DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

design document for

12 VDC / 120 VAC POWER INVERTER

submitted to:
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EXECUTIVE SUMMARY

Mobility and versatility have become a must for the fast-paced society today. People can no longer afford to be tied down to a fixed power source location when using their equipments. Overcoming the obstacle of fixed power has led to the invention of DC/AC power inverters. While the position of power inverter in the market is relatively well established, there are several features that can be improved upon. A comparison analysis of the different power inverter has been compiled. Aside from the differences in power wattage, cost per wattage, efficiency and harmonic contend, power inverters can be categorized into three groups: square wave, modified sine wave, and pure sine wave. A cost analysis of the different types of inverter shows that sine wave power inverter, though has the best power quality performance, has a big spike in cost per unit power. Another feature which can be improved is the efficiency of the inverter. The standard sine wave in the market has an average efficiency of 85-90%. Power dissipated due to efficiency flaws will be dissipated as heat and the 10-15% power lost in the will shorten operational life span of inverters. The quality of the output power could also be improved. It is imperative that the output signal be as clean as possible. Distortion in the output signal leads to a less efficient output and in the case of a square wave , which has a lot of unwanted harmonics, it will damage some sensitive equipment.

In designing any type of power supply, it is important to examine the intended market and place the product in a particular niche market. Our market niche will be to design a 300watts power inverter that will provide optimum pure sine wave performance with minimal cost. In meeting the design requirements, there are several technical challenges that must be overcome. Our single, most difficult constraint will be to produce power at a lower power per unit cost than exists in the market. Our efficiency will be greater than 90 percent. This insures that, with a maximum load, less than 10% of power will be dissipated as heat. The total harmonic distortion will be less than 5 percent. With a total harmonic distortion this low and a pure sine wave output, we will be able to power even the most sensitive loads.

The fundamental step in approaching the challenges was to examine the methods used by existing companies for building power inverters. In examining their methods, many areas were open for potential improvement. These areas include the DC/DC step up converter, the DC/AC inverter, and the feedback control system. The DC/DC step up converter in our design will use a high frequency transformer, enabling us to reduce the size of the converter considerably. The use of a high frequency transformer will also enable us to meet our efficiency constraint. A high switching frequency will improve the efficiency of the inverter. In theory, a 100 percent efficient converter could be created. However, due to the limitations of actual device material, our efficiency will be between 90 and 100 percent. The DC/AC inverter circuit will use a microprocessor to digitally pulse the transistors. This will allow us to produce a pure sine wave output. This feature will also allow us to enter other markets more easily. For instance, in Europe the fundamental frequency is 50 Hz. The frequency can be changed from 60 Hz to 50 Hz by simply editing the source code. The feedback control system will be used to regulate the output voltage of the DC/DC converter. This is necessary since the current will vary will the load. The feedback control system will be accomplished using by sampling the output with an integrated circuit.

Most of the design constraints set for the inverter were met. However, the one important constraint which the power inverter didn't meet was the 300W continuous power, which was probably because of the transformer and the traces on the PCB. The inverter produces a clean sine wave with 7% of harmonic distortion and has efficiency greater than 90%. Overall, it is a well designed project and a lot has been accomplished over the two semesters. This design if well marketed, will offer the power inverter market a premium product at a lower cost than before. Future work could be done to further improve efficiency, total harmonic distortion, and size. With these additional improvements, the standard could be raised for future DC/AC power supplies.

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1. PROBLEM

Power inverters, regardless of size, are typically constructed of a DC-DC converter and a DC-AC inverter. These are the two major circuit components that work together to convert the input voltage from a vehicle battery into a desirable AC output waveform. In the U.S., the standard AC output waveform consists of a voltage of 120 VAC and a frequency of 60 HZ. Due to this standard,

Electronic mobility has always been an issue when it comes to our mobile environment. Therefore, a mobile means of providing AC voltage is needed. The majority of portable electronic devices are more easily powered using 120 VAC. When these devices need to be used in a remote or mobile setting there is a problem. Most people have access to 12 VDC generated by the standard power supply system of a mobile vehicle, such as an automobile, ATV, or agriculture equipment. A power inverter of DC to AC type will be needed to convert 12 VDC to 120 VAC with acceptable power output.

Power inverters were first invented using a square wave as the output form. This led to many different problems involving the functionality of devices that were being powered because they were designed to work with a sine wave instead of a square wave. There were some changes made to the hardware to eliminate the harsh corners from the square wave to transform it to a "modified sine wave". It was mainly marketers who coined the term "modified sine wave" which in all reality is nothing more than a modified square wave. Power inverters that used a "modified sine wave" did not eliminate the problems associated with square wave inverters. They did however, minimize these problems. Although most people without a background in electronics do not know the difference, a "modified square wave" can have detrimental effects on electrical loads. First of all, abnormal heat will be produced, causing a reduction in product reliability, efficiency, and useful life. Another disadvantage of a "modified sine wave" is that its choppy waveform can confuse the operation of some digital timing devices. This can cause a device to perform undesirable or abnormal functions. Also, nearly 5 % of household electronics will not even work with a modified sine wave. The advantages of a true sine wave inverter are usually reflected in the final market price. The average cost of a true sine wave inverter is between $200 and $500. We have estimated that we can build a true sine wave inverter for about $150.

Power inverters are usually described as having either a high or low switching frequency. Switching frequency refers to the rate at which the input DC voltage is oscillated to create an AC output. Low frequency inverters oscillate a DC voltage at 60 Hz. Then they step that voltage up to the desired amplitude using a bulky and a heavy transformer. High frequency inverters, on the other hand, use a small and lightweight transformer. A high frequency inverter will produce many harmonics near the range of the switching frequency. However, most of the harmonics are relatively higher in order than the 60 Hz fundamental frequency. These harmonics can be isolated using a small low-pass filter. In turn, isolation of harmonics will result in less buzzing in audio equipment and less interference in other electronic equipment such as radios and televisions.

When you think mobility, a unit that's the size of a laptop doesn't seem awfully large. But consider the trend in electronics these days, a laptop seems gigantic as compared to some of the microscopic devices and apertures that are being massed produced. Therefore a trend in electronics, as is has been in the past decades, is miniaturization. Size and bulk determines mobility. And for a unit as useful as a power inverter, smallness should be one of the top priorities in designing this unit. In order to create a more compact unit, it requires the use of as many devices of negligible size as possible. These devices, or integrated circuits, must also be able to accomplish as many feats as possible within there small stature. Multiple functions in these integrated circuits are a property that should be examined first.

The increase in demand for mobile AC power sources has led to an increase in market supply. However, these inverters that use the "modified sine wave" technology tend to produce a lot of heat do to power loss. Their efficiency is also less than proficient. The price of an inverter like this is considerably less than one with a pure sine wave output, but it is also reflected in their operational efficiency. The design that we will implement will solve the problem associated with “modified sine wave” inverters by using a microprocessor to obtain a more efficient and smooth means of switching the inverter’s transistors. This will reflect, in the overall design, a greater efficiency, less power loss to heat, the ability to power even the most sensitive digital devices, minimize the size of the final product, and make it a more versatile product in the global economy.

2. DESIGN REQUIREMENTS

There are several factors involving power that can be easily overlooked by the average person. These issues deal primarily with efficiency but are not limited to it. First, the amount of power consumed by the load must be looked at. Different devices call for different power wattages. Because of this fact, our inverter would not be able to power larger devices that require a lot of power. This does not affect the efficiency of our device; it is just one of its limitations. Next, the sensitivity of the load being driven should be considered. This means the output signal of the inverter must provide a cleaner signal without distortion for more sensitive devices. The amount of undesired harmonics present in our output signal would need to be limited.

2.1. Technical Design Constraints

Our five technical design constraints are shown in Table 1. These design constraints will rely heavily on the pure sine wave output. A pure sine wave output will be obtained through the use of a microprocessor and high frequency switching.

The DC/AC power inverter being built will be driven using 12 VDC. It will then convert this DC voltage into a functional 120 VAC power source. This power source will be capable of supplying 300 watts of continuous power and 600 watts of peak power. The output obtained will be as close as possible to a pure sine wave signal. The design will accomplish this through the use of high frequency switching and implementation of a microprocessor to digitally pulse our transistors. The use of the microprocessor will also make issues involving alarms much more accurate and precise. Voltage overload, temperature, and short circuit protection will be monitored using the microprocessor. As mentioned before, the major factor in power is efficiency. This is directly related to the output signal of the power supply. Due to this fact, it is extremely critical that the output be as close to a pure sine wave as possible. Most power inverters do not produce a pure sine wave output, and their performance is a reflection of that fact.

The use of a microprocessor is essential in a project of this nature. The microprocessor will be used to digitally drive the transistors on the inverter side of the circuit. This will result in pulses at precise time intervals. The slope and magnitude of the output signal will be exact, as opposed to the unstable signal generated by other power inverters that use analog technology. Implementing the use of a microprocessor also allows for the different alarms and tests which deal with the health and safety concerns.

This power inverter will operate using high frequency switching technology. The harmonics that are produced using high frequency switching will include those near the range of the switching frequency, and those that are of a relatively higher order than the 60 Hz frequency. Most of the harmonics will be the ones that are higher in order than the 60 Hz frequency. These harmonics can be isolated using a small low-pass filter. This translates into a much cleaner output signal. The power inverter will produce an output signal that contains no more than 5 % of total harmonic distortion. Also, the use of high frequency switching will minimize the size of parts used for the construction of the inverter.

Name	Description
Voltage	We will convert 12 (V DC) to 120 (V AC).
Power	We will provide 300 (W) indefinitely. We will provide 600 (W) during a power surge.
Efficiency	The inverter will operate at no less than 90 %.
Output	This inverter will produce a pure sine wave output.
Total Harmonic Distortion	The amount of undesirable harmonics present in our output will be less than 5%.

Table 1. Technical design constraints for the DC/AC power inverter.

2.2. Practical Design Constraints

Our five practical design constraints are shown in Table 2. These design constraints will shield the user from unnecessary harm and give the user a functional device. The basic economics of a project like this has to do with the price of parts. The price of parts dictates the price of the inverter. The most costly part will be the microprocessor. By minimizing the parts cost, the price of the inverter should be comparable to other sine wave inverters on the market.

Protection of the user is also of the utmost importance. There will be thermal and short circuit protection offered on this inverter. Thermal protection will be implemented through the microprocessor. Short circuit protection will reduce the risk of electrical shock or fire due to bare or unprotected wires or implements. Other protection will be offered to protect the user's voltage supply or battery from damage. A low voltage alarm will be used to alert the user of a low supply voltage at about 10.7 VDC. If the decrease in voltage still remains the unit will shut down at a supply voltage of 10 VDC.

For practical use, a cigarette lighter adapter will be used to connect the inverter to the 12 VDC system of an automobile. Appropriate gauge wire will connect the cigarette lighter adapter to the inverter. A blade style fuse will protect the inverter form over-current conditions. The output will be provided using a single output receptacle to deliver the 120 VAC. For mobility sake the whole inverter will be no larger than 8" long, 4.75" wide, and 2.5" high.

Type	Name	Description
Economic	Cost	The expected retail value of this product is expected to be $175 based on parts costing less than $43.75.
Protection	Shield	The inverter will shut down if a voltage greater than 15 V or less than 10 V is supplied to the input side of the inverter. There will be a low voltage alarm at 10.7 V and will shut down at 10V.
Functionality	User Interface	A heavy duty wiring harness will be used to access a vehicles electrical system, and a single output receptacle will deliver the output power.
Manufacturability	Size	The physical dimensions will be 8" long, 4.75" wide, and 2.5" high.
Health and Safety	Safety	Safety will be given high priority to avoid electrical fires and shock. This will be implemented using thermal and short circuit protection.

Table 2. Practical design constraints for the DC/AC power inverter.

3. APPROACH

This section explains the theory that must be considered along with the approach that has allowed for the successful implementation of the power inverter. It is worth mentioning that power inverter design requires knowledge of various areas in electrical and computer engineering including circuit analysis, power electronics, microprocessors, electromagnetic, signals and systems, and feedback controls. A general knowledge of these areas is critical in order to fully understand the physical behavior of each circuit component, as well as the interaction with other components. This section begins with a general overview of the technology considered in this project and then elaborates on the key design issues pertaining to both the hardware and software.

3.1. POWER INVERTERS

Though the methods involved in constructing a power inverter are practically unlimited, they all encompass the common goal of altering an incoming DC voltage to form a sinusoidal output signal. Regardless of the specific design implementation, a quality power inverter should provide the end-user with desirable voltage, current, and frequency output characteristics that meet or exceed the standards for specific appliances. Often, consumers are satisfied with the least expensive inverter that will provide an adequate power level to allow constant operation of particular devices. Regardless of price, a close examination of the output waveform can distinguish the quality between particular power inverters. For example, many inexpensive power inverters create what is called a "modified sine wave". Figure 1 shows an actual power inverter sold inexpensively at Wal-Mart.

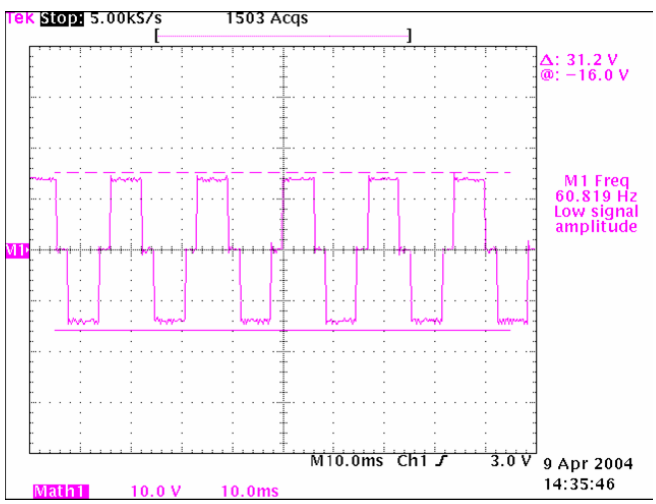

Figure 1. "Modified sine wave" output from an inexpensive power inverter

The problem with this type of inverter is the harshness with which it switches. Harsh switching causes a high harmonic distortion in the output signal. Harmonic distortion is simply the amount of power that is contained in other frequencies other than the fundamental frequency. The harsh switching actually causes voltage and current spikes in the output signal. This often reduces the useful life of electronic devices. In many case, the connected device may fail to operate. This is why a sinusoidal waveform is the preferred and more expensive output waveform.

3.2. Hardware Design

One of the most important considerations in building a pure sine-wave inverter is the output signal. As the name implies, a pure sine-wave inverter should produce an output signal with few fluctuations in voltage and current. These signal fluctuations, or harmonics, are generated by rapidly switching the transistors that are used in creating the final output. In order to meet the 5% total harmonic distortion design requirement, a pulse width modulated (PWM) switch-mode power supply was chosen over the square-wave or modified square wave topologies. The PWM method allows for filtering many unwanted harmonics in the output signal, which is not possible in square-wave and modified square wave inverters.

