DEVELOPMENT OF LABORATORY MODULE FOR SMALL WIND TURBINE CONTROL SYSTEM

DESIGN DOCUMENT

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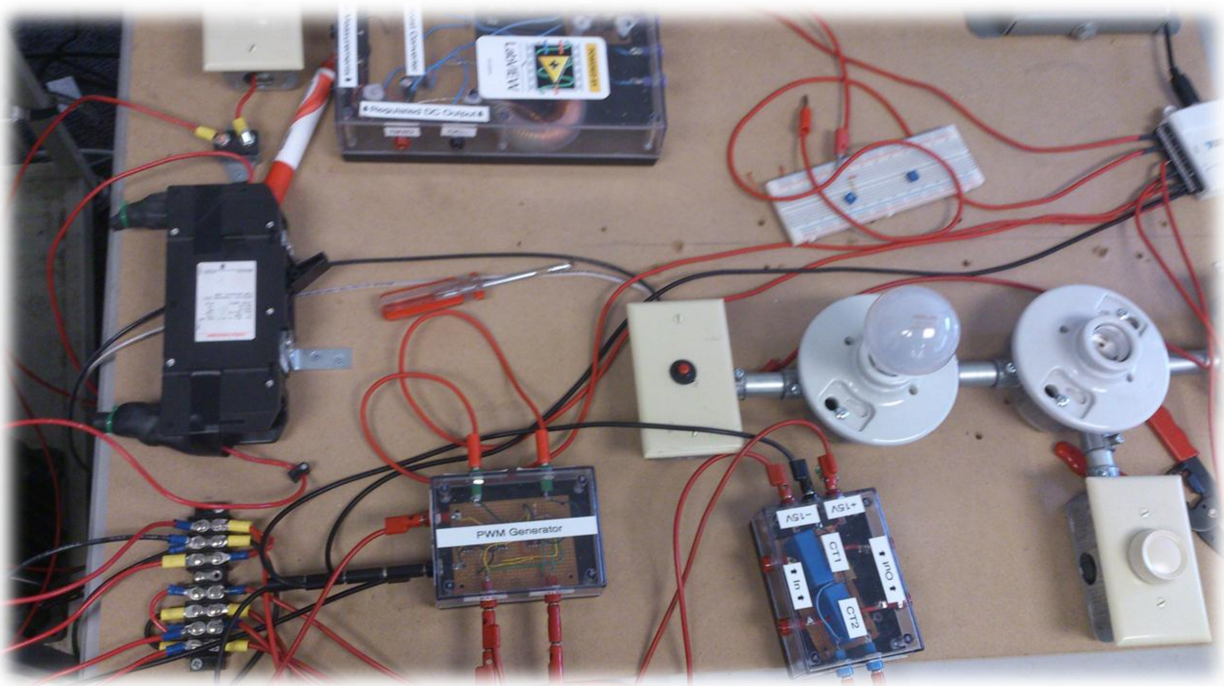
CONTENTS

INTRODUCTION

This project acts as an educational tool for students learning about the effects of wind energy on a power system. The objective of the project is to take wind measurements and simulate the power output to the system. Being Phase V of the project, our goal is to improve the existing system and build upon or alter Phase IV according to the required specifications.

ORIGINAL SYSTEM

Phase IV left us off with new rearrangement of circuitry, the power from the turbine now flowing directly into the inverter. We had batteries bypassing the system unless the system needed the backup energy or when the batteries need charged. The buck-boost converter, PWM, diode rectifier, and new motor/mount were all added to the system, resulting in the motor being the primary power source for the load.



INTENDED USE

This project main objective is aimed to be an educational tool to grasp the technology used in wind turbine systems. Besides the hardware, we also will have user interface that will allow the user to monitor and adjust the system to have wind or backup power for our adjustable load. Currently our system is located in the power systems lab but we hope to add mobility as an option for the user.

