and continuous linear and nonlinear systems, and can also be applied to various simulation systems with different sampling rates [3]. The visual simulation environment Simulink is used for modeling, simulating and studying nonlinear control, power system, communication system and other systems. Its advantages are its streamlined operation and when the user makes the simulation it can build up the mathematical modeling of the research system and simulate it [3].

Three Leg Inverter Research

The three level converter, an existing inverter topology that is in use within SAPS. Utilizing the articles provided from Dr. Yaramasu we have a head start in understanding how these converters work. Independent research on Google Scholar has yielded a few promising articles as well, one of those articles being "Comparative Study Between Two And Three Level Converter For Electrical Application" by the International Journal of Advances in Engineering & Technology. This article discusses the different types of three level converters that exist, provides figures for they look like and a pros and cons of each. The three most common 3 level topologies that are currently available are the diode clamped converter, the flying clamped converter and the cascading converter [4]. While we are not expected to use a three level converter for our project this article and the books provided by Dr. Yaramasu we have a better understanding of the goal of a converter circuit, to efficiently convert power over from different subsystems throughout the overall system.

The unique structure of the three-level voltage converter is that they can be used without transformer in series because the output reaches low harmonic voltage. Significantly reduced harmonic content of the output voltage waveform. Compared with the two-stage inverter, three-level inverter has smaller output voltages. In addition, the switching frequency of the output waveform provides an effective signal, which is double the actual switching frequencies output [5]. Three-level NPC converter compared to the standard two level converters adds a number of improvements. They are most commonly used is the application of wind energy, one of them is the power converter. Half the DC-link capacitor can only stand in the DC-link voltage, so the converter can handle twice the voltage and power values as a two-level converter [5].

Pulse Width Modulation Research

Another topic our team conducted research into was pulse width modulation (PWM). The concept itself is not a difficult subject to understand, we create a generator that pulses a square wave constantly over time. We need to understand what PWM actually accomplishes within the SAPS. By reading the textbooks Dr.Yaramasu provided and running Simulink simulations we were able to look into the effects that pulse width modulation plays into the SAPS. PWM can be used to create a reference voltage that is used within comparators and an output voltage gets generated according to the comparison results. The faster the pulses the smoother the output voltage curve but will require more power [6].

DC-DC Converter Research

Boost Converter can be used to boost output voltage. By using an inductor, the input current can be stable and a capacitor is used to generate a constant output voltage. Since it works efficiently and small in size, it is a good choice to use. Comparing these types of converters, the cost of Boost Converter can be cheapest. However, this design is known to cause large ripples in the output voltage [7].

The buck converter is used in SMPS circuits where the DC output voltage needs to be lower than the DC input voltage. Beginning with the switch open, the current in the circuit is zero. When the switch is first closed, the current will begin to increase, and the inductor will produce an opposing voltage across its terminals in response to the changing current [7].

The Buck – Boost converter can turn up or down the output voltage and the range of the output voltage is bigger than the input. It operates with 4-switch topology to set the circuit as diodes. Buck - Boost converter can retain a constant output voltage whatever the varying input voltage, but the current output is discontinuous [7].

The Ćuk converter is one type of DC – DC converter that can give higher output voltage or lower output voltage than the input voltage. Also, this converter converts current into voltage, then voltage into current. This converter works when either of the switches are open or closed by using the energy stored in the capacitor. Using only a capacitor instead of inductor is the main thing that makes this converter different than the other converters [8].

PCB Research

Our team researched the details of PCB design because we need to convert wind energy into electricity, we need AC-DC converters and DC-AC converters. The design circuit consist of different components placed into the PCB board. I have learned some knowledge of the PCB design from Youtube. I have gained some information from my professor. The following is what I know about the PCB. A printed circuit board (PCB) mechanically supports and electrically connects electronic components using conductive tracks, pads and other features etched from copper sheets laminated onto a non-conductive substrate. Components (e.g. capacitors, resistors or active devices) are generally soldered on the PCB. Advanced PCBs may contain components embedded in the substrate. PCBs can be single sided (one copper layer), double sided (two copper layers) or multi-layered (outer and inner layers). Conductors on different layers are connected by bore. Multi-layer PCBs allow for much higher component density [9].