Choosing parts for the power inverter involved extensive research of the advantages and disadvantages of particular circuit topologies. Some of the major factors that determined the topology of choice for this project include power capabilities, efficiency, size, and cost. This project has been broken down into two major circuit topologies. The two circuit topologies are the DC/DC converter and the DC/AC inverter. A block diagram of the power inverter is shown in Figure 2 below.

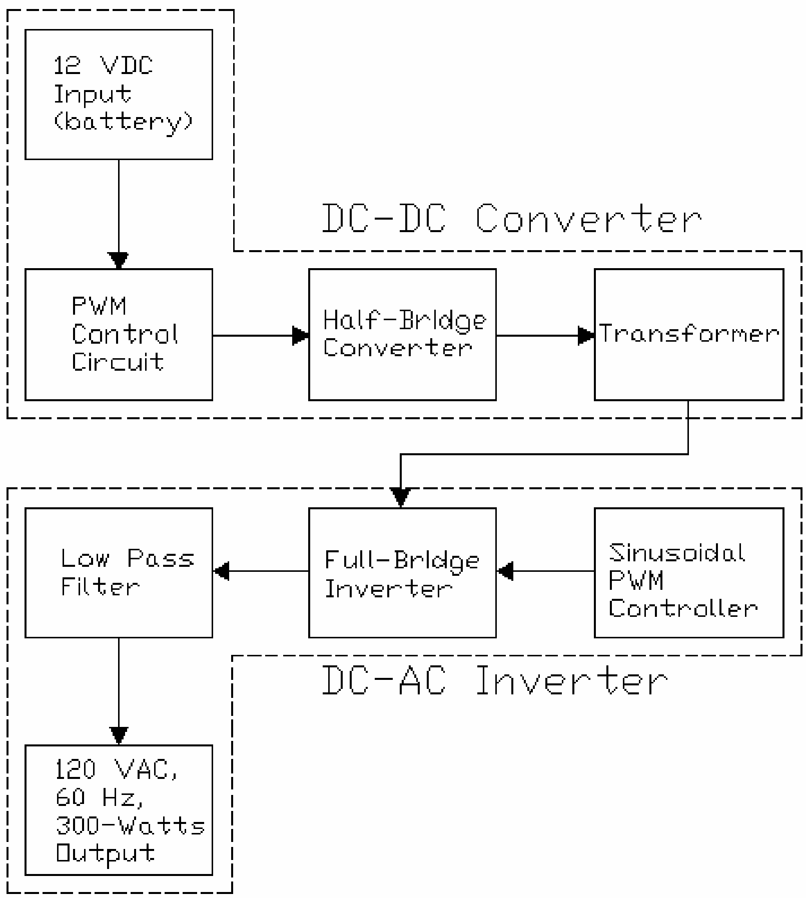

Figure 2. Power inverter block diagram

3.2.1. PWM Control Circuit

The PWM control circuit, shown in Figure 2 below, contains two major components. These components are the MC34025 PWM chip and the IR2184 MOSFET gate driver chip. The most important purpose of the PWM control circuit is to pulse the half-bridge transistors, thus chopping up the voltage supplied by a vehicle battery so it can be stepped up by a transformer for use in the DC/AC circuit. The MC34025 PWM chip was chosen primarily for because of its capabilities to vary the duty cycle by simple varying the values of C1, C2, and R1 in Figure 3. In order to reduce the size of the half-bridge inverter transformer, a switching frequency of 100 kHz was chosen. The MC34025 PWM chip also had connections for a feedback network, which came in handy for implementing a voltage regulation circuit. The voltage regulation circuit built for the power inverter is basically a voltage divider circuit, which samples the output of the half-bridge transformer. When the voltage falls below 170 VDC, the required voltage for proper operation, the duty cycle of the MC34025 PWM chip will increase. The duty cycle will continue to increase until the sampled voltage is maintained at 170 VDC. The MC34025 PWM chip operates with a 50% duty cycle under normal conditions, which maximizes the amount of energy to be converted by the half-bridge circuit.

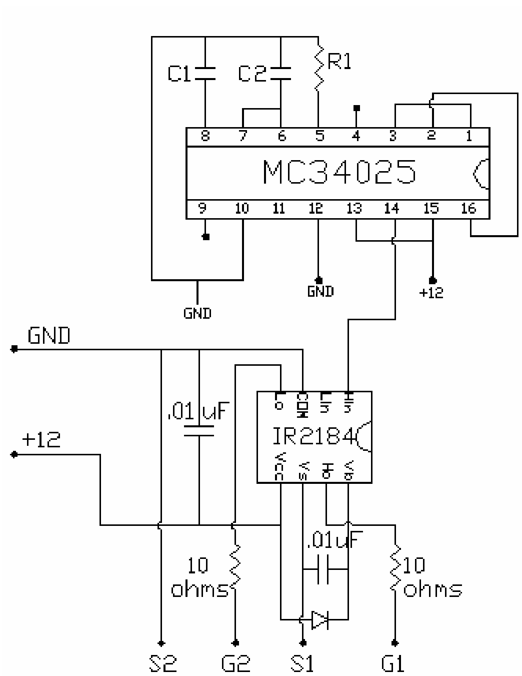

Figure 3. PWM control circuit

The IR2184 MOSFET gate driver circuit was added to the PWM control circuit for two reasons. First of all, it was chosen to amplify the 5V signal from the MC34025 PWM chip to obtain a 12V signal, enough voltage to fully turn on the transistors of the half-bridge circuit. Secondly, the IR2184 MOSFET gate driver was used to provide electrical isolation between the control circuit and the voltage needed to operate the half-bridge circuit. Initially, small isolation transformers with a 1:1 turns ratio were utilized to obtain magnetic isolation. The problem was that the MC34025 PWM circuit was not capable of producing enough power to drive the half-bridge MOSFETs with no amplification stage. Another problem examined with the initial design using isolation transformers was the fact that they caused a great deal of distortion.

3.2.2. Half-bridge converter

A schematic of the half-bridge converter is shown in Figure 3. The major components of the half-bridge converter are the two transistors, which are illustrated in Figure 4. The purpose of the half-bridge converter is to chop up the 12 VDC supplied by a vehicle battery so that an alternating current is seen by the transformer. The red and blue paths have been added to Figure 4 to illustrate the switching technique used to create and alternating current from direct current. The red path shows that current is forced across the primary side of the transformer when the upper transistor is open and the lower transistor is closed. When the transistors are toggled, the current is forced in the direction of the blue path, thus producing an AC waveform. Since the pulses that control the transistors are complimentary, both half-bridge transistors will never be on at the same time and the process repeats 100,000 times per second.

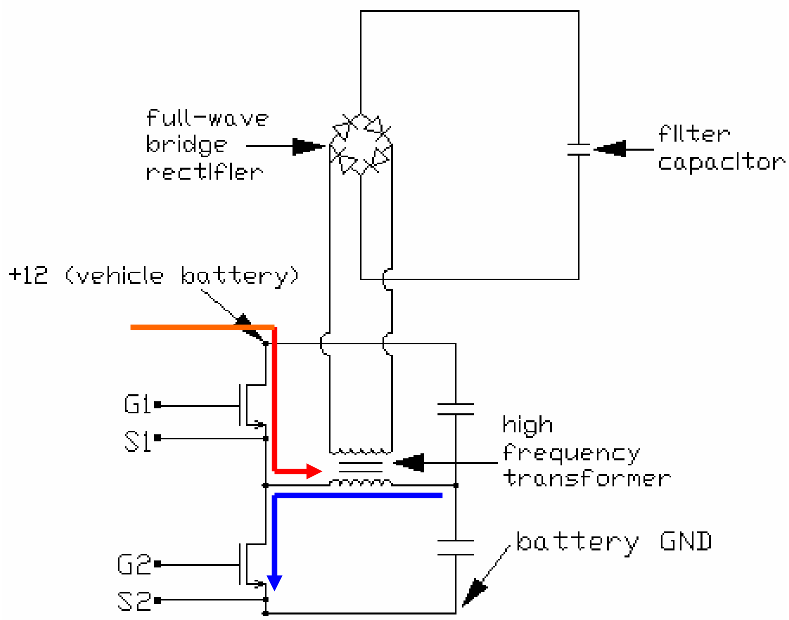

Figure 4. Half-bridge converter circuit

The transistors selected for the half-bridge were IRF530 by International Rectifier. The IRF530 dissipated the least amount of heat for long durations of operation. This is primarily because the IRF530 internal resistance of 0.16 Ω which is relatively small compared to the initial IRF730A transistors, which have an internal resistance of 0.55 Ω.

3.2.2. Transformer

The transformer is the part of the circuit that is responsible for boosting the voltage. It does this by means of a ferrite core, primary, and secondary windings. It is important to note that the transformer does not create power; it merely transforms or transfers it. Ideally, power in is equal to power out, but in a real world case there is some power loss in the device. The transformer operates by inducing a magnetic flux on the core from the current flowing through the primary winding. This flux passing through the core is induced onto the secondary winding and current flows out of the device.

The transformer used in this project, which is also illustrated in Figure 4 above, is used to step up the voltage from the half-bridge converter to provide an approximate voltage of 340 VAC with an approximate frequency of 100 kHz. Choosing such a high switching frequency has allowed a decrease in the size of the transformer needed. A transformer operating at the conventional 60 Hz receiving the rated power and outputting the needed power would weigh approximately 15-20 lbs. Operating at a higher frequency allows us to drastically reduce the size of this device to one that is less than 1 pound.

Without having the proper equipment needed for winding a transformer, the task did not seem very practical. Therefore, the design team agreed to have a transformer custom built for the power inverter. Figure 5 shows the hand-made transformer on the left hand side and the custom built transformer on the right and side. The custom built transformer operated properly in the power inverter, but a sacrifice of 8 mm extra for both the length and width.

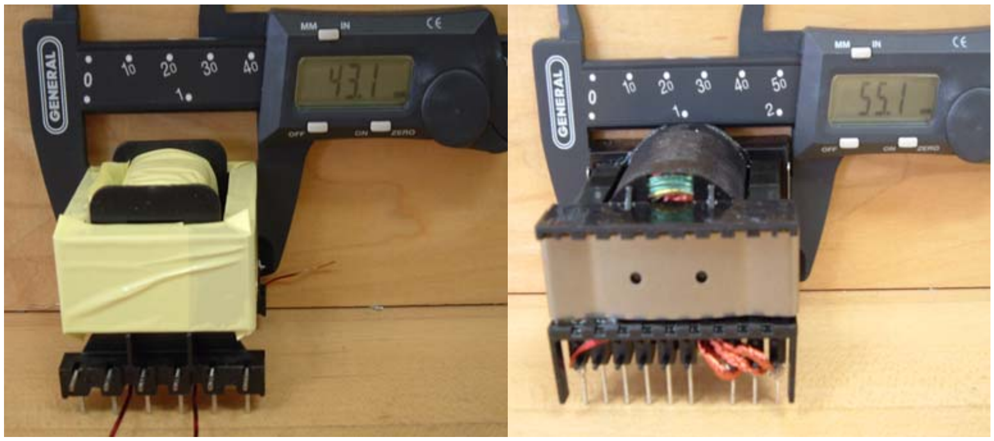

Figure 5. Physical width dimensions of hand made transformer (left) and custom built transformer (right)

Attached directly to the secondary side of the transformer is a full-wave bridge rectifier that is used to convert the 340 AC signal to 170 DC, the voltage needed by the full-bridge inverter. The output of the rectifier alone would have a peak value of 170 volts, but as Figure 6 shows, the signal is not held at a constant 170 V. To smooth out the ripple, a 220 uF electrolytic capacitor has been added in parallel with the rectifier.

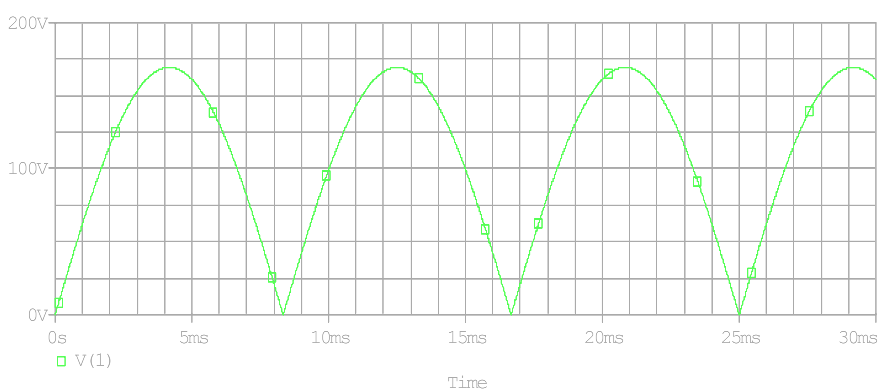

Figure 6. Simulation of rectified transformer output (before filtering)

3.2.4. Sinusoidal PWM controller

Various PWM techniques have been used to create transistor drive circuits. Before microcontrollers became popular, varying PWM circuits usually consisted of analog-to-digital comparator circuits. These circuits compared a small voltage sinusoidal wave (reference signal) to a small voltage saw-tooth wave (control frequency signal). At each point where the sinusoidal and saw-tooth signals intersect, the output of the comparator toggles from a high state to a low state. To illustrate the theory behind sinusoidal

PWM, Figure 7 shows the expected output of a sine wave compared to a saw-tooth wave. The duty cycle actually varies according to the time between sampling the reference sine wave.

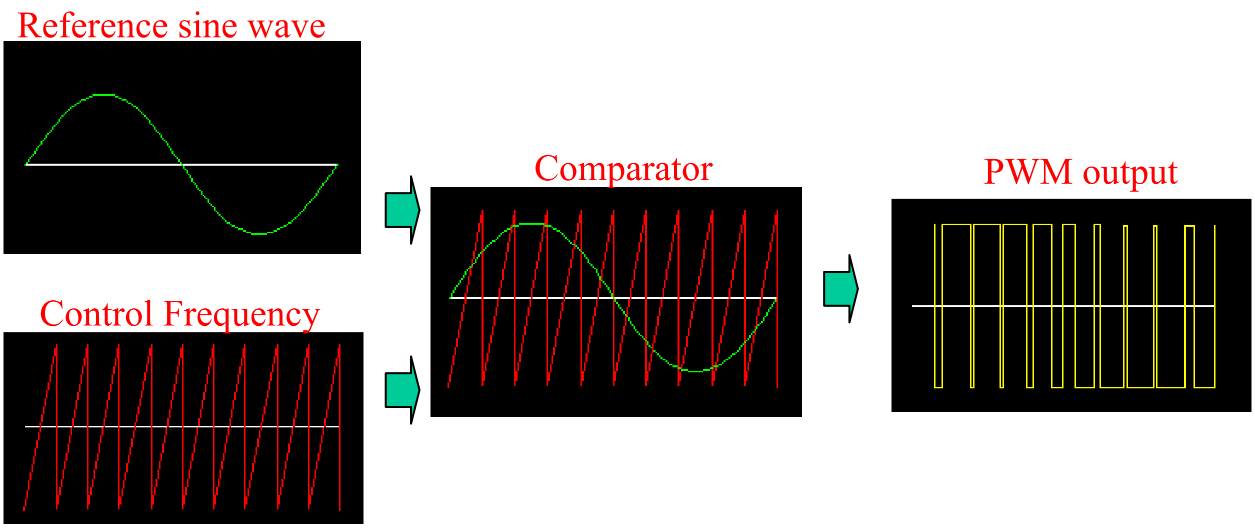

Figure 7. Theory of PWM components

A schematic of the sinusoidal PWM controller circuit is shown in Figure 8 below. The major components for this circuit include a microcontroller, an oscillator, and two MOSFET gate driver chips. This circuit produces two output pulses with varying duty cycles in order to drive the full-bridge inverter circuit.