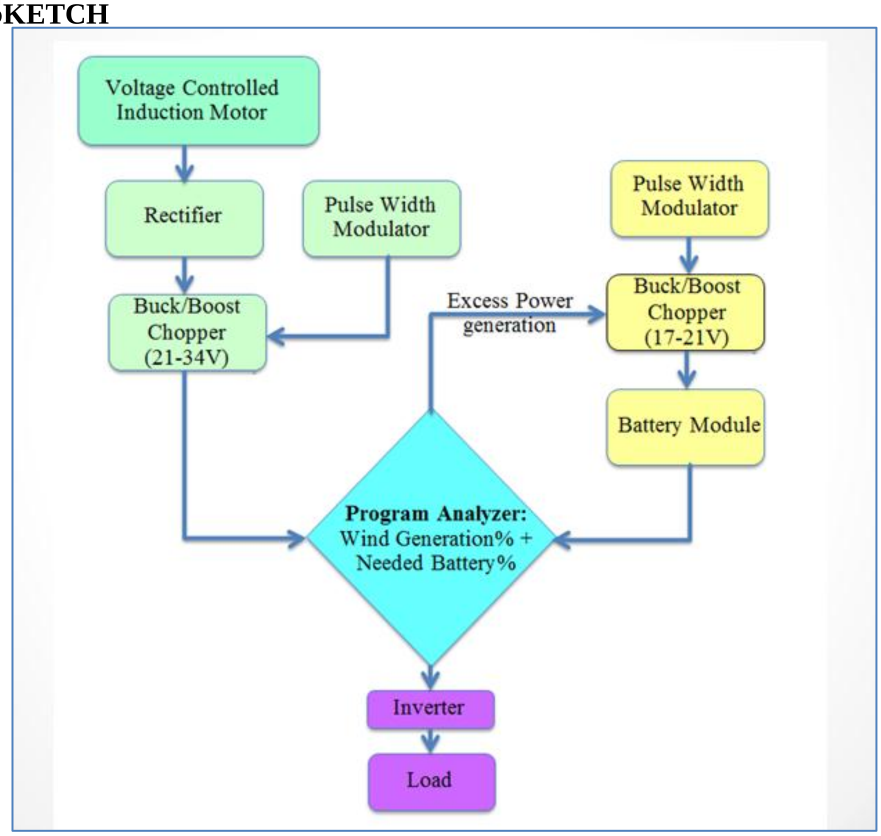
Operating Environment

When simulating the system, everything will be done in a controlled lab environment where the induction motor will be mounted to a table. The original design of the wind turbine was going to be placed on a building in the university, however due to safety reasons that got changed. Therefore, the project is centrally located in our power systems lab. Since our AC induction motor is in replace of our wind turbine, we will manually record our readings at set values relating to our wind sensor. The wind senor will accurately record real wind conditions so we can simulate the system to see the results.

System Updates

Currently at this stage we have implemented a change in our rectifier design to optimize our results. We found faults in our circuit wiring that we changed to match schematics of the system. We changed Buck-Boost converter to Boost converter only, since we found that there is no need to buck the voltage in our design. In addition we fixed our Buck-Boost converter since we found internal wiring complications that needed to be reconnected.

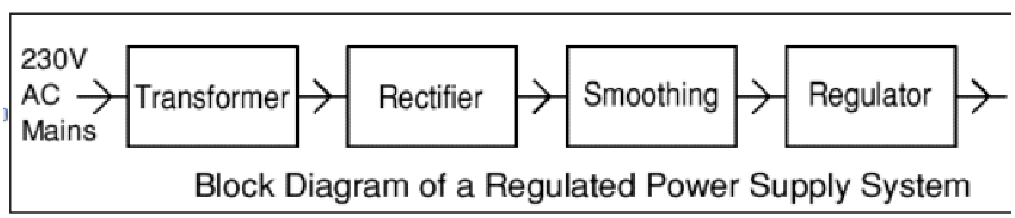
Concept Sketch



Rectifier

This is one of the very crucial component of the whole system, although it looks simple. It basically converts the variable AC input from the Induction motor, which simulates the Wind turbine into variable DC. The output of the rectifier can be sent into to the Boost Converter for further processes. As a consequence of this all the components must be rated to handle high Voltage and Amperage. We designed the rectifier based upon advanced Wheatstone's bridge and coupled it with a voltage regulator, so that the output has low tolerance. One of the important components of a rectifier is the Diodes, as per project requirements we chose MUR8100E, which was rated for high power and good response rate. We ran some simulations using Matlab PLECS and the following are our test results:

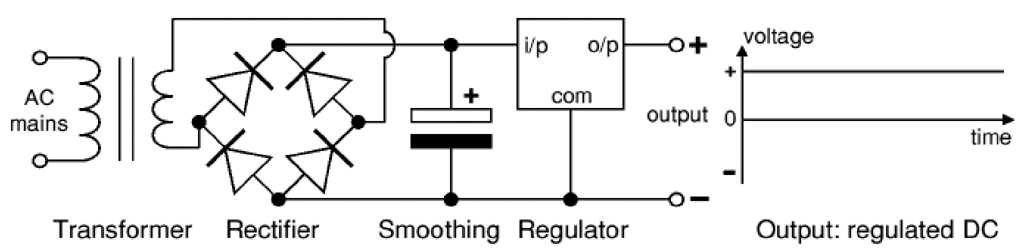
System's-Level Diagram



135 V DC

Expected Output

Transformer + Rectifier + Smoothing + Regulator



The **regulated DC** output is very smooth with no ripple. It is suitable for all electronic circuits.