Two Level Converter Research

The two-level converter is a converter that produces an output voltage or current with a level of either zero, positive, or negative. Compared to three level converters, the two-level converter produces less voltage, and its total converter distortion is reduced. The inverter gain is the ratio of AC output to DC input voltage. It has a unique structure that enables it to reach high levels of energy without the use of transformers. One of the useful articles about two level inverters is "HVDC converter". The article illustrates the working concept of two level converters [10]. When the upper of the two valves in a phase is turned on, the AC output terminal is connected to the positive DC terminal, resulting in an output voltage of +½ Ud with respect to the midpoint potential of the converter. In 2-level inverter the efficiency of the whole system is dominated by the rectifier losses in light loads. So, this two-level converter has better efficiency than the normal HVDC, which means better efficiency at rated power means also smaller heat sink and better reliability [10].

Classical Control Research

While the topic of classical control will not be used in our project it is still relevant knowledge we can learn from. Classical control theory is a branch of control theory that deals with the behavior of dynamical systems with inputs, and how their behavior is modified by feedback, using the Laplace transform as a basic tool to model such systems. Classical control theory deals with linear time-invariant single-input single-output systems. The Laplace transform of the input and output signal of such systems can be calculated [11].

Altium Designer Research

Altium Designer is a PCB design software, an electronic design automation software package for printed circuit board, FPGA and embedded software design, and associated library and release management automation [12]. They provide electronic circuit editing functionality including: component library management, schematic document editing, and pre-layout signal integrity analysis. Printed circuit board design module allows: dynamic display of clearance boundaries during routing, component footprint library management, automatic trace routing, automated multi-channel layout and routing and so on. By using this software, the design of the convertor can be fixed [13]. For designing printed circuit boards (PCB's) we will be using the Altium software. We have been provided several resources by Dr.Yaramsu in order to learn the designing process. Also, YouTube is full of tutorials on how to learn designing PCB's using Altium.

Standalone Power System Research

Standalone power system with integrated design has high reliability and fully autonomous operation. The majority of users use it for agricultural and pastoral areas, scattered households without conventional power protection, remote household liquidity and strong field work units and river, lake, sea fishing operations without electricity and power shortage areas that need specialized design and manufacture [14]. Electricity is typically generated by one or more of the following methods: Photovoltaic system using solar panels, wind turbine, geothermal source and the like. Standalone power systems are designed to operate independent of the electric utility grid, and are generally designed and sized to supply certain DC and/or AC electrical loads. Worldwide, standalone solar installations are very popular. For example, in stand-alone photovoltaic power systems, the electrical energy produced by the photovoltaic panels cannot always be used directly. This system is an excellent system for providing electricity economically [15].

Model Predictive Control Research

The problem under investigation is how we can use the predictive converter to achieve voltage stability for wind turbine based on power controls. Because solar and battery energy is intermittent, they are connected to the direct current (DC) to compensate for the fluctuating power levels and regulate the bus voltage. The technology that is needed is that of maximum power point tracking (MPPT) for checking of photovoltaic (PV) systems and control of DC-DC converter for charging and discharging battery storage system. A system controller should be used and tested through different steps to increase input of the wind turbine [16].

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Requirements and specifications

Mechanical Requirements

Our Converter needs to be 228.6 mm by 132.2 mm and implemented over 5 layers. For our weight, since it will be in an enclosure we won't move after installation so weight will not be a factor. All of our parts need to be provided by companies that Dr. Yaramasu has accounts for such as Amazon, Digikey, Newark and Semikron. Our interconnections are constrained by the floors need to attach using vertical pins, and the wiring must work with the IGBT. Our design will not require any sort of packaging. To protect our design we are constrained by a heatsink, and we want our converter to be enclosed in metal, similar to that of transformers.