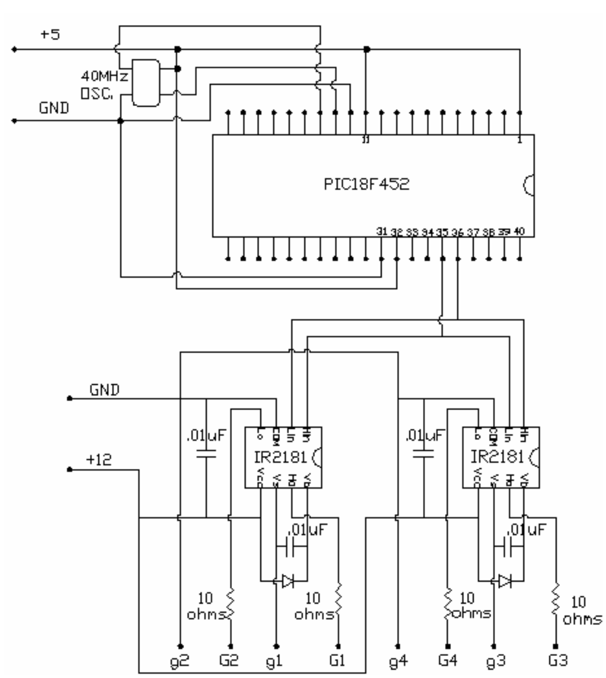

Figure 8. Sinusoidal PWM controller circuit

The microcontroller is utilized for storing pre-programmed duty cycles with its memory. This eliminated the need for large analog components which often have a tendency to become unstable. The microcontroller of choice for this project was Microchip's PIC18F252. The PIC18F252 was chosen primarily because it had enough on-board memory to store all of the necessary duty cycles values. Sufficient program memory will allow us to increase the number of duty cycles that make up one cycle of a 60 Hz sine wave. In turn, an increase number of duty cycles allows for a more precise resolution in the final output signal of the packaged product. Other advantages of the PIC18F252 were reflected by the low cost, fast processing speed, flash memory, and the ability to add extra features (such as low voltage alarms, extra phases, temperature sensors, etc.) in the future.

The following equations were used to calculate the modulation amplitude and modulation frequency for the PWM signal:

$$\text{Amplitude Modulation Ratio} = \frac{V_{control}}{V_{tri}} \quad (1)$$

$$\text{Frequency Modulation Ratio} = \frac{f_s}{f_1} \quad (2)$$

where, $V_{control}$ is the peak amplitude of the reference sine wave with frequency of f_1 and V_{tri} is the peak amplitude of the saw-tooth wave with frequency of f_s. By equations 1and 2 the amplitude of the PWM pulse is directly proportional to $V_{control}$ and the frequency of the PWM pulse is directly proportional to fs. A thorough discussion of the programming process involved in this project is located in the Software Design section of this document.

The amplitude ratio could not be changed in this case since the microcontroller was only capable of outputting a 5 volt logic signal. The frequency modulation ratio for this project came out to be approximately 300, which means that there were 300 completely different duty cycle values that make up a single half-cycle of the final output waveform. The frequency modulation was calculated by equation 4, where the reference sine wave (f_1) was set to 60 Hz and the saw-tooth wave (f_s) was set to 18 kHz. The switching frequency was set to 18 kHz in order to achieve a high resolution of the final output waveform. Through research, it was found that switching frequencies above 20 kHz start to increase transistor switching losses.

The IR2181 MOSFET gate driver chips play two vital roles in creating drive pulses suitable for operation of a full-bridge inverter circuit. First of all, the IR2181's amplify the 5-volt logic signals output by the microcontroller to obtain a 12 volt signal necessary to fully turn on the transistors of the full-bridge circuit. A transistor drive pulse of less than 12 volts could result in excessive heating which occurs when the transistors being driven are operating in the linear mode of operation, which by the physical transistor construction, happens to be the most resistive regions of operation. The other role played by the IR2181 chips is to provide electrical isolation between the upper control pulses and the upper transistors of the full-bridge inverter circuit. Electrical isolation is extremely important in biasing the upper full-bridge transistors with the appropriate drive signal voltages. Without proper electrical isolation the upper transistors would be considered "floating". In other words, the upper full-bridge MOSFETs would have a gate-to-source voltage ranging from 0 VDC to 170 VDC because they are not directly referenced to ground potential.

The IR2181 gate driver chips provide electrical isolation by inserting a capacitor and diode, also known as a "bootstrap supply", are shown in Figure 9 below. When V_s is pulled down to ground (either through the low side FET or the load, depending on the circuit configuration), the bootstrap capacitor (C_{bs}) charges through the bootstrap diode (D_{bs}) from the 15 V_{cc} supply. This provides a supply to V_{bs}.

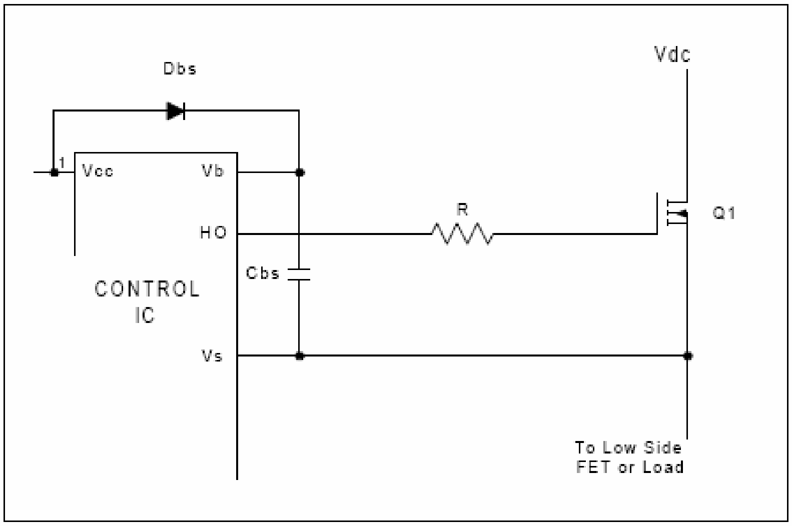

Figure 9. Bootstrap diode/capacitor circuit used with IR control IC's

The following equation gives the minimum charge which needs to be supplied by the capacitor:

$$Q_{bs} = 2Q_g + \frac{I_{qbs(\max)}}{f} + Q_{ls} + \frac{C_{bs(leak)}}{f} \qquad (3)$$

where:

Q_g = Gate charge of high side FET
$I_{cbs(leak)}$ = bootstrap capacitor leakage current
Q_{ls} = level shift charge required per cycle = 5nC (for the 600 IC that was used in this design)
I_{qbs} = quiescent current for the high side driver circuitry

The bootstrap capacitor must be able to supply the charge given by equation 1 and retain its full voltage. Otherwise, there will be a significant amount of ripple on the V_{bs} voltage which could cause the HO output to stop functioning. Therefore, the charge in the C_{bs} capacitor must be a minimum of twice the value given by equation 1. The minimum capacitor value can be calculated from the equation below:

$$C \geq \frac{2\left[2Q_g + \frac{I_{qbs(\max)}}{f} + Q_{ls} + \frac{I_{cbs(leak)}}{f}\right]}{(V_{cc} - V_f - V_{ls})} \qquad (4)$$

where:

V_f = forward voltage drop across the bootstrap diode side FET
V_{ls} = voltage drop across the low side FET

The bootstrap diode (D_{bs}) should be able to block the full power rail voltage, which is seen when the high side mosfet is switched on. For this design, the bootstrap diode was selected to withstand at least 170

VDC, the upper power rail of the full-bridge inverter. The bootstrap diode should also be an fast recovery diode to minimize the amount of charge fed back from the bootstrap capacitor into the V_{cc} supply.

3.2.5. Full-bridge inverter

The full-bridge inverter circuit, as shown in Figure 10, is very simple to construct because it only consists of four switches. The function of the full-bridge inverter is to convert the 170 VDC link voltage supplied by the DC-DC converter into a 340 VAC (120 V RMS), 60 Hz sine wave. The transistors chosen for the full-bridge inverter circuit were the IRF740A's. The IRF740A transistors were chosen because they have the appropriate voltage and current ratings (Vdss = 400V, Id = 10A).

The two complimentary PWM pulses produced by the sinusoidal PWM controller circuit are fed into the full-bridge inverter. One signal is sent in parallel to transistors T1 and T4. The other signal is sent in parallel to transistors T2 and T3. Programming the signals into the microcontroller as compliments of one another allows for transistors T1 and T4 to be on while transistors T2 and T3 are off, and vice versa. The basic principle with sinusoidal PWM is to divide the period of the desired sine wave output into a large number of evenly spaced intervals. In each interval, the control signal remains on for part of the time and off for the other part of the time. The ratio of the "on time" to "off time" at any given instant determines the amplitude of the desired output signal.

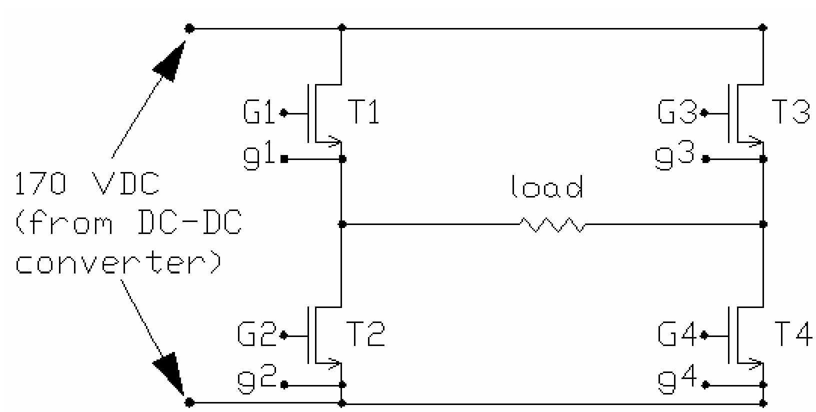

Figure 10. Full-bridge inverter circuit

The output signal of the full-bridge inverter circuit will be a pulse waveform which contains the desired output waveform along with frequency components at or around harmonics of the switching frequency. This can be seen in Figure 11, which compares the unfiltered output of the final product to a simulation. The darker areas in Figure 11 represent the actual sine wave. A low-pass filter can be utilized to extract the desired output signal (60 Hz fundamental frequency) by separating it from the switching frequency.

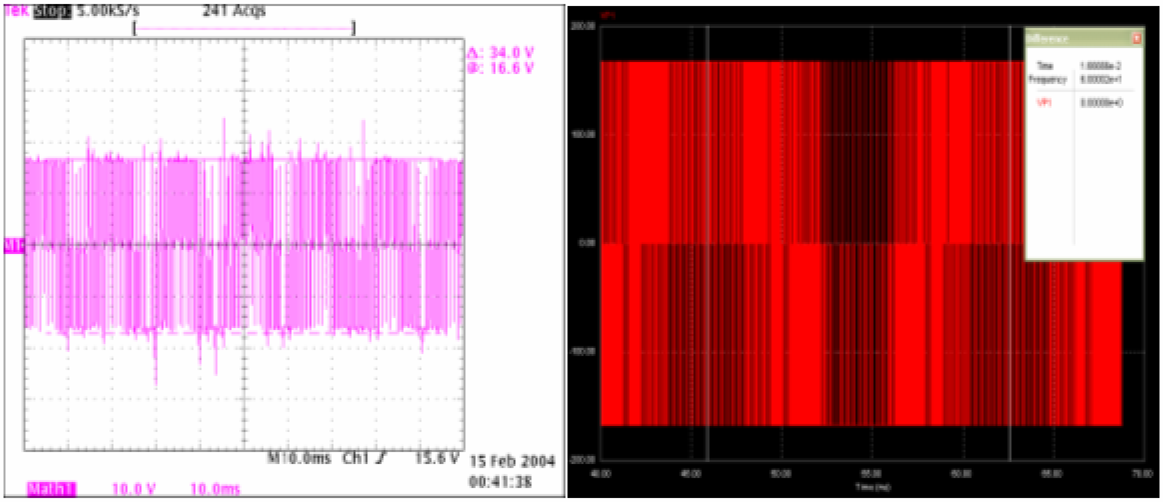

Figure 11. Unfiltered output of the final product (actual versus simulation)

3.2.6. Low-pass filter

In order to eliminate the switching frequency and all multiples of the switching frequency, a low-pass filter had to be inserted after the output of the full-bridge inverter. A low-pass filter only allows frequencies below the cutoff-frequency to pass. The filter will reject any frequency above the cutoff frequency. The cutoff frequency can be set by the following formula:

$$F_{cutoff} = \frac{1}{2\pi\sqrt{LC}} \qquad (5)$$

Figure 12 shows the switching harmonics that resulted from an 18 kHz switching frequency. It should be noted that the harmonics are located at the switching frequency and multiples of the switching frequency. The switching frequency was intentionally set at 18 kHz so it would be rather distant from the 60 Hz fundamental frequency. This would allow for a high cutoff frequency, which by equation ??, allows for small LC components. The large distance between the unwanted harmonics and the fundamental frequency is also beneficial because it allows for a large margin of error in the filter values.