System Break-Down

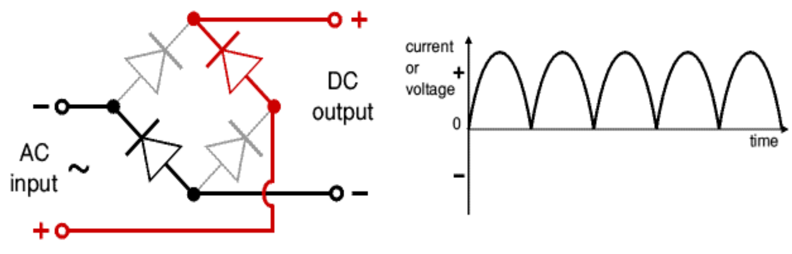
- The **transformer** steps down the high voltage 230 V AC mains to low voltage AC. The equation we used is as follows:

$$\text{turns ratio} = \frac{Vp}{Vs} = \frac{Np}{Ns} \quad \text{and} \quad \text{power out} = \text{power in}, \quad Vs \times Is = Vp \times Ip$$

Vp = primary (input) voltage
Np = number of turns on primary coil
Ip = primary (input) current
Vs = secondary (output) voltage
Ns = number of turns on secondary coil
Is = secondary (output) current

- In order to obtain the required out put voltage, we used a transformer with 4:1 turns ratio.

- The **full-wave rectifier** converts AC to DC, but the DC output is varying.

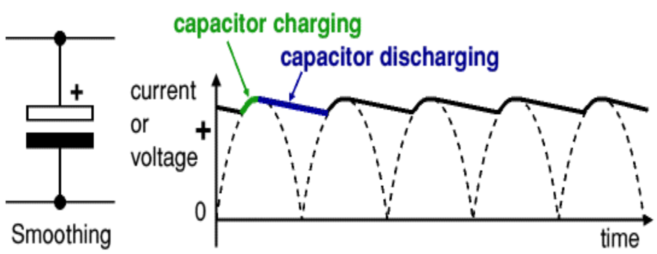


Bridge rectifier
Alternate pairs of diodes conduct, changing over the connections so the alternating directions of AC are converted to the one direction of DC.

Output: full-wave varying DC
(using all the AC wave)

- We built the bridge rectifier using four individual diodes of 1.8 V forward voltage.

- **Smoothing** involves using a capacitor to create a small ripple from the varying DC output

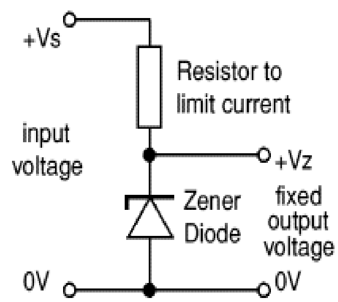


- We used a 12.5 uF capacitor connected across the DC supply to act as a reservoir, supplying current to the output when the DC voltage from the rectifier is falling. The capacitor charges quickly near the peak of the varying DC, and then discharges as it supplies current to the output. However, smoothing is not perfect due to the capacitor voltage falling a little as it discharges, giving a small ripple voltage. The equation we used to find the capacitor value was as follows:

$$\text{Smoothing capacitor for 10\% ripple, } C = \frac{5 \times Io}{Vs \times f}$$

C = smoothing capacitance in farads (F)
Io = output current from the supply in amps (A)
Vs = supply voltage in volts (V), this is the peak value of the unsmoothed DC
f = frequency of the AC supply in hertz (Hz), 50Hz in the UK

❖ Finally, the **regulator** eliminates ripple by setting the DC output to a fixed voltage. We designed a simple voltage regulator using a resistor and a zener diode connected in reverse as shown below:



Regulator

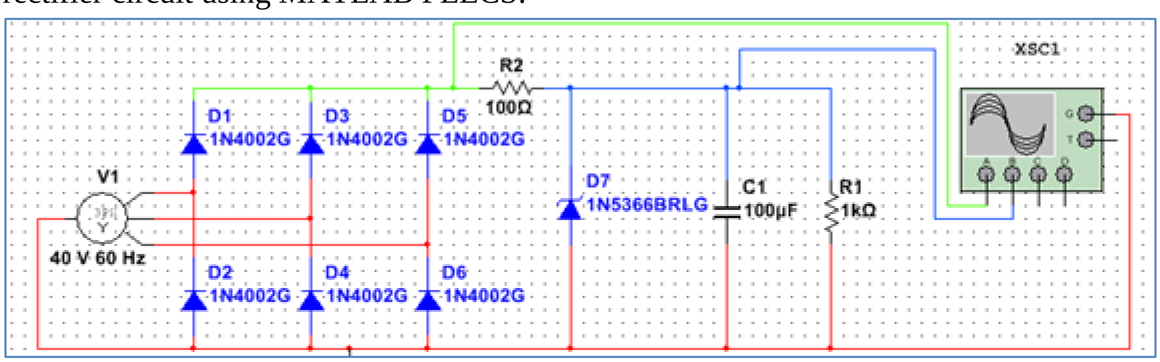
❖ The resistor serves to limit the current, therefore the current through the resistor is constant, so when there is no output current, all the current flows through the zener diode and its power rating must be large enough to withstand this. We chose the values of the zener diode and the resistor in the following manner:

1. The **zener voltage Vz** is the output voltage required
2. The **input voltage Vs** must be a few volts greater than Vz
   (this is to allow for small fluctuations in Vs due to ripple)
3. The **maximum current Imax** is the output current required plus 10%
4. The **zener power Pz** is determined by the maximum current: Pz > Vz × Imax
5. The **resistor resistance**: R = (Vs - Vz) / Imax
6. The **resistor power rating**: P > (Vs - Vz) × Imax

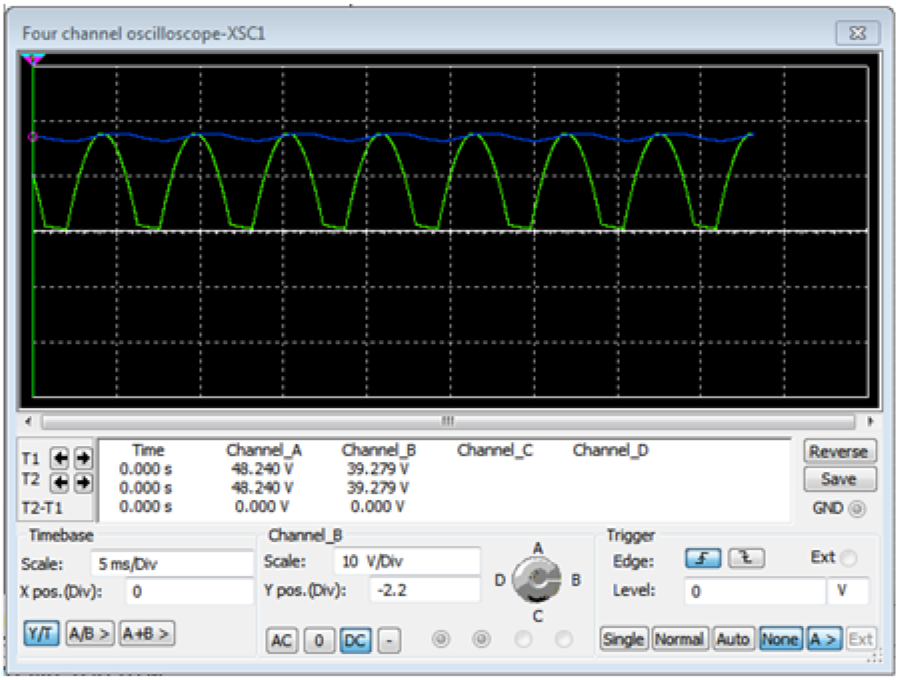
Our zener diode and resistor values were 157.5 V and 100 ohms respectively.