Size (Width, length, height) mm	228.6 x 132.2 x 5 layers (board spacing TBC)
Weight	Not a Concern
Organization	AMPERE Laboratory
Interconnections	Board to board connectors (Exact connection TBC) and spacers.
Package	NEMA Enclosure
Protection	Heatsink

Table 1: Mechanical Requirements

Electrical Requirements

Since we will be attempting to power households with our converter will need to run under conditions that it would experience out in the field. We would like to have our measurements be as accurate as they possibly can, in the field we are unsure of how accurate we can get but for simulation purposes our system is as accurate as we determine it to be. Our interfacing is constrained by Semikron's IGBT circuits that will control our switching state, and we need an off switch similar to a circuit breaker on our Nema enclosure. We would like our converter to last as long as the house does but we are not focused on making a lasting circuit but an efficient one. Our system is constrained by the consumer needs; three-phase, 5 Kw 208 line to line volts at 60 Hz to produce a dc voltage of 367V.

Power	5 Kw, 208 line to line voltage at 60 hz with a dc voltage of 367 V (expected to be scaled down)
Accuracy	MATLAB calculation accuracy
Values, Ranges	200-400 Volts, 60 Hz, AC and DC voltages (expected to be scaled down)
Interfacing	IGBT switching circuit (powered by a separate controller) DSpace (for physical tests)
Aging	Not a Concern

Table 2: Electrical Requirements

Environmental Requirements

Because our power converter is going to be in an indoor Nema enclosure we do not have to tailor our circuit for extremes in weather. We do not need to focus on disasters for our circuit either, that is we don't need our converter to be flame retardant or resistant to drops. Since our Nema enclosure is indoors we will not need to worry about other factors such as mold, or exposure to sunlight. Our converter needs to be able to operate at room temperatures, with 30-50 percent humidity, low vibrations and shock.

Temperature	25 degrees C (room temperature)
Humidity	30-50 percent humidity (room humidity)
Vibration, Shock	Not a Concern
Dust, mold	Not a Concern

Table 3: Environmental Requirements

Documentation Requirements

We need to provide a manual that will go over circuit operation and some trouble shooting, due to the high voltages it is not recommended that the user attempts to fix or alter the converter without a trained electrician. Because of this we will not create a user’s manual or maintenance guide to encourage our customer to call a professional if problems should arise. Our team is constrained to using Latex and Adobe Illustrator for creating a manual.

Operator’s Manual	A full schematic with trouble shooting tips
Maintenance Manual	None needed, it will be inside the operators manual
User’s Guide	Not a Concern, only a certified electrician should work with this
Platform	Abode Illustrator (visuals) and Latex (text editor)
Code	Not a Concern

Table 4: Documentation Requirements

Software/GUI Requirements

In order to obtain accurate simulation results our team will need to utilize software that can create and interact with our power converter. Building the PCB’s that our circuit will be built on will also require a PCB editing software. Various programming languages exist that can help us model our circuit but we need to be careful to only select a language that can be used for most if not all of our simulations. With the tools that we have been provided by Dr. Yaramasu, all of our code is constrained to MATLAB Simulink. We are also constrained to utilizing the Altium software to create our PCB’s and we are also constrained to use DSpace for simulation purposes.

Code	Mathematical relations and formulas.
Language	MATLAB
Software Required to Use	MATLAB, Simulink (for digital simulations), DSpace (for physical circuit testing)
GUI’s Required to Use	Simulink

Table 5: Software Requirements

General Requirements

We need our converter to be fully function at all times. We need our SAP to be self-calibrating, thus a model predictive control scheme (MPC) to allow the SAP the ability to adjust its parameters automatically will be utilized. However the MPC is not a part of our scope so our team will not be concerned with it. Since we are sourcing many parts from many vendors our vendor preferences are listed below. Since we will be producing data for research purposes our preferred client is going to be other power converter researchers who could use our results to help improve upon our proposed design.

Reliability	Should operate 24/7 without going under threshold voltage (that value will be determined later)
Self-Calibrating	Predictive control (not developed by us)
Vendor Preferences	Amazon, DigiKey (general circuits and parts) Semikron (IGBT modules) E-TERNET (PCB) Wakefield (heatsink) Ampheon (Cables)
Client Preferences	Researchers and developers of standalone power sytems

Table 6: General Requirements

Project Break Down

Our project will need multiple systems to ensure our converter functions properly. We will need a system to dissipate heat from the voltage converter board to protect the circuit elements to prevent premature failure. The switches on the voltage converter board will need to be adjusted to ensure the converter is running at its most efficient state for a given load requirement. To test our boards through DSpace we will need a way to connect test sources to the boards to the DSpace control panel. Finally, in order to test signals we will need a way to read voltages and currents without having to open the converter or taking the boards apart.