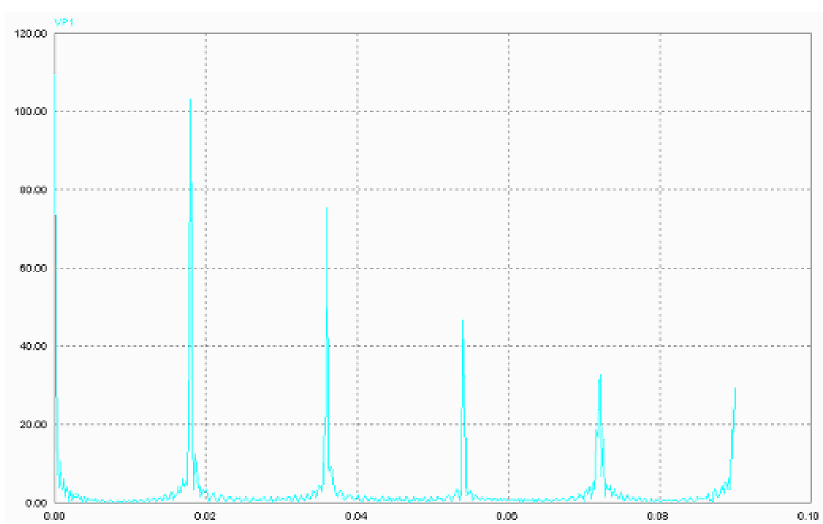

Figure 12. Frequency spectrum of unfiltered full-bridge inverter output

An L-C low-pass filter was chosen for the power inverter. This topology, as shown in Figure 13, is simple to build, contains few components, and can handle high currents.

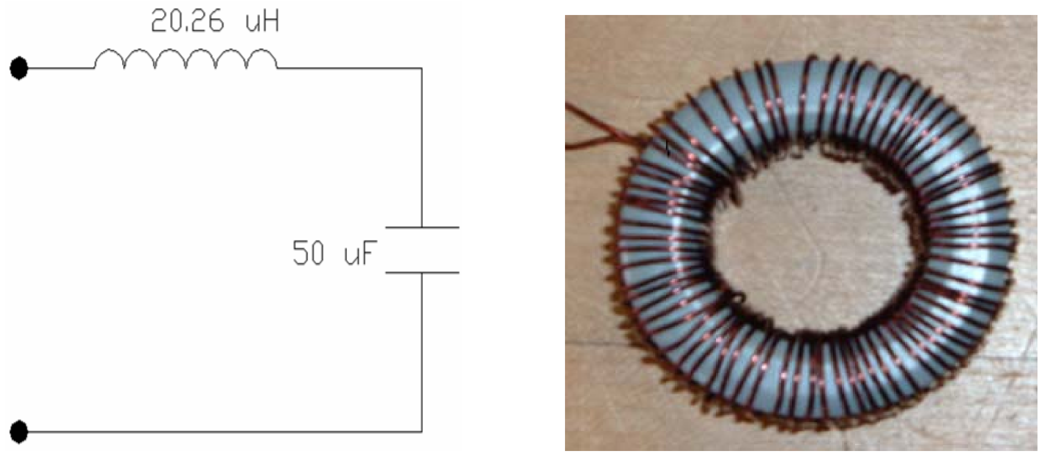

Figure 13. L-C low-pass filter schematic (left) and hand-made inductor (right)

3.3. Software Design

Figure 14 illustrates the software flow diagram for PIC18F252 program. Basically the program uses pre-calculated duty cycle values which are stored in tables at the end of the program.

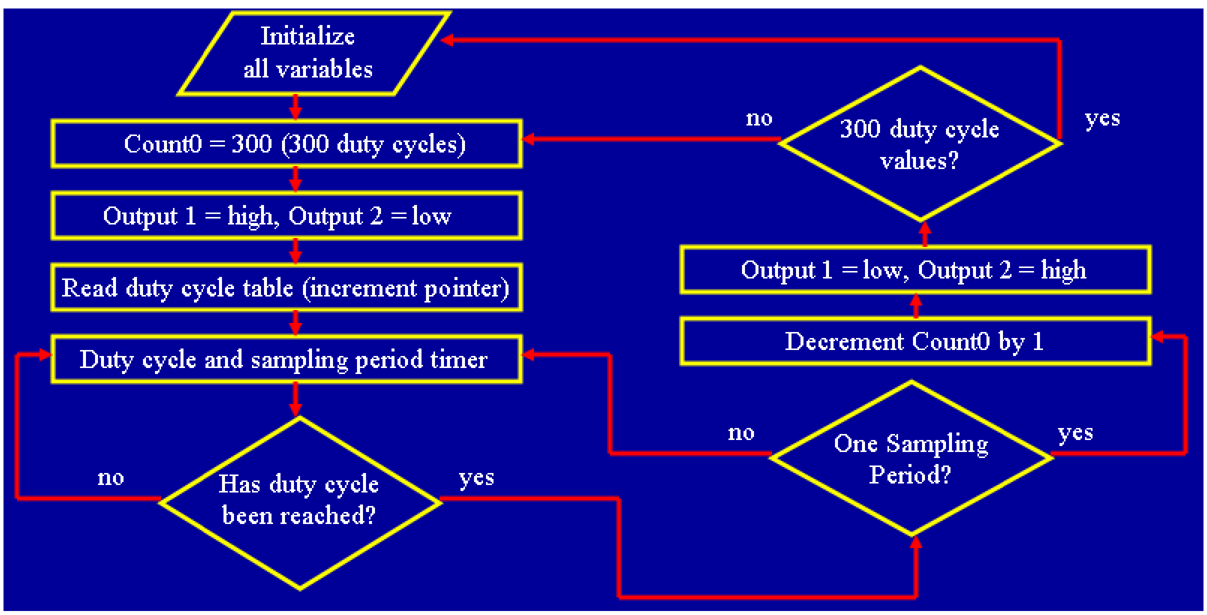

Figure 14. Software flow diagram for full-bridge inverter microcontroller

4. EVALUATION

4.1. Test Specification

The test specifications explain the methods used to show that design constraints have been met. The power inverter is composed of many components that require testing separately and as a complete system. Testing each component individually helps to locate unique problems that are specific to each component. Complete system testing will ensure that each hardware and software component is fully functional at a mutual level. Table 3 illustrates each main system component, the design constraints relative to each component, and the various testing methods that will be utilized in designing a single phase power inverter.

Constraints \ Testing Equipment		Pspice	Oscilloscope	Digital Multi-meter
DC-DC Converter	**Half-bridge PWM Control Circuit**			
	Frequency		✓	✓
	Output Voltage		✓	✓
	Half Bridge			
	Output voltage	✓	✓	✓
	Output current	✓		✓
	Transistor Dead time	✓	✓	
	Efficiency	✓	✓	✓
	Transformer			
	Output Voltage		✓	✓
	Output Current			✓
	Efficiency		✓	✓
DC-AC Inverter	**Sinusoidal PWM Controller**			
	Output Voltage		✓	✓
	Frequency		✓	✓
	Full Bridge Inverter			
	Output voltage	✓	✓	✓
	Output current	✓	✓	✓
	Transistor dead time	✓	✓	✓
	Frequency	✓	✓	✓
	Efficiency	✓	✓	✓
DC-DC Inverter	**Low Pass Filter**			
	Output Voltage	✓	✓	✓
	Output current	✓		✓
	Efficiency	✓	✓	✓
	THD	✓	✓	

Table 3. Component constraints and testing methods

A block diagram for the power inverter is shown in Figure 15. The diagram consists of each individual sub-system that will be tested prior to integration and final product assembly. The code for the sinusoidal PWM controller will be tested in the MPLAB compilation environment. Each of the other components will be initially simulated using circuit simulation, such as PSPICE. Upon verification of fully functional circuit simulations, each hardware component will be susceptible to being tested in a laboratory setting with precise measuring instrumentation.

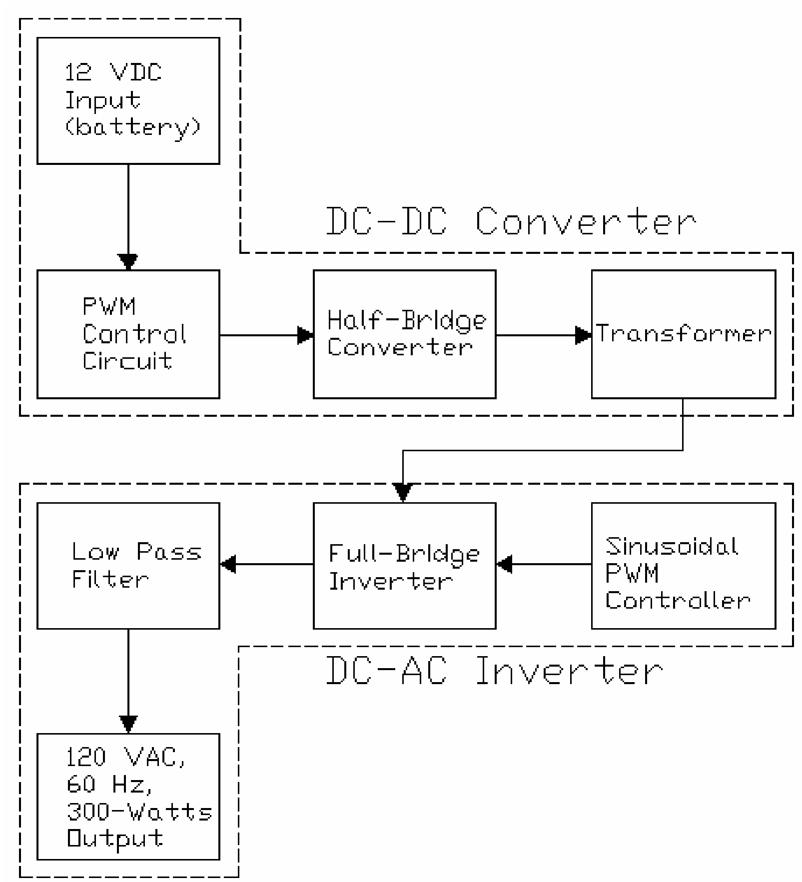

Figure 15. Power inverter block diagram

4.1.1. Simulation

PSpice is a vital circuit simulation environment that allows rapid testing of parameters such as voltage, current, power, frequency, and total harmonic distortion. PSpice only generates theoretical circuit output values which would only be observed under ideal conditions. Therefore, PSpice will only be used as a guide for the comparison of hand calculated measurements or laboratory experimentations.

The PSpice circuit simulation environment will be used to verify the design of the DC-DC converter and the DC-AC inverter. Both circuits and corresponding sub-circuits will be simulated in a similar manner, with the proper parts selected from existing PSpice libraries. Most of the analog parts that comprise the power inverter are standard parts and will pose no problems in simulation; however, the microcontrollers for both the DC-DC converter and the DC-AC inverter will be simulated with the use of ideal sources that will be modified to duplicate each controller's desired output waveform.

The DC-DC circuit contains a half-bridge converter and a transformer that were simulated in PSpice to compare simulated results with experimental results. For correct operation of the DC-DC converter, two complementary square wave pulses must constantly pulse the two MOSFET transistors of the half-bridge circuit. Specifically, these two square-wave pulses were created by selecting "vpulse" from the PSpice library. By double-clicking each "vpulse" part, the switching frequencies were set to 100 kHz, the duty cycles were set to 50 %, and the phase was adjusted to make one of the sources the complement of the other. The half-bridge circuit was configured in PSpice by using two default N-channel MOSFET transistors and two coupling capacitors. A desired simulation of the half-bridge topology should result in a 100 kHz, 12V square pulse. An ideal transformer was used to step up the 12V square wave to a 340 V square wave. Next, a full-wave bridge rectifier was constructed by using four diodes to rectify the 340 V square wave to 170 VDC. A 220 µF capacitor in shunt with the full-wave rectifier was used to filter out the ripple voltage to achieve maximum efficiency. Complete simulation of the DC-DC converter includes performing measurements of voltages, currents, efficiency, and transistor dead times.

The DC-AC inverter circuit contains a full-bridge inverter and a low-pass filter. The inverter circuit was simulated in PSpice and was used to verify the experimental results. Four N-channel MOSFET transistors were used to construct the full-bridge inverter. To obtain the necessary sinusoidal PWM signal to switch the four MOSFETs, two comparators with part number uA741 were used. Both comparators were set up to compare a 60 Hz sine wave with an 18 kHz saw tooth wave. The PWM output of the comparators was used to switch the transistors to "chop" the 170 VDC link voltage supplied by the DC-DC converter to an 18 kHz PWM waveform. An LC low-pass filter was added to the full-bridge inverter to filter frequencies higher than the 60 Hz fundamental frequency. The complete DC-AC inverter simulation yielded a voltage of 120 VAC, a frequency of 60 Hz, and a total harmonic distortion of less than 5%.

4.1.2. Hardware

All individual hardware design is tested using an oscilloscope and a digital multi-meter. The key components of the overall power inverter are a PWM control circuit, a half-bridge inverter, a transformer, a sinusoidal PWM controller, a full-bridge inverter, and a low-pass filter. Each component was tested for the desired voltages, currents, efficiencies, and frequencies. The following sub-sections demonstrate the tests that were performed on the power inverter hardware.

Half-bridge PWM Control Circuit

The test setup for the Half Bridge PWM control circuit is shown in Figure 16. Beneath the figure are the instructions for verifying proper operation of the controller.

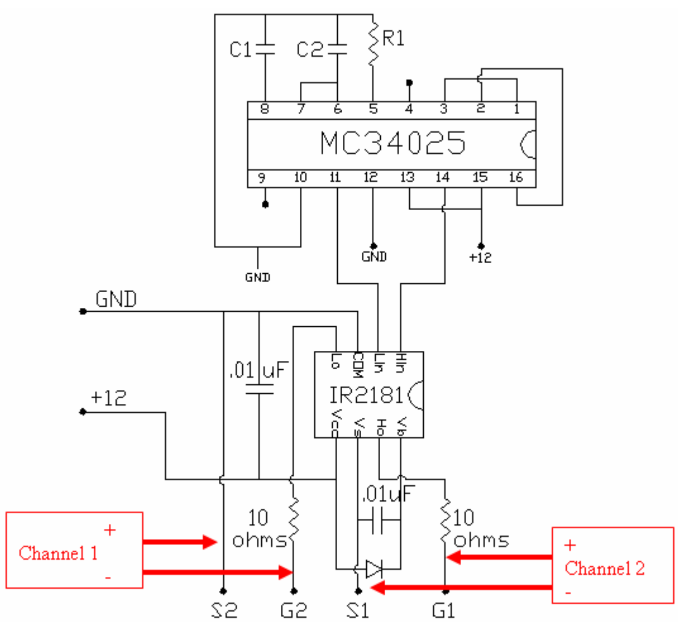

Figure 16. Testing setup for the half-bridge PWM controller

1. Connect the circuit as shown in Figure 16.
2. Display the two outputs of the control circuit by connecting channel 1 of the oscilloscope across S1 and G1 and connect channel 2 across S1 and G1.
3. Verify that each waveform is a 12 V square pulse with 100 kHz frequency. The two control pulses should be complements of one another.

Half Bridge Converter

Figure 17 shows the test setup for the half-bridge dc-dc converter. Below Figure 17, a step-by-step testing procedure is listed in order to ensure peak performance of the half-bridge topology.