Final PLECS Design

With all said and done, the following was the design that we put together for our rectifier circuit using MATLAB PLECS:



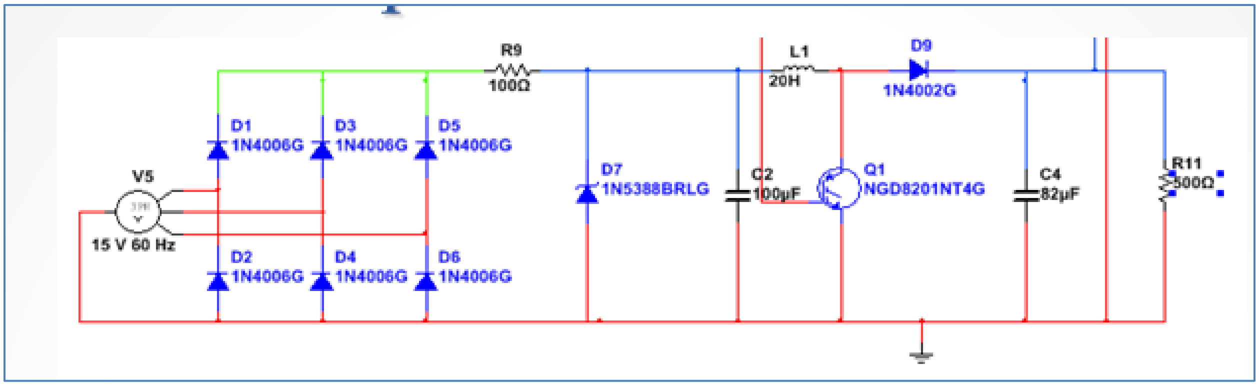
When we simulated our circuit for two outputs: current and voltage, the output was as we had expected a fixed voltage of around 39 V:



Buck Boost Converter

A buck boost converter converts DC voltages to DC voltages. It will either step up the voltage (boost) of step it down (buck). Operation of a buck boost converter depends on the switching frequency (how much the switch turns on and off per second) and the duty cycle of the IGBT (the percentage of the amount of time the switch is on). These are controlled by a Pulse Width Modulation (PWM) circuit.

In this project, the buck boost converter is connected to directly after the rectifier so that constant DC voltages are attained for the inverter load of the converter. The circuit set up is shown below:



Note:

- The buck boost converter will be in discontinuous mode i.e. when an inductor falls to zero during a commutation cycle (the inductor is completely discharged). The output voltage not only depends on the duty cycle, but also on the inductor value, the input voltage and the output current.

- The output voltage should be between 18-24 VDC which is required by the inverter. The equation used to calculate this is shown below:

$$V_o = \frac{V_i}{1-d+r_L(1-d)} \quad \text{or} \quad V_o = -\left(\frac{d}{1-d}\right)V_i$$

- The load R is the inverter
- V_i is the rectifier output voltage
- The inductance should be large enough to support the load (inverter)

$$L > \frac{(1-d)^2 R_{load}}{2f_{sw}}$$

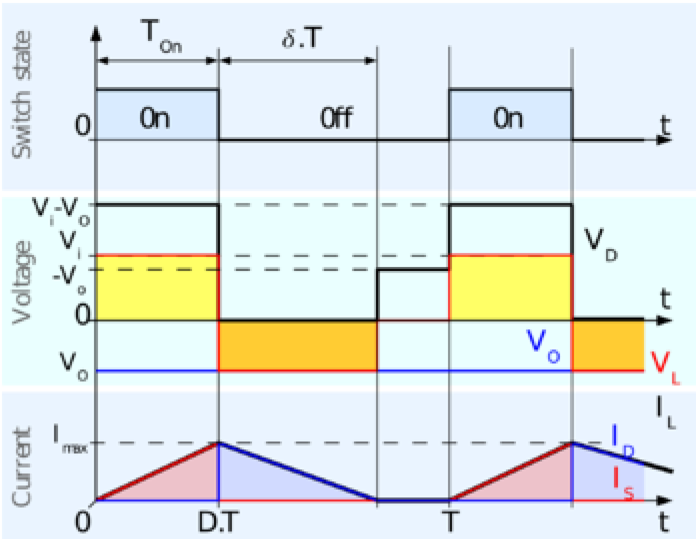
- Since a buck boost converter operates under the switching frequency f_{sw} and the duty cycle d of the IGBT, S, an IGBT with a favorable switching frequency of the converter should be chosen