Heat Dissipation

With the high switching frequency our board will be expected to undergo allot of heat will be generated. In order to protect the components we will need to develop a system that will pull heat out of the circuit to prolong our circuit's lifetime.

Possible Solutions

Nothing: Our team could let the circuit run without any system in place to cool it outside of the ambient air, while this may work in cooler regions this would cause problems in hot environments such as the desert.

Heatsink: Utilizing a heatsink we can pull heat from the circuit to the bottom of a metal plate which has many cuts under it, air flowing between these will pull heat from the heatsink.

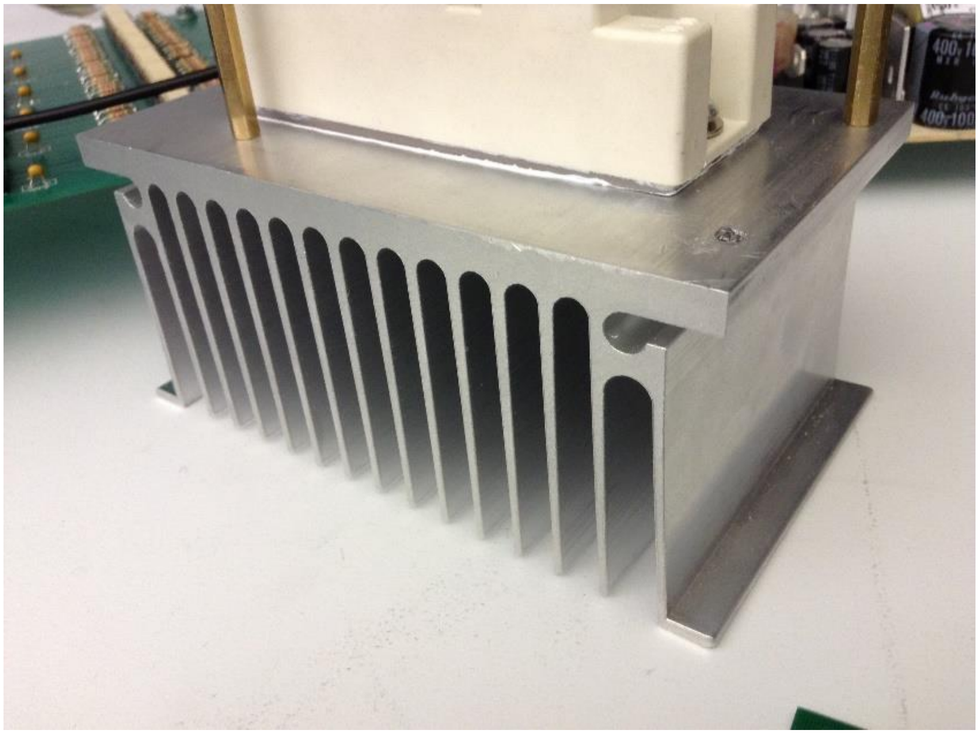

Figure 2: Heatsink

Fan: Our team could attach a fan(s) to blow heat off of the circuit. It could also be possible to attach fans to the heatsink to increase airflow.

Power Conversion

The power generated from the source may need to be changed to a different form so that it can be stored into a battery. The power from the battery, or source if we do not use battery storage, would need to be changed so that the consumer can be able to power what they need to run.

Possible Solutions

Two-level Voltage Source Converter: A two-level voltage source converter is the simplest topology to implement but is less efficient as the voltage level increases.