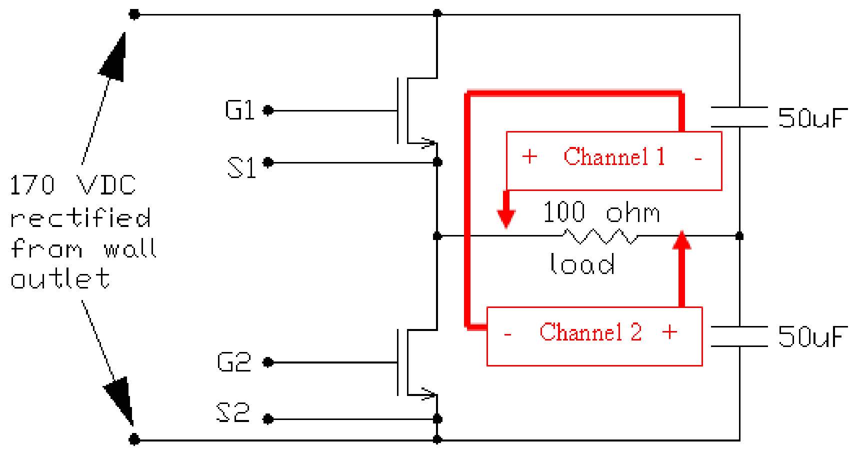

Figure 17. Test setup for the half Bridge converter

1. Connect the circuit as shown in Figure 17.
2. Feed the two pulses from the PWM control circuit to the two MOSFET transistors.
3. Display the output voltage of half-bridge across the 50 Ω load by making a differential measurement on the oscilloscope. Note: a differential measurement must be performed in any case where the measurement point is not at ground potential.
4. Verify that the output waveform is a 12 V square wave with a 100 kHz frequency.

Transformer

The test setup for the transformer is shown in Figure 18. Beneath the figure are the instructions for verifying proper transformer operation.

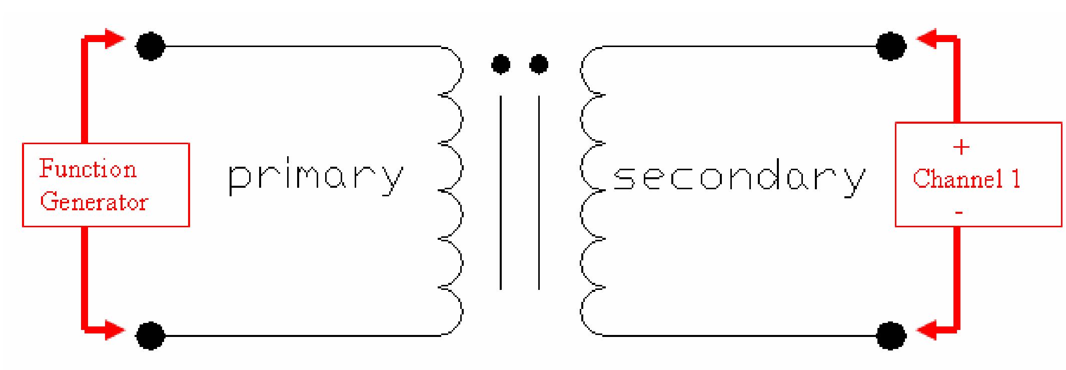

Figure 18. Test setup for the transformer

1. Use the function generator to emulate the output square pulse of the half-bridge converter. Set the voltage to 12 V, the waveform to square wave, and the frequency to 100 kHz.
2. Feed the output of the function generator into the primary side of the transformer.
3. Connect channel 1 of the oscilloscope to the secondary side of the transformer and verify that the output is a 340 V square wave with a 100 kHz frequency.

Sinusoidal PWM Inverter Control Circuit

A complete test setup of the sinusoidal PWM control circuit is shown in Figure 19. Instructions for ensuring proper operation are listed below Figure 19.

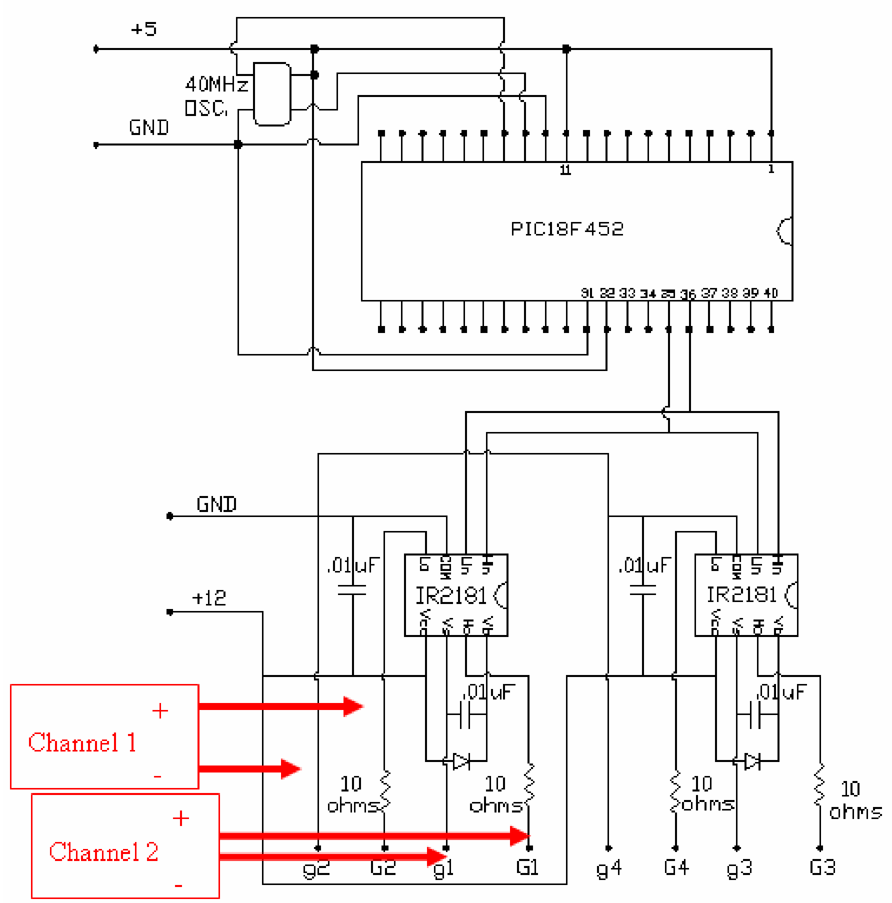

Figure 19. Sinusoidal PWM control circuit test setup

1. Setup the control circuit as shown in Figure 19.
2. Connect channel 1 of the oscilloscope across g2 and G2 and channel 2 across g1 and G1. Verify on the oscilloscope that the waveforms of the voltages are square pulses complimentary to each other with frequencies of 18 KHz and amplitudes of 12 V.
3. Repeat step 2 with channel 1 across g4 and G4 and channel 2 across g3 and G3.

Full Bridge Inverter

The test setup for the full bridge inverter is illustrated in Figure 20. The procedure for testing the full bridge inverter is located below the test setup.

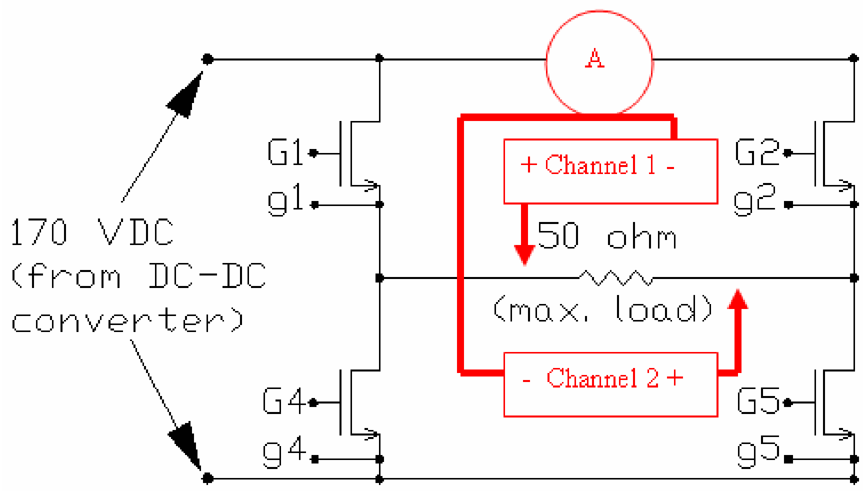

Figure 20. Test setup for the full-bridge inverter

1. Connect the circuit shown in Figure 20.
2. Feed the outputs from the sinusoidal PWM controller to the four MOSFET transistors as shown in Figure 19.
3. Using the oscilloscope, perform a differential measurement across the 50 Ω load. Note: the 10X probes must be used when measuring voltages over 100 VAC.
4. Verify that the voltage across the 50 Ω load is a PWM pulse that is 340 V peak-to-peak with a frequency of 18 kHz.
5. Verify that the ammeter reads 2.5 A.

Low Pass Filter

The test setup for the low-pass filter is illustrated in Figure 21. The procedure for testing the low-pass filter is located below the test setup.

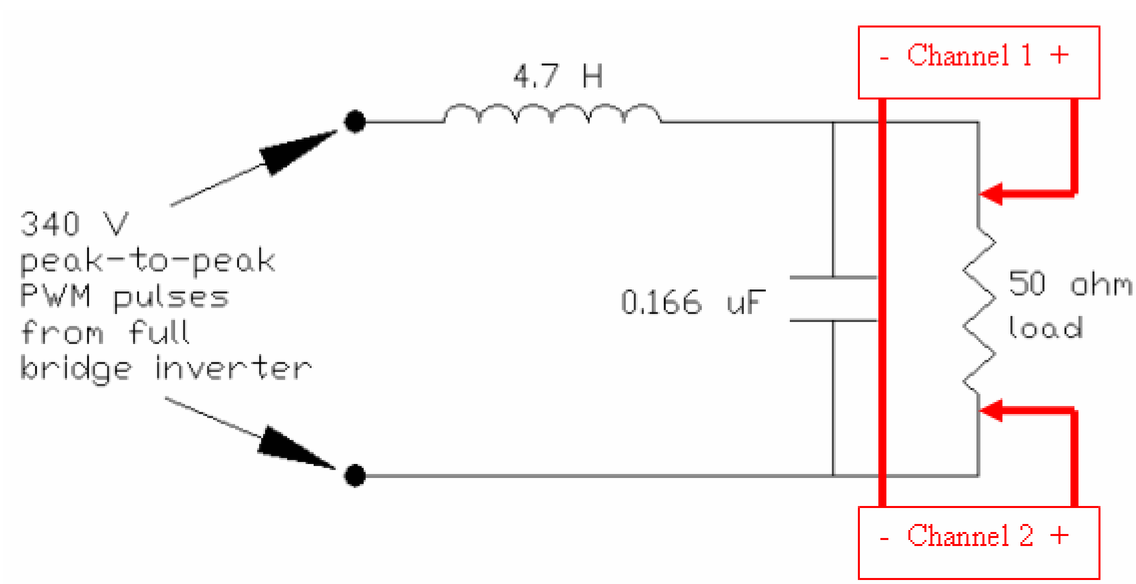

Figure 21. Low-pass filter test setup

1. Connect the circuit as shown in Figure 21.
2. Feed the 340 V peak-to-peak PWM pulse from the full-bridge inverter to the LC filter.
3. Perform a differential measurement on the oscilloscope across the 50 Ω load.
4. Verify that the voltage is 340 V peak-to-peak with a frequency of 60 Hz. Note: the 10X probes must be used when measuring voltages over 100 VAC.

4.1.3. Software

MPLAB

MPLAB is emulation software that allows for compiling programs that are specifically written for MicroChip microcontrollers. MPLAB will be used to test that the assembly language code written for the microcontroller will execute properly. Once the code executes properly, it can be programmed into the PWM microcontroller. Since MPLAB supports flash memory, the program sent to the microcontroller can be erased by the click of a button. The following steps were taken to program the microcontroller:

1. Download the microcontroller program to the MPLAB workspace.
2. Attempt to compile the program using the built-in compiler. MPLAB will check the program for any errors in syntax or parameterization.
3. After successfully compiling the program, load it onto the microcontroller using the MicroChip programmer.

Software Verification

To test the operation of the microcontroller, an oscilloscope will be used to observe the output waveforms of the microcontroller. Following is the procedure of the test.

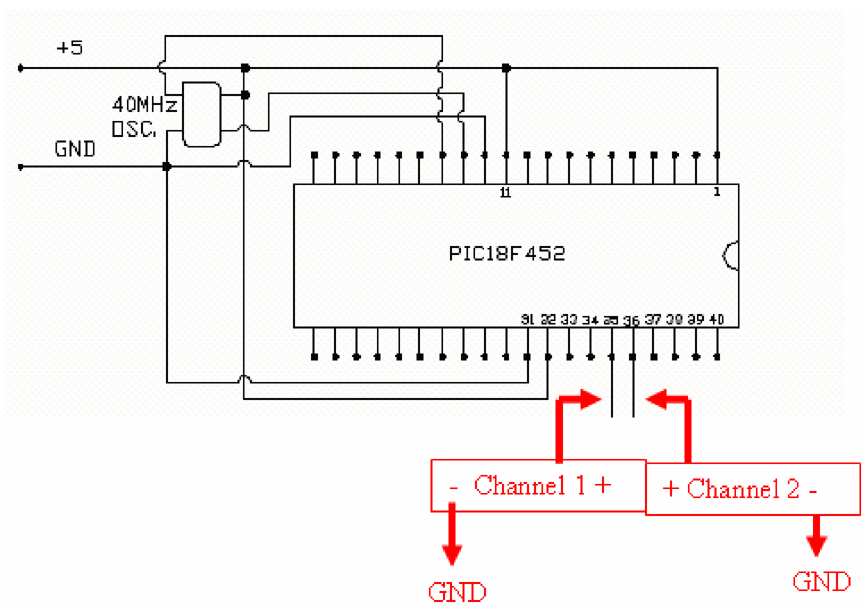

Figure 22. Software testing setup

1. Connect the circuit as shown in Figure 22 above.
2. Power the microcontroller with 5V DC from the bench power supply to pin 1, pin 11 and pin 32.