$$f_{sw} = \frac{1}{t_{ON} + t_{OFF}}$$

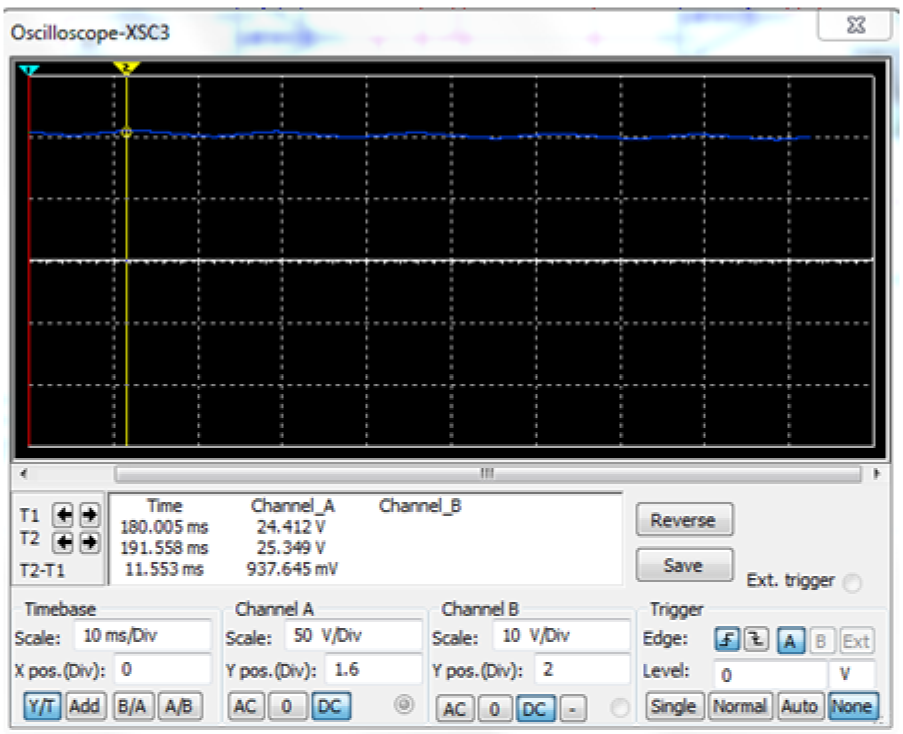
$$d = \frac{t_{ON}}{t_{ON} + t_{OFF}}$$

(where t_{ON} = amount of time the IGBT if on and t_{OFF} = amount of time the IGBT is off)

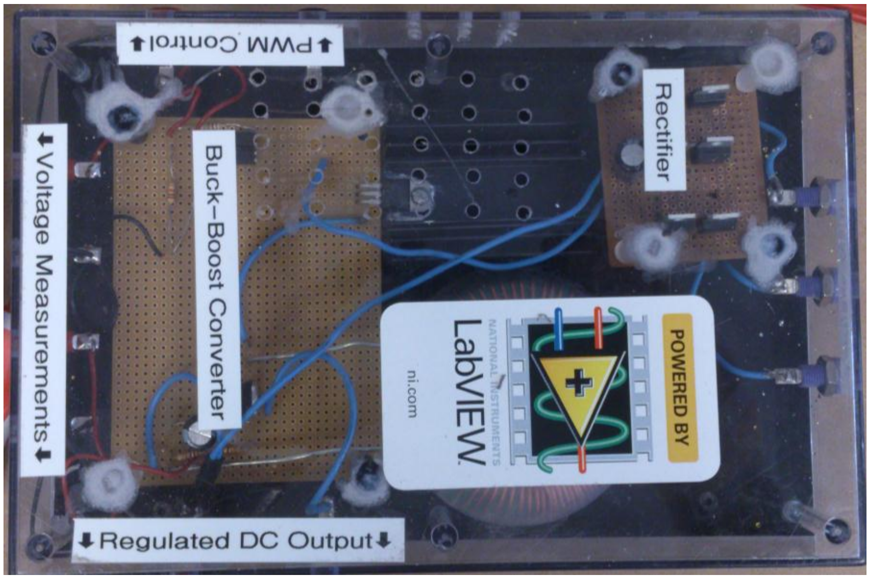
Expected plot:



Actual Graph



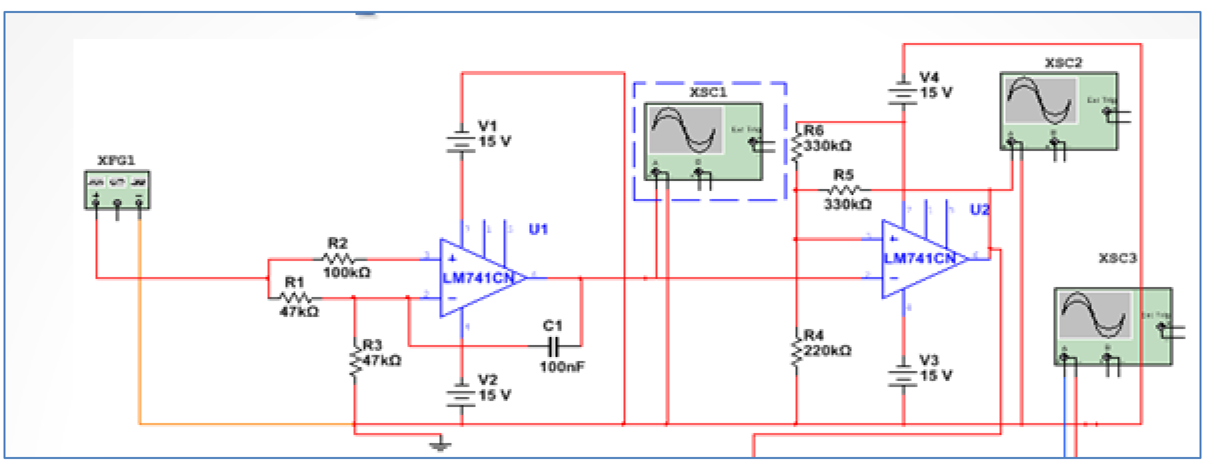
Hardware design



Phase IV Rectifier and Buck Boost Converter

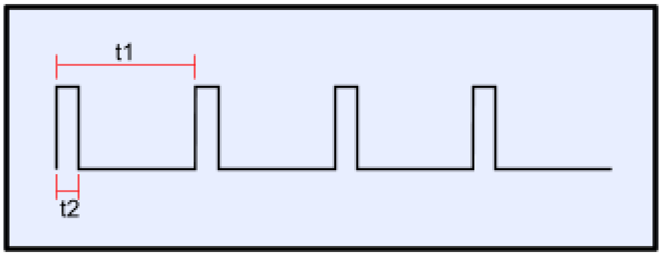
PULSE WIDTH MODULATION

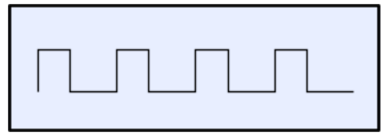
Pulse **W**idth **M**odulation is a powerful way of controlling analog circuits and systems, using the digital outputs of microprocessors. Defining the term, we can say that PWM is the way we control a digital signal simulating an analog one, by means of altering it is state and frequency of this.



PWM signal

This is how a PWM signal would look like:

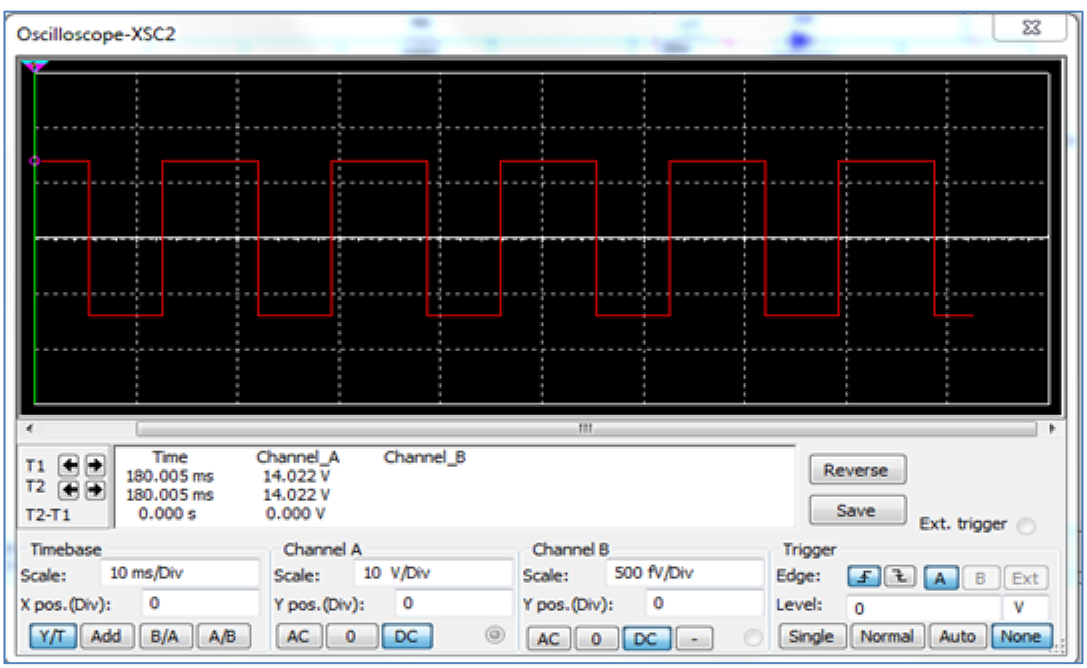




Square wave

The PWM is actually a square wave modulated. This modulation infects on the frequency (clock cycle) and the duty cycle of the signal. A PWM signal is characterized from the duty clock and the duty cycle. These are the basic parameters that characterize a PWM signal. The clock cycle is essentially the frequency of the signal measured in Hz. Whereas, the duty cycle has to do with the switching time of the signal. The clock cycle is measured in Hz and the duty cycle is measured in hundred percent (%). The main advantage of PWM is that power loss in the switching devices is very low. When a switch is off there is practically no current, and when it is on, there is almost no voltage drop across the switch. Power loss, being the product of voltage and current, is thus in both cases close to zero. PWM also works well with digital controls, which, because of their on/off nature, can easily set the needed duty cycle.

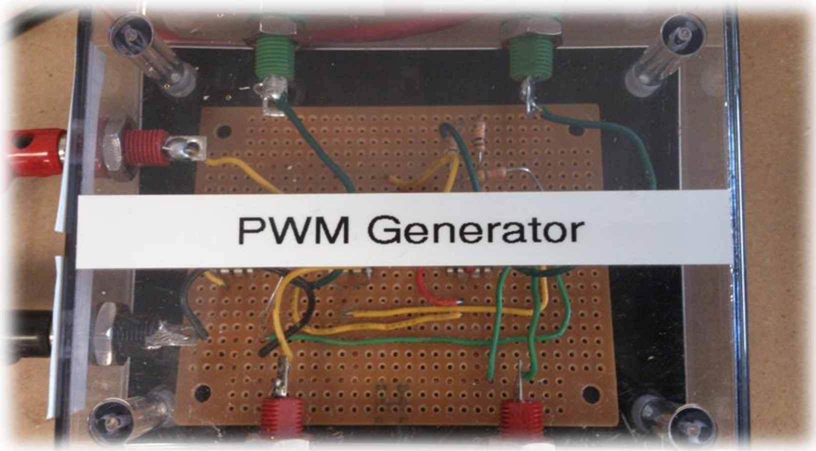
Actual graph



Power Control

The purpose of the Pulse Width Modulation (PWM) circuit, which is controlled using LabVIEW, with regards to our project, is to control the duty cycle and switching frequency of the IGBT of the buck-boost converter. The frequency and the duty cycle of the PWM circuit is controlled using an analog voltage outputs of the USB-6008. The principle behind its operation is that the pwm uses a rectangular pulse wave whose pulse width is modulated resulting in the variation of the average value of the waveform. By altering the duty cycle, we can alter the power delivered by the supply. And because the waveform is a square wave, the power supplied each time is calculated by:

$$\mathbf{P_{DELIVERED} = P_{SUPPLIED} \times DutyCycle}$$



Phase IV PWM Generator

WIRING

One of the most significant issues, which we came across when debugging Phase IV of our project, was the circuit wiring. All wires were tangled, color weren't consistent, not properly secured and labeled. This hindered our circuit analysis and also confused us a lot, as a consequence of this we have decided to label everything and also color code, for example power source is red, ground is black, intermodal connections can be two or more colors and have a physical legend, so it is easier for an individual to understand and visualize the schematic better and efficient.

BATTERY

When there is no wind present, a backup source is needed to the power the load. For this task, the system uses two 12V batteries in series with each other. This amount of voltage used is used is due to the minimum of 21V needed to be delivered to the inverter. In order to prevent damage to the batteries, the voltage level shouldn't exceed 26 volts or go lower than 17 volts.

Specifications

Model: UB 12120 12V 90Ah

Constant Voltage charging at 20˚C	Voltage regulation	Initial current
Standby use	13.6-13.8V	13.5A
Cycle use	14.5-14.9V	27A

UB 12120

DATASHEET

The following are some of the datasheets for the components we intended to use after researching each and every element, which were the best fit for our design.

- ☑ Diode Datasheet
- ☑ Regulator Datasheet
- ☑ Induction Motor Datasheet

REFERENCES

"Buck–boost Converter." *Wikipedia*. Wikimedia Foundation, 14 Oct. 2012. Web. 27 Oct. 2012. <http://en.wikipedia.org/wiki/Buck–boost_converter>.

"PWM Modulation." *PWM Modulation*. Web. 27 Oct. 2012. <http://pcbheaven.com/wikipages/PWM_Modulation/>.