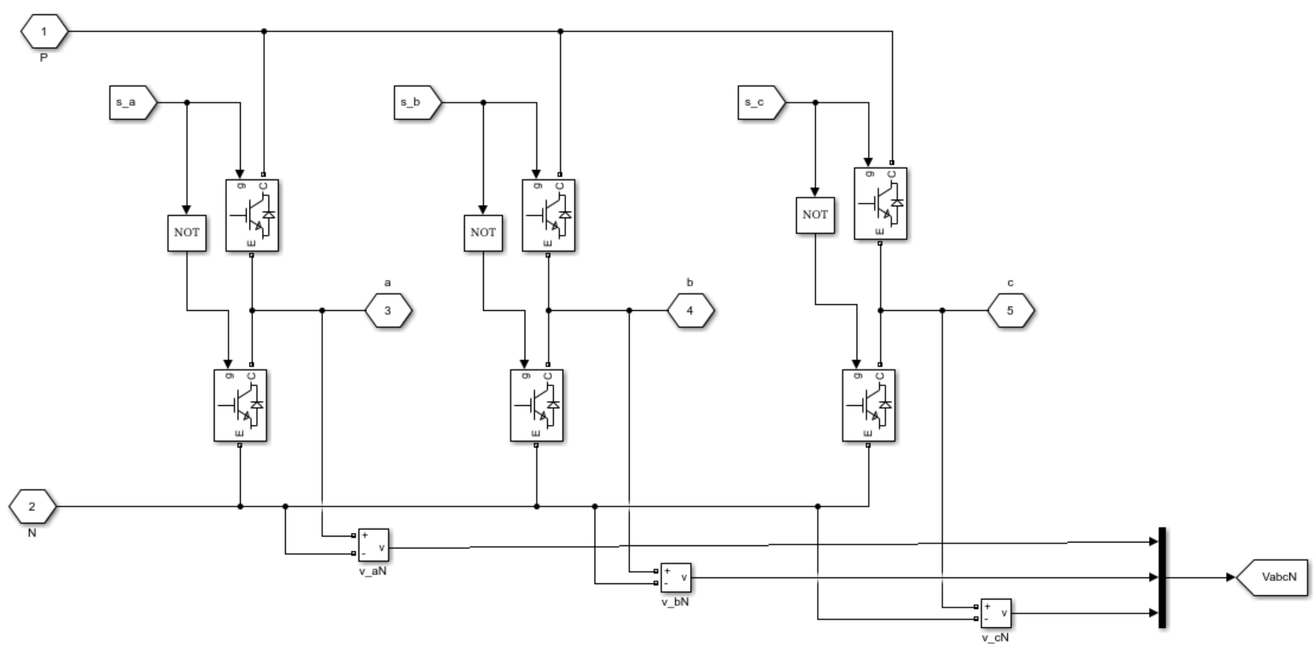

Figure 3: Our teams model of the two-level voltage source converter

Three-level Voltage Source Converter: A three-level converter is more complex to implement but will contain more possible switching states and levels out output voltages. This will also require a more powerful processor for switch control.

Four-level Voltage Source Converter: A four-level converter is not a well-studied topology and requires complex math and a large amount of computational power.

Switch Operation

Our converters utilize switches to control the output signals. Depending on what requirements our load has, that will change over time, we need to find a way to adjust the switches to ensure the circuit is running at an optimal condition.

Possible Solutions

Human Control: We could have the consumer change the switches manually with the aid of a guide to describe when the switches should change.

Wireless Microcontroller Control: Utilizing a microprocessor like the Arduino we can program it to send signals to a motor that will change the switching state of the converter.

Programmable Gate-Drivers: Utilizing IGBT’s circuitry we could purchase a gate-driver that can be controlled using a cost function algorithm that would be developed by us.