3. Connect pin 35 of the microcontroller to channel 1 of the oscilloscope.
4. Connect pin 36 of the microcontroller to channel 2 of the oscilloscope.
5. Line the output waveforms one on top of the other and confirm that they are complement of one another as shown in Figure

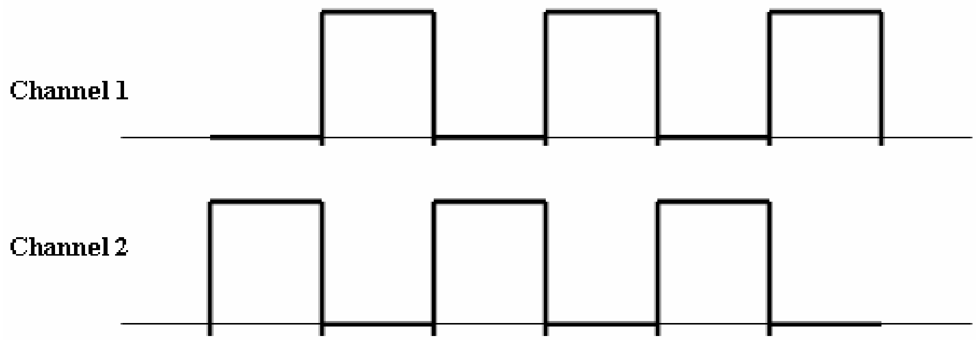

Figure 23. Output waveforms of microcontroller

4.2. Test Certification – Simulation

The DC/AC power inverter was simulated in the PSIM environment. The entire project, except for the half-bridge PWM control circuit and the full-bridge sinusoidal PWM control circuit, was simulated using ideal parts in PSIM. The complexity of the two PWM circuits was such that they could not be simulated effectively or exactly implemented using the available parts in PSIM. The test procedures written in the test specification section of this document were followed step by step in order to ensure that the power inverter worked according to theory. The two major circuits tested in PSIM were the DC/DC converter and the DC/AC inverter, which are discussed below.

DC/DC Converter

Figure 24 shows the PSIM schematic that was used to simulate the output of the DC/DC converter. The expected output of the DC/DC converter is 170 VDC. Figure 25 certifies that the DC/DC configuration works theoretically in an ideal environment.

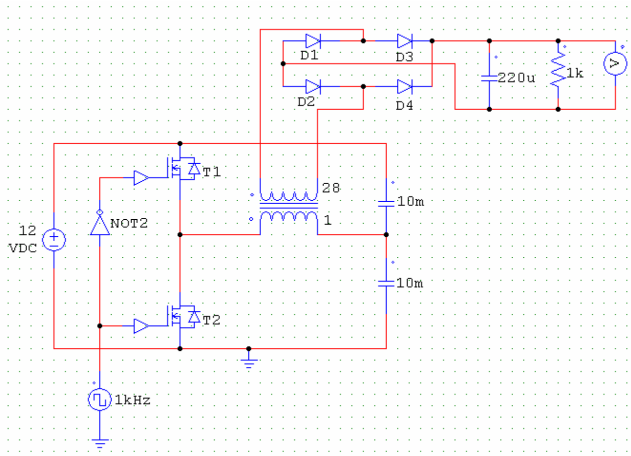

Figure 24. PSIM DC/DC schematic

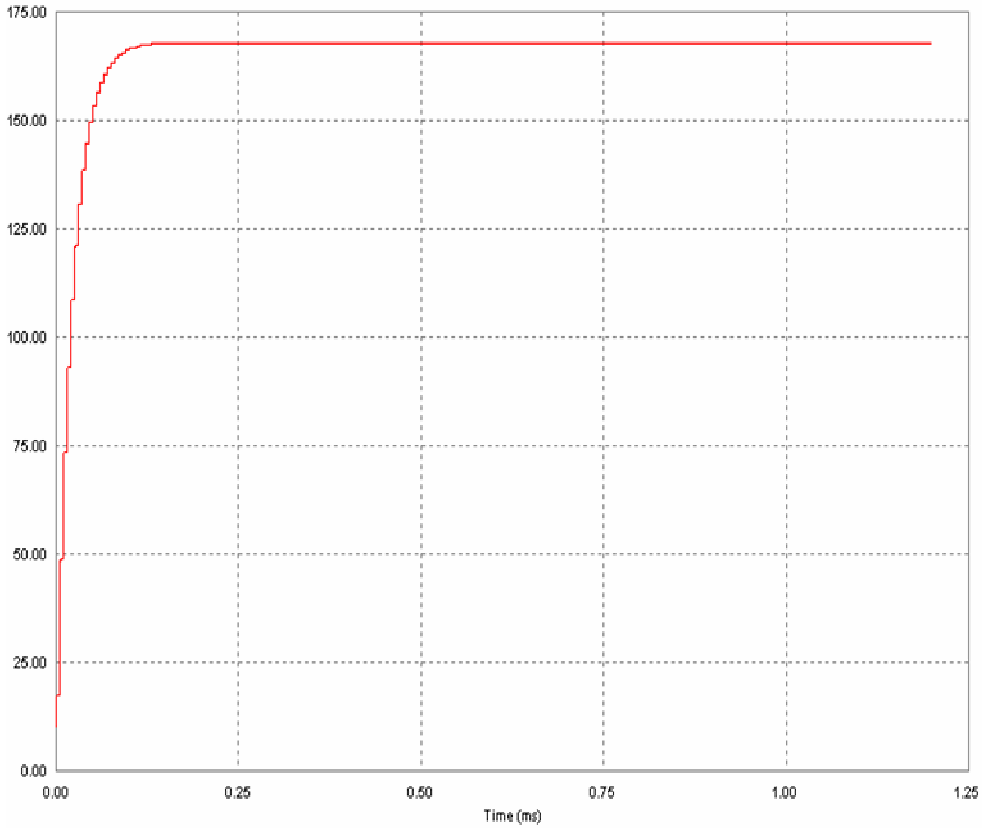

Figure 25. Simulation certification of DC/DC converter

DC/AC Inverter

Figure 26 shows the PSIM schematic that was used to simulate the output of the DC/AC inverter. The expected output of the DC/AC inverter is a 120 VAC RMS, 60 Hz sine wave. Figure 27 shows the unfiltered 340 VAC (peak-to-peak) waveform that will be filtered to create the expected output. Figure 28 shows the filtered output and proves that DC/AC inverter should function properly. Figure 29 is an added simulation test result showing that only the 60 Hz fundamental frequency remains after filtering with a low-pass filter.

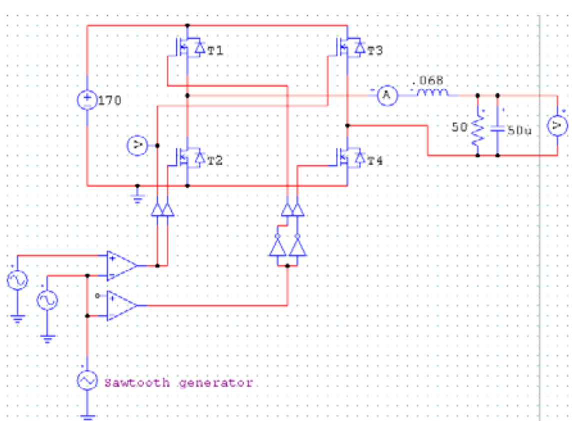

Figure 26. PSIM schematic of DC/AC inverter

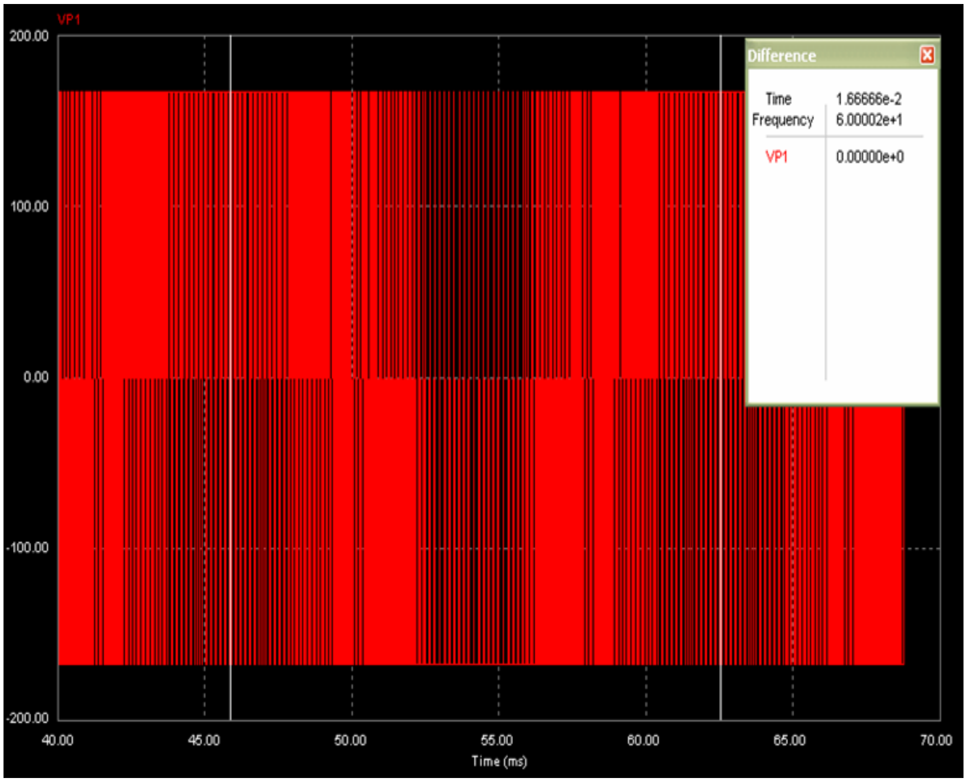

Figure 27. Simulation certification of unfiltered DC/AC inverter output voltage waveform

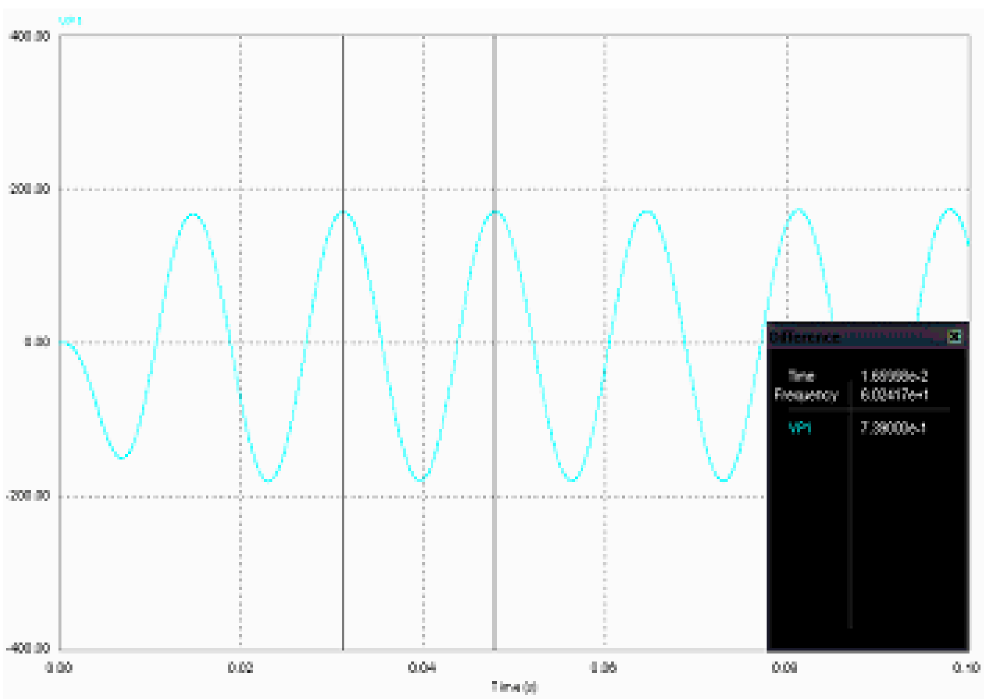

Figure 28. Simulation certification of filtered DC/AC inverter output voltage waveform

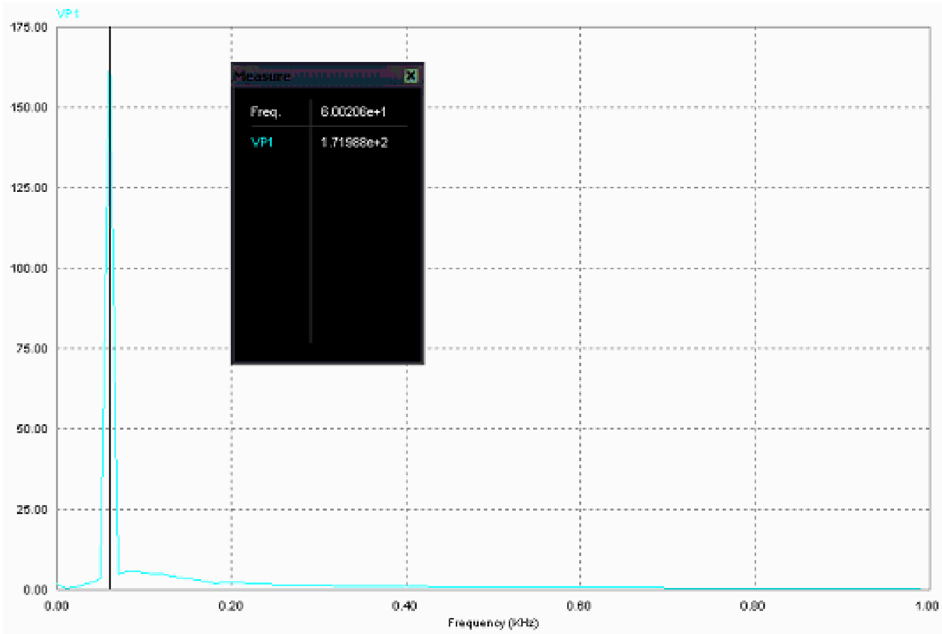

Figure 29. Simulation certification of filtered DC/AC inverter frequency spectrum

4.3. Test Certification – Hardware

4.3.1. Prototype

Half-bridge PWM Control Circuit

Figure 30 illustrates the prototype output from a breadboard. The results were found using the test procedure located in section 4.1.2 of this document. This control circuit is used to pulse the MOSFETs of the half-bridge converter. The expected output is two complimentary pulses that are 180º out of phase with amplitude of approximately 12 VAC at a frequency of 100 kHz. The results were close enough to verify that the prototype works correctly.

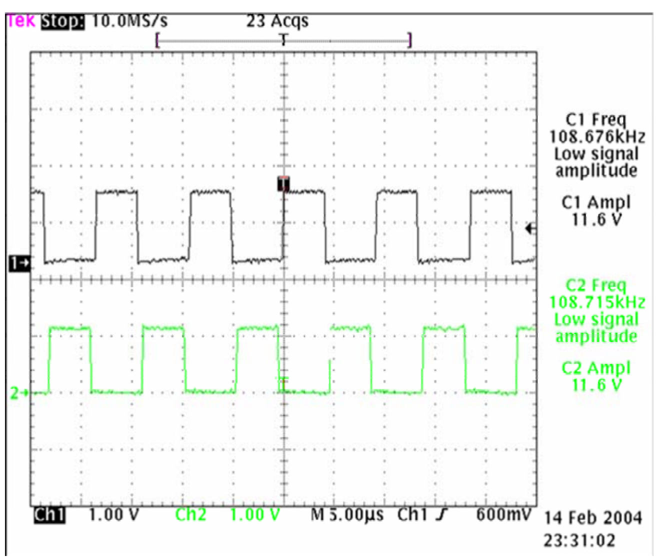

Figure 30. Half-bridge control circuit pulses

Half-bridge Converter

Figure 31 shows breadboard results of the half-bridge converter. The expected output, using test procedures explained in section 4.1.2, is a 12 VAC, 100 kHz square pulse. Figure 31 certifies that the half-bridge prototype is functional.