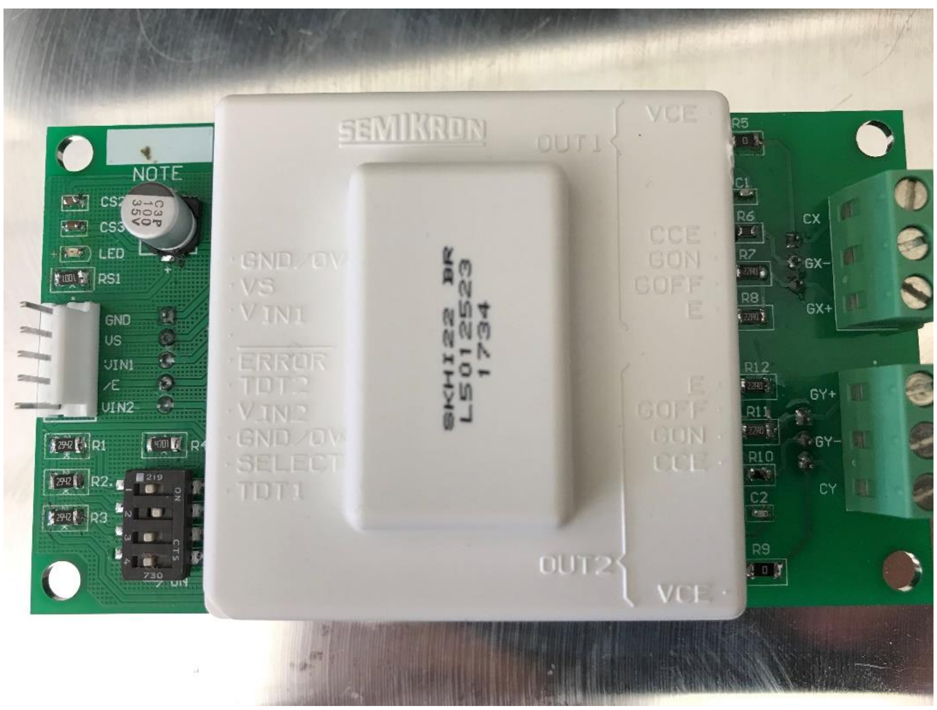

Figure 4: Our teams gate drivers

Interfacing

Our prototyping environment will utilize DSpace, as such our circuit will need a way to communicate with the control panel and other external components such as filters and power supplies.

Possible Solutions

Each board has an interface circuit integrated into itself: By having the interface circuitry integrated into each board each board will have the ability to connect to the control panel.

A single interface board that can work with all the boards independently: By having a board dedicated to having connections for all components we can decrease the size and complexity of the other boards.