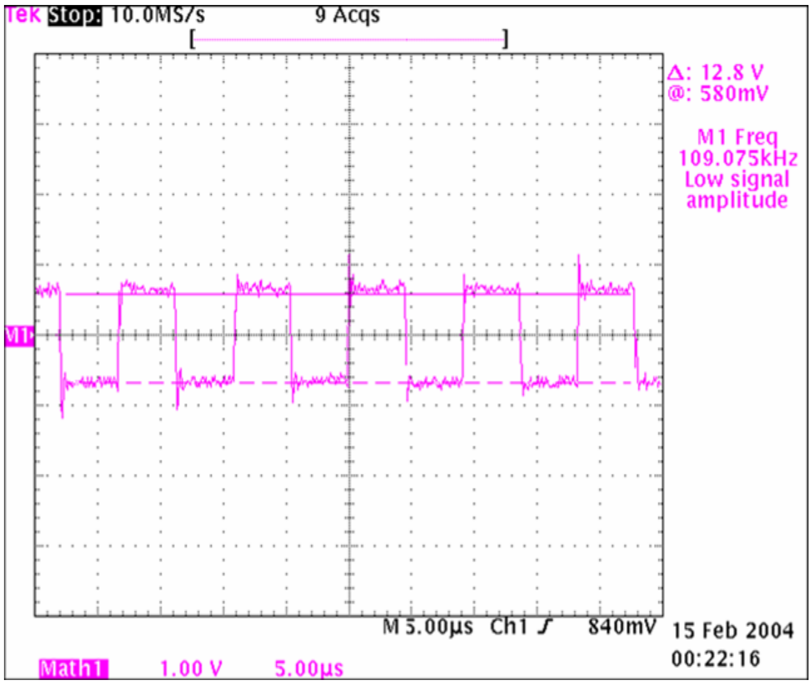

Figure 31. Half-bridge converter output voltage waveform

Transformer

The test procedure for the transformer explained in section 4.1.2.was implemented on the prototype transformer. Unfortunately, because of improper construction, no useful measurements could be obtained. Most of the output was sporadic and output voltages ranged from the input of 12 VAC to a maximum value of 140 VAC.

Sinusoidal PWM Inverter Control Circuit

The outputs of the sinusoidal PWM inverter control circuit are shown in Figure 32. The control circuit is expected to output two pulses with varying duty cycles that are 180º out of phase with an 18 kHz switching frequency. The 10X oscilloscope probes were used in making the measurements. The results are very close to the expected values, which certify that the sinusoidal PWM inverter control circuit is functioning appropriately.

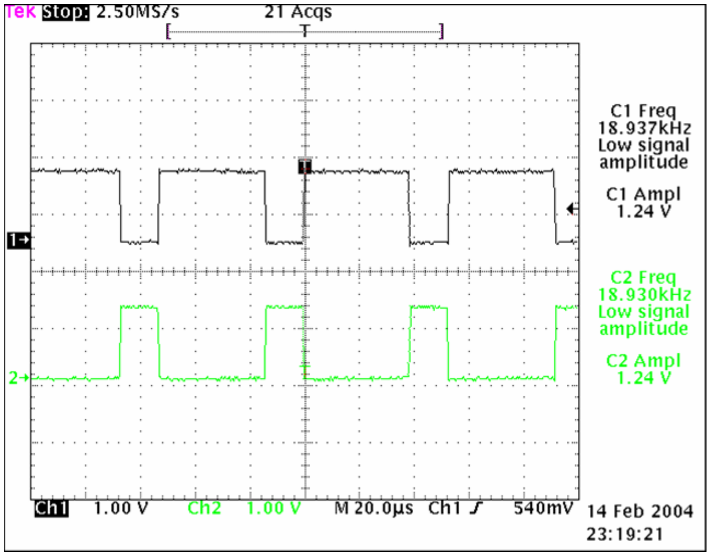

Figure 32. Sinusoidal PWM inverter control circuit pulses

Full-bridge Inverter

Figure 33 reflects the unfiltered output of the full-bridge inverter as constructed on a prototyping breadboard. The full-bridge inverter is supposed to produce a 340 VAC (peak-to-peak) PWM waveshape in which the remnants of a sinusoidal wave can be seen. The 10X oscilloscope probes were also used in this case since voltage was quite excessive. As seen by the darker shades of pink, the desired sine wave can be reached by filtering.

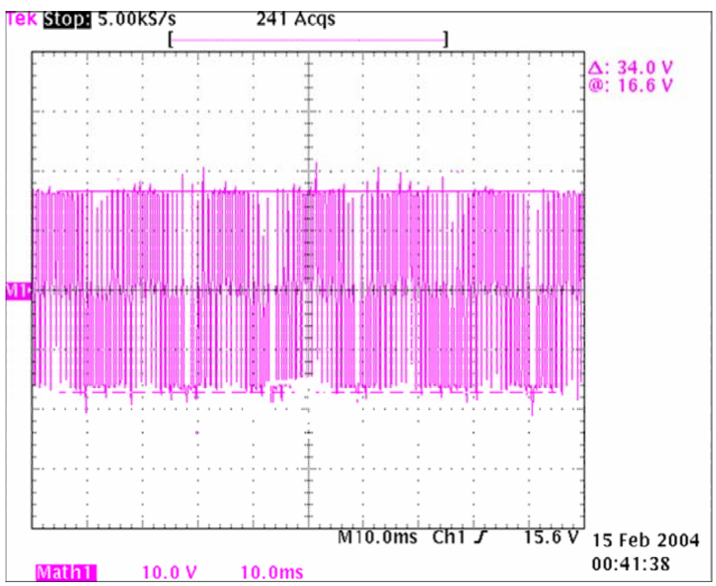

Figure 33. Full-bridge inverter unfiltered voltage output waveform

Low Pass Filter

Figure 34 illustrates the filtered version of the final power inverter output. The expected output after the low pass filter is a 340 VAC (peak-to-peak) or 120 VAC RMS sinusoidal waveform. The voltage amplitude is 345 VAC using the 10X oscilloscope probes, which is at a desirable level. By closer examination, excessive voltage spikes are present and the waveform has much distortion. This shows that with properly matched filter components a low-pass filter will function properly.

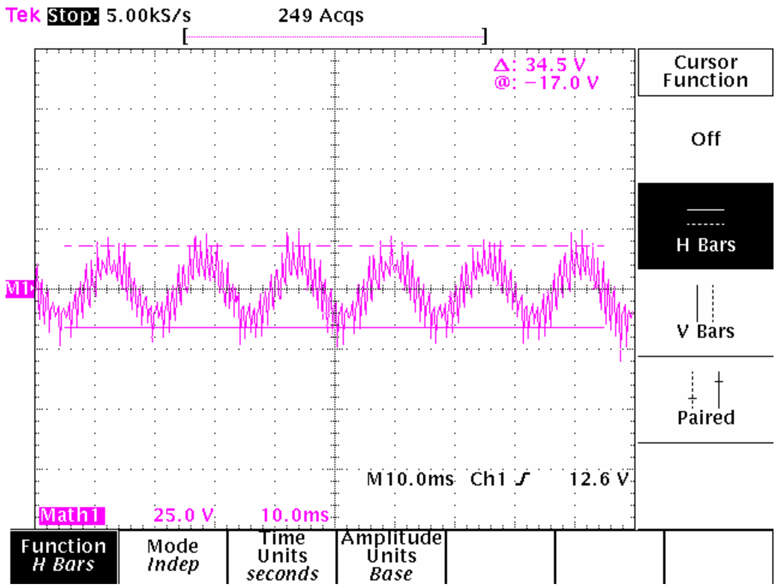

Figure 34. Filtered low-pass filter voltage output waveform

4.3.2. Packaged Version

The test results for the packaged version of the power inverter are very similar to those of the prototype. The same procedures were followed for testing each major circuit component. Below are the packaged version test results for each of previously tested prototype circuit components. With the exception of the transformer and the low-pass filter, the output waveforms are very similar. The following subsections show the outputs for each major component of the final product based on the same tests run on the prototype. Any major differences will be explained. Otherwise the results are comparable to the prototype.

Half-bridge PWM Control Circuit

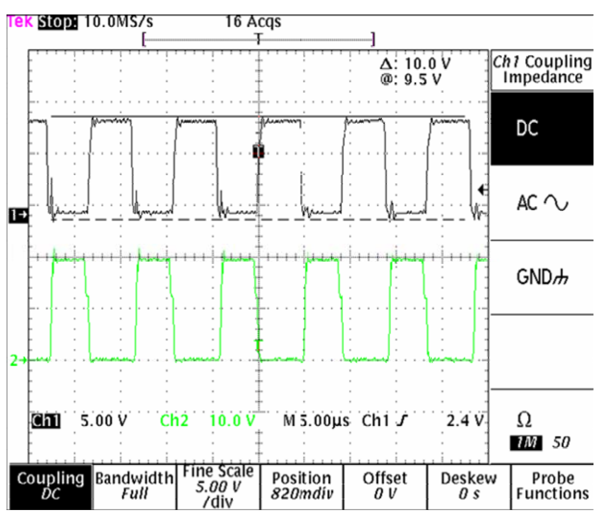

Figure 35. Half-bridge control circuit pulses

Half-bridge Converter

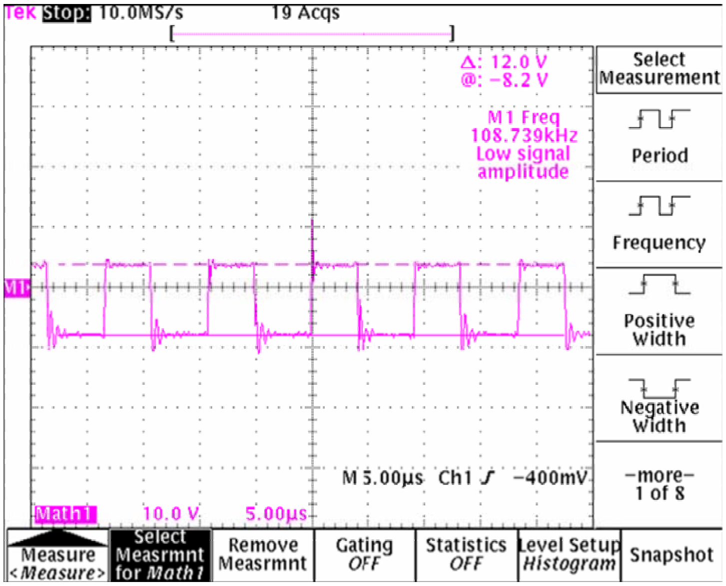

Figure 36. Half-bridge control circuit pulses

Transformer

Because of problems with construction of the prototype transformer, the design group decided to have transformer custom made. Giving general design constraints to the engineer at West Coast Magnetics, he blueprinted a custom transformer. Using the test setup mentioned in test specification of this document, several measurements were made on the secondary side of the transformer. The output was confirmed to be at or over 340 VAC at 100 kHz frequency. However, when a load was placed on the secondary side of the transformer, the output voltage dropped very significantly. After talking with the engineer, he suggested two quick fixes for the transformer problems. The first was to place a capacitance in series with the primary winding of the transformer to reduce the capacitance of the primary windings. The second was to place paper between the two E-cores of the transformer to act as a dielectric gap. Neither one of these quick fixes worked so a second transformer was constructed. Using the same test procedure, the output voltage with and without the load was verified. The results of each of the transformer tests have been recorded and are shown in Table 4 below.

Transfomer	Output Voltage Without Load	Output Voltage With Load
Prototype	140	12
West Coast Magnetics 1	354	24
West Coast Magnetics 2	347	339

Table 4. Voltage comparison for load and no-load of various transformers

Sinusoidal PWM Inverter Control Circuit

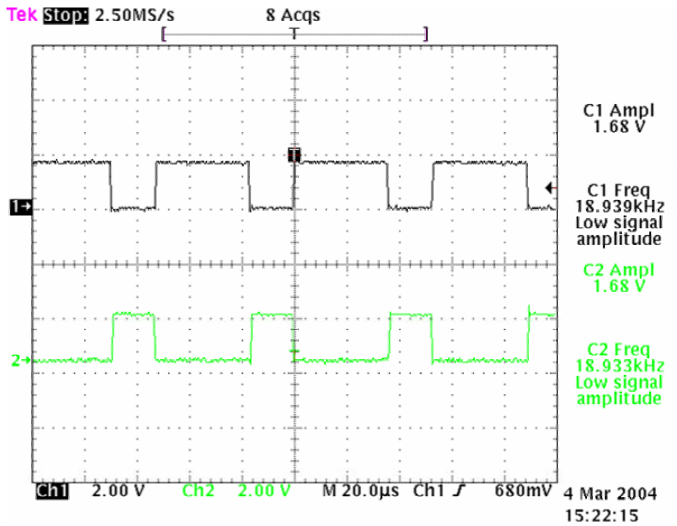

Figure 37. Sinusoidal PWM inverter control circuit pulses

Full-bridge Inverter

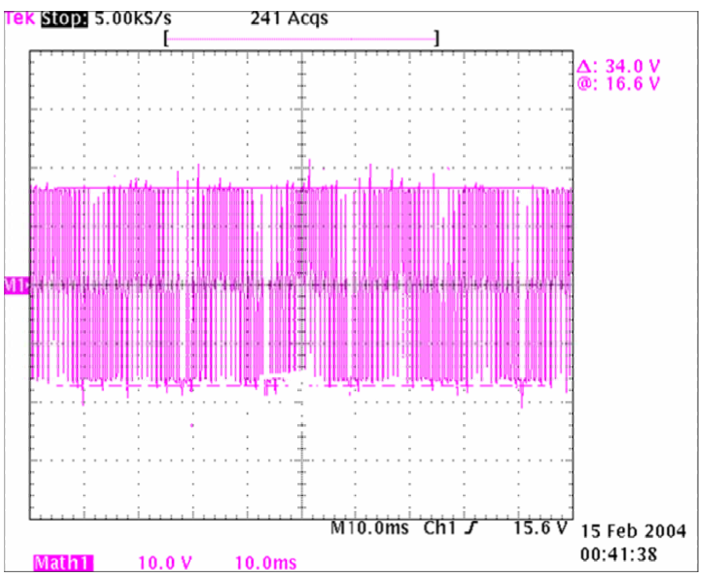

Figure 38. Full-bridge unfiltered output voltage waveform

Low Pass Filter

Figure 39 shows a major improvement in the final output waveform as compared to the prototype. The improvement is a direct result of changes made to the low-pass filter. Specifically, a ferrite toroid inductor was wound with 64 turns of 18 AWG wire to create a more efficient filter. The advantage was that the inductor could be wound turn by turn until the best possible output was found.

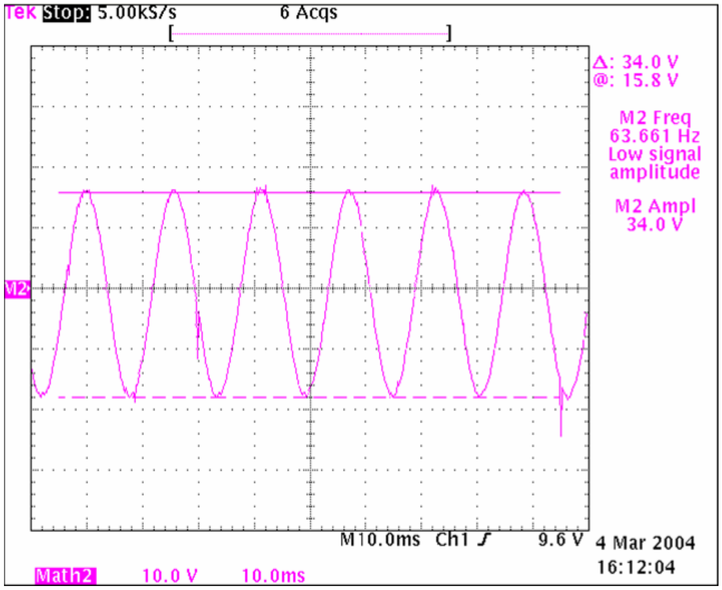

Figure 39. Voltage waveform of final inverter output

4.4. Test Certification – Software

4.4.1. Prototype

Figure 40 shows the control pulses that where produced by the PIC18F252. Using the test procedures that were aforementioned the varying duty cycle and amplitude of the prototype were certified. Because of excessive heating of the MOSFETs in the full-bridge inverter it was discovered that an insufficient amount of "dead-time" was programmed into the PIC program. An example of the amount of dead-time is presented in Figure 41. Figure 41 is a zoomed in screen shot of the exact same pulses as the ones in Figure 40. The pulses have been placed one on top of the other in order to show that the dead-time of 150ns is present between the time one set of MOSFETs is turned off and another is turned on.

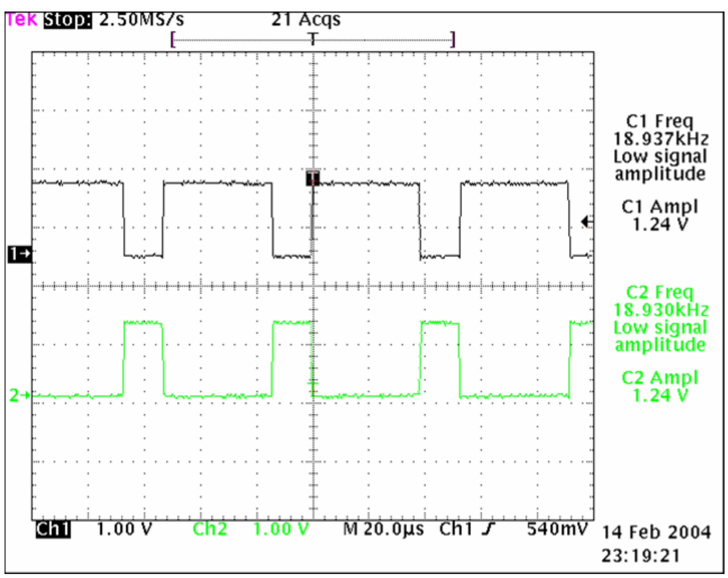

Figure 40. Control pulses from PIC18F252 microcontroller

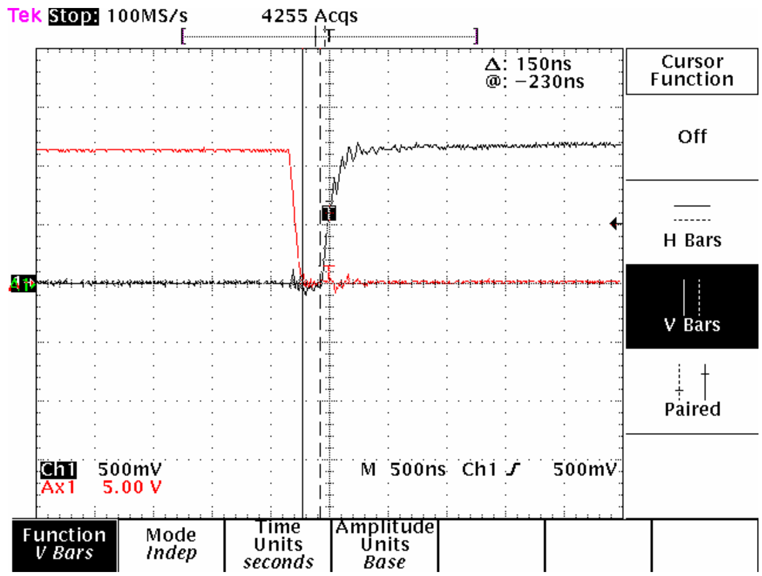

Figure 41. Insufficient dead-time programmed in PIC18F252 microcontroller

4.4.2. Packaged Version

After re-programming the PIC18F252, a sufficient amount of dead time was added in order to keep the MOSFETs from overheating. The dead time was increased from a previous value of 150ns to 500ns. As shown in Figure 42, the dead time is 460ns. This amount of dead time was deemed significant enough to prevent cross conduction and overheating of the MOSFETs. The dead time was increased by adding 16 timing loops in order to delay toggling of the pulses. A significant aspect of the software was the ability to further change the dead time settings for different types or brands of MOSFETs by changing just a few hex values in the timing loops.

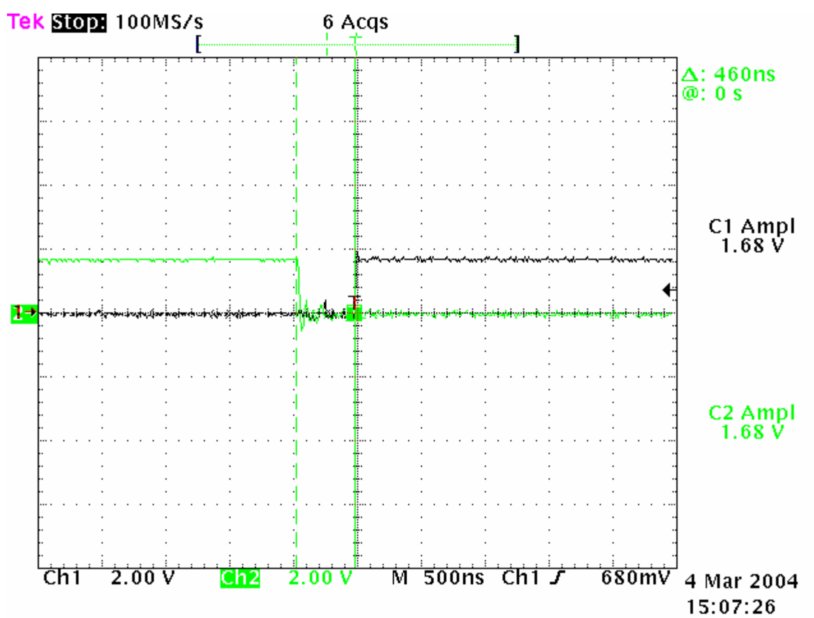

Figure 42. 460 ns of dead-time programmed in PIC18F252 to prevent cross-conduction

5. SUMMARY AND FUTURE WORK

Many of the design constraints mentioned afore in this document were not met. In Table 5 below is a list of our most important design constraints and where they stand at the culmination of the course.

Name	Design Constraint	Packaged Product Results	Pass / Fail
Voltage	Convert 12VDC to 120 VAC	12VDC to 120VAC	PASS
Power	Provide 300 W Continuous Power	<100 W Continuous	FAIL
Efficiency	>90% Efficient	>91% Efficiency	PASS
Waveform	Pure 60Hz Sinusoidal	60Hz Sinusoidal	PASS
Total Harmonic Distortion	<5% THD	About 7%	FAIL
Physical Dimensions	8” x 4.75” x 2.5”	9” x 6.5” x 2.5”	FAIL
Cost	$175	$168.44	PASS

Table 5. Packaged product results versus design constraints

As you can see from the information above most of the more important design constraints were met. The packaged product did covert 12VDC to a 120VAC, 60 Hz sinusoidal waveform. Some of the more aggressive constraints were however not met. We were unable to produce up to 300 Watts of continuous power with the implement. After reviewing the packaged product we feel that the failure of this design constraint can be attributed to two possible factors. The first factor would be a loss of power in the transformer due to flux imbalance. This problem was noticed in the first transformer turnaround from West Coast Magnetics. Due to the large capacitance of the wires used on the primary side of the transformer, the primary winding acted more like an energy storage device than a magnetically coupled transformer winding. Although the second transformer turnaround was a success for the most part we feel that it may be the reason the implement powers loads of less than 100 Watts best but can power loads of up to 150 Watts. Future work could be done to better spec the transformer out to the supplier (in our case West Coast Magnetics). Given the result of this particular project someone could use our test result and waveforms to either build their own transformer or more specifically spec out the transformer to a custom transformer retailer. Due to time constraints we were unable to properly specify to the engineer at West Coast Magnetics the more specific information that he needed to construct the transformer that we needed. The second factor that we feel could have attributed to our output power shortcomings was the size of our PCB traces. Future work could be done to lay out larger traces so that the PCB layout could handle the current requirements of this project. Our total harmonic distortion constraint failure could also be attributed to two possible factors. The first would be our PIC program. With more time and effort the PWM program that was used by our microprocessor to digitally pulse our MOSFETS of the full bridge inverter could be modified to more efficiently operate. The second factor that could have kept us form reaching our THD constraint would be the length of the traces leading form the PIC to the MOSFETS of the full bridge inverter. Some of the traces for the MOSFETS were longer than the others. This would lead to longer transit times and could be the cause of some of the voltage “spikes” that are present in our output waveform. Once again future work could be done to better layout the PCB. As for the failure of the physical dimensions of the project, we feel that this constraint was set pretty aggressively without enough knowledge of the actual size and shape of the components of the project. We feel that while this constraint was a failure that it is an acceptable failure. The packaged unit size was not so greatly increased that the implement was any less usable or functional.

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7. REFERENCES

1. M. Brown, *Power Supply Cookbook*, 2nd ed. Boston: Newnes, 2001.
2. M. J. Buckingham, *Noise in Electronic Devices and Systems*, New York: Ellis Horwood Limited, 1983.
3. M. P. Marcus, *Switching Circuits for Engineers*, 3rd ed. New Jersey: Prentice-Hall, Inc., 1975.
4. K. Brindley, *Modern Electronic Test Equipment*, London: William Heinemann Ltd., 1986.
5. I. R. Gottlieb, *Design & Build Electronic Power Supplies*, Pennsylvania: Tab Books, 1991.
6. B. Lin, "Analysis and Implementation of a Three-Level PWM Rectifier/Inverter," *IEEE Transactions on Aerospace and Electronic Systems*, vol. 36, no. 3, pp. 948-956, July 2000.
7. J. Ghijselen, A. Vanden Bossche, and J. Melkebeek, "Dynamic Control of a Fixed Pattern Rectifier," *IEEE Transactions on Power Electronics*, vol. 16, no. 1, pp. 118-124, January 2001.
8. I. Schmidt, "Secure Power Supply System with Static Power Converters," *IEEE 1977 Int'l Semiconductor Power Conversion,* pp. 222-223, Lake Buena Vista, Florida, USA, March 1977.
9. R. Dorf and J. Svoboda, *Introduction to Electric Circuits*, ed. 5, John Wiley and Sons, New York, New York, USA, 2001.
10. R. Goody, *ORCAD: PSpice for Windows*, vol. 1, ed. 3, Prentice-Hall, Upper Saddle River, New Jersey, USA, 2001.
11. E. Kamen and B. Heck, *Fundamentals of Signals and Systems: Using the Web and MATLAB*, ed.2, Prentice Hall, Upper Saddle River, New Jersey, USA, 2000.
12. D. Neaman, *Electronic Circuit Design and Analysis*, ed. 2, McGraw-Hill, Boston, Massachusetts, USA, 2001.
13. PIC18F252 Data Sheet, *Microchip Graphic Explorer – Parent Tab:PIC18F252 Device,*[online] 2002, http://www.microchip.com/download/lit/pline/picmicro/families/18fxx2/39564b.pdf (Accessed: January 2004).
14. MC34025, MC33025 High Speed Double-Ended PWM Controller, *ON Semiconductor,*[online] 1999-2004, http://www.onsemi.com/pub/Collateral/MC34025-D.PDF (Accessed: August 2003).
15. IR2181(4)(s) High and Low Side Driver, *International Rectifier – The Power Management Leader,*[online] 1995-2004, http://www.irf.com/product-info/datasheets/data/ir2181.pdf (Accessed: August 2003).

16. IR2184(4)(s) Half-Bridge Driver, *Internatinal Rectifier – The Power Management Leader,*[online] 1995-2004, http://www.irf.com/product-info/datasheets/data/ir2184.pdf (Accessed: January 2004).
17. M. Marcus, Swithing Circuits for Engineers, ed. 2, Prentice-Hall, Englewood Cliffs, New Jersey, USA, 1969.
18. N. Mohan, Tore M. Undeland and William P. Robbins, *Power Electronics: Converters, Applications, and Design*, John Wiley and Sons, New York, New York, USA, 1989.
19. B.Norris, *Microprocessors and Microcomputers and Switch Mode Power Supplies*, McGraw-Hill Book Company, New York, New York, USA, 1978.
20. Custom Designs from West Coast Magnetics, *West Coast Magnetic*, [online] 2003, http://www.wcmagnetics.com/custom.html (Accessed: Decemeber 2003).
21. Marc E. Herniter, *Schematic Capture with Cadence PSpice*, Prentice Hall, December, 2000.

APPENDIX A: PRODUCT SPECIFICATION

12 VDC / 120 VAC POWER INVERTER

Features:

- **150 watts** continuous power
- **300 watts** peak power
- High efficiency
- Voltage overload protection
- Low battery alarm / shut down
- Idle power draw of less than 800 mA
- Total Harmonic Distortion less than 3%
- Single output receptacle
- Cigarette lighter adapter included
- AC receptacle 3-Prong grounded

Efficiency > **75%**
No-load draw < **800 mA**
Output Voltage **115 VAC**
Input voltage range **10-15 VDC**
Over voltage shutdown over **15 VDC**
Under voltage shutdown under **10 VDC**
Low voltage shutdown **10 VDC**
Overload shutdown **Yes**
Thermal shutdown **Yes**
Short circuit shutdown **Yes**
Product dimensions **11"x7"x4"**

Typical Applications:

- Laptop Computers
- Portable stereos
- Cell Phones
- Camcorders
- Game Consoles
- Recording equipment
- Musical instruments