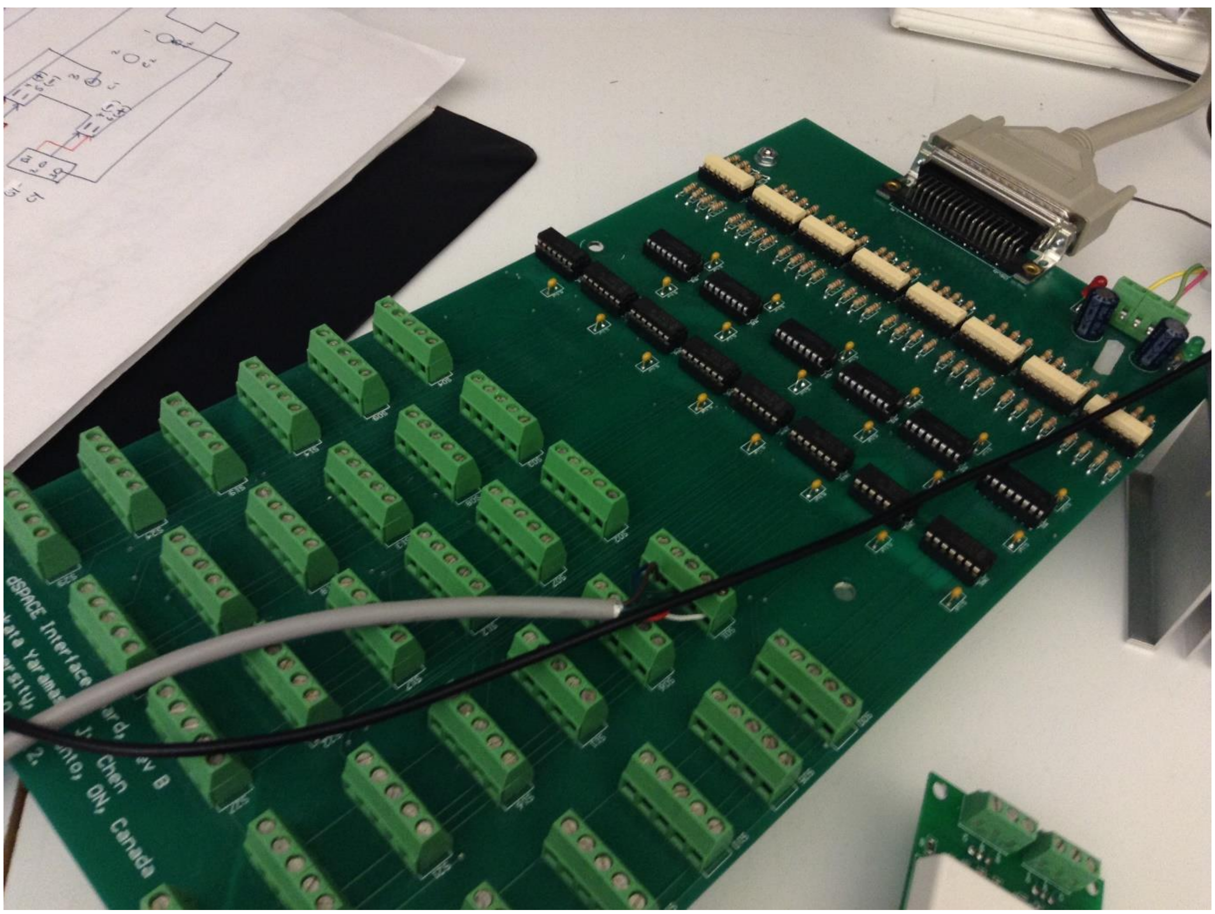

Figure 5: Our teams interface board

Measurements

A requirement of our project is that we have a way to measure internal and external signals utilizing the design of a previous sensor in a previous project.

Possible Solutions

Improve the design of the first generation current and voltage sensors: Our team has been using smaller components to make the boards smaller.

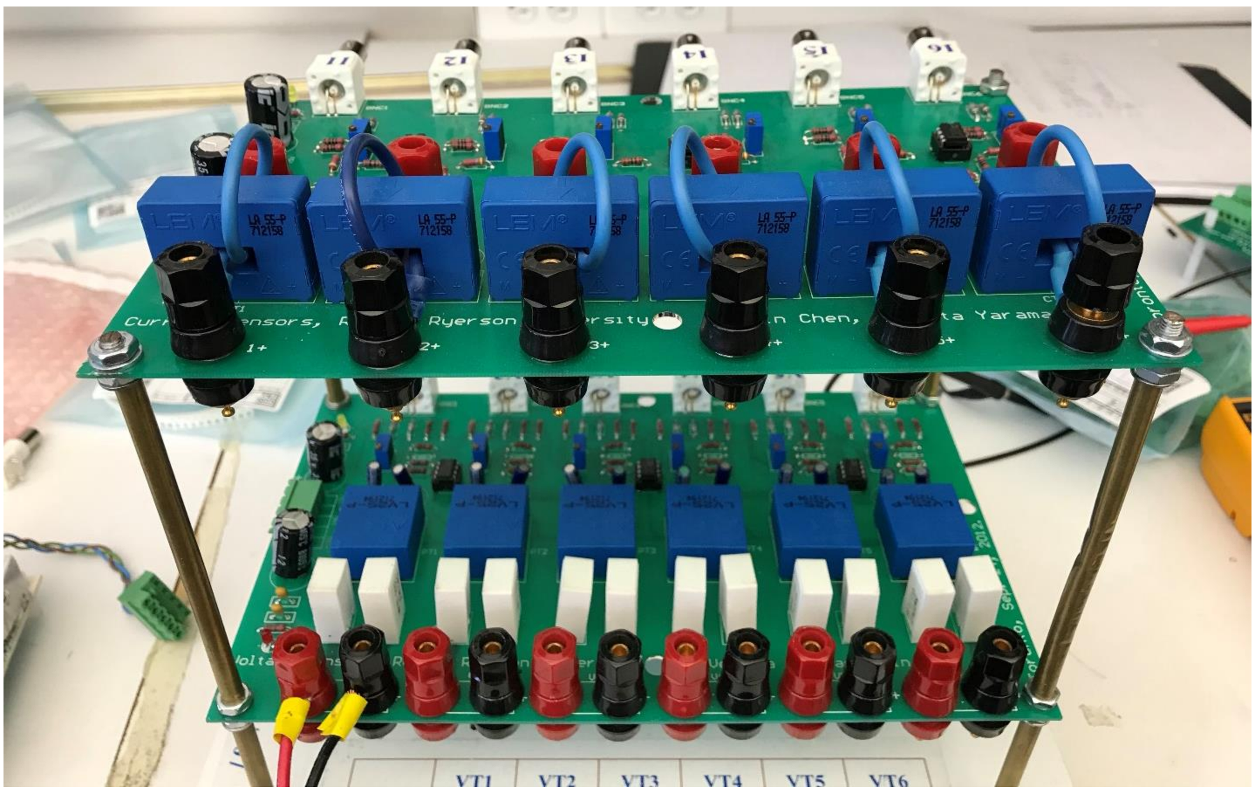

Figure 6: The first generation current and voltage sensors

Design Review Conclusions

Our team after researching the parts necessary for our subsystems has decided to implement a 6 stack converter, each stack will contain each subsystem necessary for converter operation. We have chosen this option with the advice of Dr. Yaramasu because his previous projects have the boards spread horizontally, this takes up allot of space. Our hope is that by experimenting with building up will help make prototyping and transport easier. Our team has split our subsystems up into stacks because of this, if each stack works on one function it becomes easier to test our boards and diagnose problems. Lastly our team will utilize 16-pin and 60-pin converters to send signals from board to board, our team will try to organize the stacks to minimize the distance a signal needs to travel.

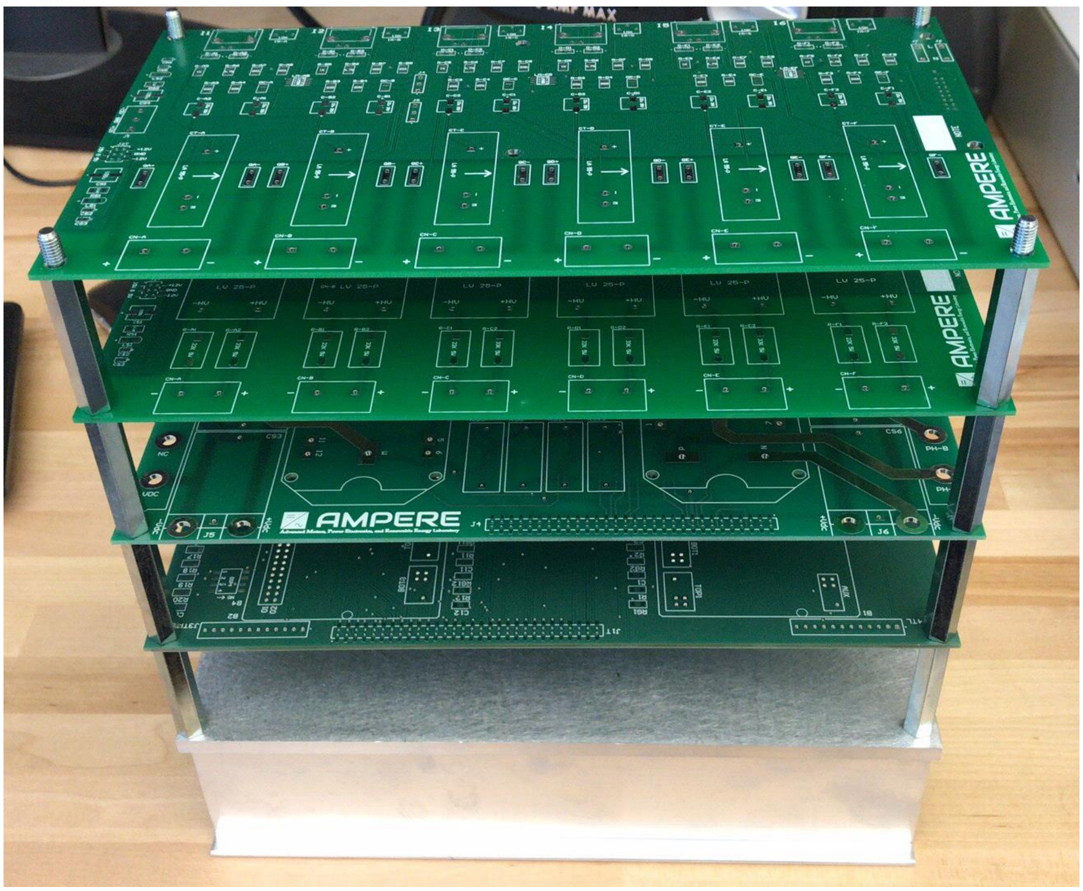

Figure 7: Our proposed strategy for combining all of our subsystems